THE USE OF CLINOPTILOLITE AS PERMEABLE REACTIVE BARRIER SUBSTRATE FOR ACID ROCK DRAINAGE

by

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ABSTRACT

This study investigated the use of clinoptilolite as a permeable reactive barrier (PRB) substrate for retaining heavy metals from Acid Rock Drainage (ARD). PRBs are one of the options for retaining metals from ARD, allowing a cleaned groundwater plume to the receiving water bodies.

The mineral clinoptilolite, a molecular sieve which has high cation exchange capacity, can retain heavy metals. Clinoptilolite is available in many locations and is inexpensive (~CDN$100-200/tonne). The suitability of clinoptilolite for the use as a PRB substrate was evaluated based on its chemical stability and metal retention in acidic environments. Results showed that clinoptilolite is chemically stable in ARD environment, the clinoptilolite structure is stable at pH >1.5. Clinoptilolite was found to retain 130.6mg Cu/kg soil (63.8% of Cu), 22.65mg Fe/kg soil (82.1% of Fe), 158mg Zn/kg soil (39.5% of Zn) and 215.4mg Al/kg soil (89.7% of Al) from the Britannia Mine natural ARD (pH 3.28) in batch equilibrium adsorption tests.

Pretreatment of clinoptilolite with NaCl solution helped improve the retention of metals and reduced the leaching of Mn from the clinoptilolite. The performance of the clinoptilolite was evaluated using column leaching tests to simulate on-site conditions. Breakthrough curves were obtained at various flowrates and influent metal concentrations. Copper and zinc were the major contaminants of concern in the ARD. The breakthrough of copper occurs at 40 pore volumes (pv), manganese at13 pv, zinc at 45 pv and aluminum at 38 pv, whereas iron precipitated once introduced to the leaching cell. Metal retention was found to be dependant on the flow rate. Selective extractions of metals on the clinoptilolite was conducted. Results

indicated that partitioning was dependent on the flow conditions and the chemical characteristics of the leachate (pH and chemical composition).

An algorithm was developed in the geochemical model PHREEQC for the design of the clinoptilolite barrier. The model helps to predict the performance and the transport of contaminants based on the amount of exchange sites, influent composition and concentration within the clinoptilolite PRB system, which are useful for estimating the service life and thickness required in the design of clinoptilolite PRB systems.

TABLE OF CONTENTS

ABSTRACT II

TABLE OF CONTENTS IV

LIST OF FIGURES VIII

LIST OF TABLES XV

ACKNOWLEDGEMENTS XVII

CHAPTER 1 INTRODUCTION 1

1.1 STATEMENT OF PROBLEMS 1

1.2 RESEARCH OBJECTIVES 6

1.3 RESEARCH PLAN 7

1.4 RESEARCH CONTRIBUTIONS 10

1.5 ORGANIZATION OF THESIS 11

CHAPTER 2 LITERATURE REVIEW 13

2.1 ACID ROCK DRAINAGE 13

2.1.1 Generation of Acid Rock Drainage 16

2.1.2 Characteristics of ARD 25

2.2 BACKGROUND OF BRITANNIA MINE 26

2.2.1 Geological characteristics at the Britannia Mine 27

2.3 PERMEABLE REACTIVE BARRIER SYSTEMS 30

2.3.1 Design requirements 32

2.3.2 Uses of permeable reactive barrier systems 35

2.4 PROPERTIES OF ZEOLITE 37

2.4.1 Minerological properties of Clinoptilolite 38

2.4.2 Stability in low pH 39

2.4.3 Adsorption capability 41

2.4.4 Surface Sorption Phenomena 42

2.4.5 Availability of the substrate material 49

2.5 GEOCHEMICAL MODELS 50

CHAPTER 3 MATERIALS AND METHODS 55

3.1 ARD SAMPLING 55

3.2 LABORATORY INVESTIGATION OF ZEOLITE CLINOPTILOLITE 57

3.2.1 Physical-chemical characteristics of zeolite clinoptilolite 57
3.2.2 Minerological characteristics of zeolite clinoptilolite 60
3.2.3 Adsorption capacity and chemical stability 62
3.2.4 Column leaching tests 67
3.2.5 Chemical analyses for clinoptilolite and water sample after column leaching tests 74
Water sample analyses 77
3.3 APPLICATION OF THE GEOCHEMICAL MODEL 78

CHAPTER 4 CHARACTERISTICS OF CLINOPTILOLITE AND ACID ROCK DRAINAGE AND THEIR COMPATABILITY 80

4.1 CHARACTERISTICS OF BRITANNIA MINE ACID ROCK DRAINAGE 80
4.1.1 Chemical characteristics of ARD used in batch equilibrium adsorption tests 81
4.1.2 Chemical characteristics of ARD used in column-leaching tests 82
4.2 PHYSIO-CHEMICAL, PHYSICAL AND MINERALOGICAL PROPERTIES OF CLINOPTILOLITE 83
4.2.1 Physical-chemical properties 83
4.2.2 Mineralogical properties 84
4.3 pH STABILITY TESTS 90
4.3.1 Chemical stability 90
4.3.2 Physical stability – hydraulic conductivity 93
4.3.3 Mineralogical changes 94
4.4 NEUTRALIZATION ABILITY OF CLINOPTILOLITE 96

CHAPTER 5 RETENTION OF METALS ON CLINOPTILOLITE 99

5.1 ADSORPTION OF METALS 99
5.1.1 Adsorption isotherms of metals on clinoptilolite 99
5.1.2 Adsorption of metals affected by pH 104
5.2 EFFECT OF RETENTION OF COPPER WITH CONTACT TIME 107
5.2.1 Effects of mixing in batch adsorption tests on the retention of copper 108
5.2.2 Effects of flow rates in mini-column leaching cell tests on the retention of copper 109
5.2.3 Effects of copper concentration in column leaching tests on the adsorption onto clinoptilolite 111
5.2.4 Summary of comparison of the retention of copper onto clinoptilolite in different testing methods 112

CHAPTER 6 COLUMN LEACHING CELL TESTS 115

6.1 COLUMN LEACHING TESTS (I) – BULK CLINOPTILOLITE 115

6.2 COLUMN LEACHING TESTS (II) – PRETREATED CLINOPTILOLITE 119
6.2.1 Leachate analyses 119
6.2.2 Analysis of clinoptilolite – post-leaching 139
6.3 COLUMN LEACHING TESTS (III) – CHANGES IN CLINOPTILOLITE WITH TIME 155
6.3.1 Leachate analyses 155
6.3.2 Analyses of the clinoptilolite 166
6.4 DESIGN OF CLINOPTILOLITE PERMEABLE REACTIVE BARRIER SYSTEM 179
6.4.1 Conceptual design of the clinoptilolite permeable reactive barrier 179
6.4.2 Recognition of time frame 180
6.4.3 Design parameters 181
6.4.4 Application of clinoptilolite PRB in a hypothetical ARD scenario 184
6.4.5 Design recommendations 190

CHAPTER 7 GEOCHEMICAL MODEL 192

7.1 DATA COLLECTION 192
7.1.1 Characterization of solid media 192
7.1.2 Characterization of groundwater 193
7.1.3 Assumptions in the model 193
7.2 CONSTRUCTION OF THE MODEL ALGORITHM 194
7.2.1 Components included in the model 194
7.2.2 Types of geochemical reactions included in the model 195
7.2.3 Selection of model thermodynamic and kinetic data 197
7.3 SCRIPT DEVELOPMENT OF THE CONCEPTUAL MODEL 197
7.4 INTERPRETATION OF MODELING RESULTS 200
7.5 MODEL PREDICTIONS 202
7.6 LIMITATIONS AND POSSIBLE SOURCES OF ERRORS 203

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS 205

8.1 CONCLUSIONS 205
8.2 RECOMMENDATIONS FOR FURTHER RESEARCH 209

REFERENCES 212

APPENDICES 218

Appendix A Methods of chemical analyses

A-1 Selective sequential extractions on tested clinoptilolite 220
A-2 Water sample analyses 222

Appendix B Chemical compositions of ARD and residue

B-1 Chemical composition of ARD.....224
B-2 Chemical composition of residues from ARD filtration.....225
B-3 Comparison of chemical compositions between filtered and non-filtered mine drainage from the 4150 Portal 226

Appendix C Mineralogical characteristics of clinoptilolite

C-1 Investigations of the X-Ray Diffractorgrams for semi-quantitative analysis of the mineral composition of clinoptilolite.....227
C-2 Major elements in the clinoptilolite sample by X-Ray Fluorescence (XRF) and Inductive Coupled Plasma (ICP) spectroscopy.....239
C-3 Compaction curve of clinoptilolite.....242
C-4 Sample calculation for the compaction of material and its compaction properties . 243

Appendix D Langmuir Isotherm and Langmuir constant determination.....245

D-1 Adsorption isotherm of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in single species solutions.....248
D-2 Adsorption isotherm of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in multiple species solutions – Distilled water with nitric acid as background solution.....253
D-3 Adsorption isotherm of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in multiple species solutions – Natural acid rock drainage as background solution.....261

Appendix E Leaching of metals from clinoptilolite.....266

Appendix F Determination of pretreatment methods.....268

Appendix G Column leaching cell tests water sample analyses results.....270

Appendix H Column leaching cell tests soil analyses results

H-1 Results of metal fractionations on soil samples extracted from column leaching cells.....332
H-2 Numerical and graphical presentation of metal fractionations on soil samples after deducting background metal concentrations.....350

Appendix I Results of water sample analyses from Critical Path Analysis column leaching cells.....373

Appendix J Results of soil analyses on tested clinoptilolite from Critical Path Analysis leaching column cells

J-1 Results of metal partitioning on clinoptilolite extracted from leaching cell after 15, 26, 38, 45, 57, 73, 85, and 96 pore volumes.....406
J-2 Numerical and graphical presentation of metal partitioning on clinoptilolite after subtracting background concentration from 1M treated clinoptilolite.....415
J-3 Changes of the amount and percentage partitioning of metals (Cu, Fe, Mn, Zn, Al).....432

Appendix K Geochemical model development

K-1 Description of mode codes.....438
K-2 Model output.....448

LIST OF FIGURES

Figure 2.1 Bacterial activities of *Thiobacillus ferrooxidans* 17

Figure 2.2 Effect of temperature on biological and chemical oxidation rate 19

Figure 2.3 Effect of pH on biological and chemical sulphide-oxidation rate 20

Figure 2.4 Stages in the formation of acid rock drainage (Adapted from Guidelines for ARD prediction in the North, Indian and Northern Affairs Canada, 1993) 23

Figure 2.5 Regional location map of the Britannia Mine site 26

Figure 2.6 Regional map showing sampling sites at the Britannia Mine (adapted from Price et al., 1995) 28

Figure 2.7 Interior of the adit at the Britannia Mine 29

Figure 2.8 Water containing high iron precipitates ponding at downstream of 4100 Portal, Britannia Mine site 29

Figure 2.11 The diffuse-ion layer (Adapted from Mohamed and Antia,1998) 43

Figure 2.12 An illustration of metal ion sorption on (hydr)oxide (Adapted from Sparks, 1995) 47

Figure 3.1 Sampling location at the 4150 Portal, Britannia Mine 55

Figure 3.2 Sampling location at the 4100 Portal, Britannia Mine 56

Figure 3.3 Setup of the variable-head permeameter 60

Figure 3.4 The work plan of the retention kinetics study of copper onto clinoptilolite 64

Figure 3.5 Schematic diagram of the procedures for non-mixing batch adsorption tests for retention kinetics 66

Figure 3.6 Schematic diagram of the experimental setup of mini-column-leaching cell 67

Figure 3.7 Setup of mini-column leaching cell 67

Figure 3.8 Configuration of column-leaching cells 69

Figure 3.9 Assemblage at the end-caps 69

Figure 3.10 Setup of column leaching cells 70

Figure 3.11 Schematic diagram of the column leaching cell 70

Figure 4.1 Diagrams illustrating layer-weathering and edge-weathering of micas by exchanging interlayer potassium with hydrated exchangeable cations. Mica particles would normally be much wider in relation to thickness than the zone represented in the diagram. (Adapted from Dixon and Weed, 1977) 86

Figure 4.2 Scanning electron microscopic image of bulk clinoptilolite (particle size 2-50 μm) 90

Figure 4.3 Leaching of ions from clinoptilolite acid treatment at various pHs with time: (a) Amount of Al ions leached; (b) Amount of K ions leached 91

Figure 4.4 The leaching of Si and Na relative to Al in multiple species solutions with background matrix of: (a) nitric acid, pH 2; (b) natural ARD, pH 3.28 92

Figure 4.5 Scanning electron microscopic (SEM) diagrams of clinoptilolite with particle size ranges 2 to 50 μm: (a) after water treatment; (b) after ARD treatment 96

Figure 4.6 The changes of pH in the ARD after 24-hour exposure of clinoptilolite to ARD of various pH levels 96

Figure 5.1 Adsorption of metal ions in multiple Cu, Al, Fe and Zn species on clinoptilolite with natural ARD (pH 3.28) as background solution 102

Figure 5.2 Multiple Cu, Al, Fe and Zn species adsorption on clinoptilolite with background solution of nitric acid/distilled water at pH 2 102

Figure 5.3 The leaching of metals from clinoptilolite in 24-hr batch equilibrium tests with natural ARD at various pH level: (a) overview of the adsorption curve, (b) zoomed-in view of Figure 5.3a at the metal leaching to adsorption transition 104

Figure 5.4 Comparison of the retention of Cu onto clinoptilolite between mixing and non-mixing batch tests 108

Figure 5.5 Comparison of the retention of Cu onto clinoptilolite at different flow rates in mini-column leaching tests 110

Figure 5.6 Comparison of the retention of Cu onto clinoptilolite in mini-column-leaching tests with different solute concentrations 111

Figure 5.7 Adsorption of Cu with time on clinoptilolite in various testing conditions 113

Figure 6.1 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell with bulk clinoptilolite, non-filtered natural ARD, and flow rate of 1 m/day. (Column ID: NTNFC1) 118

Figure 6.2 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; and (h) concentration of Zn, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered natural ARD, and flow rate of 1.5 m/day. (Column ID: PTB1C1) 120

Figure 6.3 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD of

maximum design concentration, and flow rate of 1.5 m/day. (Column ID: PTB3) 121

Figure 6.4 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD of maximum design concentration, and flow rate of 1.5 m/day. (Column ID: PTB4) 122

Figure 6.5 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 1.5 m/day. (Column ID: PTB5) 123

Figure 6.6 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 1.5 m/day. (Column ID: PTB6) 124

Figure 6.7 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 0.5 m/day. (Column ID: PTB8) 125

Figure 6.8 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 0.5 m/day. (Column ID: PTB9) 126

Figure 6.9 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e)

concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (Column ID: PTB11) 127

Figure 6.10 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (Column ID: PTB12) 128

Figure 6.11 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (Column ID: PTB13) 129

Figure 6.12 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (Column ID: PTB14) 130

Figure 6.13 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered natural ARD, and flow rate of 0.5 m/day. (Column ID: PTB15) 131

Figure 6.14 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 30 cm; (k) 40 cm; and (l) 50 cm for

leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 0.5 m/day in a packed bed system. (Column ID: PTB17) 132

Figure 6.15 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 30 cm; (k) 40 cm; and (l) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered natural ARD, and flow rate of 0.5 m/day in a packed bed system. (Column ID: PTB18) 133

Figure 6.16 Concentration of Mn in the water sample in (a) bulk clinoptilolite – without pretreatment, (b) clinoptilolite after 1M NaCl pretreatment 134

Figure 6.17 pH of the water sample in (a) bulk clinoptilolite – without pretreatment, (b) clinoptilolite after 1M NaCl pretreatment 135

Figure 6.18 Comparison of breakthrough volume with various ARD concentrations in columns of flow rates: (a) 0.5 m/day; (b) 1.5 m/day 138

Figure 6.20 Partitioning of Cu in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day 143

Figure 6.21 Partitioning of Fe in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day 144

Figure 6.22 Partitioning of Mn in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day 145

Figure 6.23 Partitioning of Zn in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day 146

Figure 6.24 Partitioning of Al in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day 147

Figure 6.25 Comparison of retention of Cu in column leaching cells in adsorption isotherms 151

Figure 6.26 pH of water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 158

Figure 6.27 Redox potential (expressed in millivolts, mV) of water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 159

Figure 6.28 Electrical conductivity of water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 160

Figure 6.29 Concentration of Cu in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 161

Figure 6.30 Concentration of Fe in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 162

Figure 6.31 Concentration of Mn in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 163

Figure 6.32 Concentration of Zn in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 164

Figure 6.33 Concentration of Al in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 165

Figure 6.34 Partitioning of Cu on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 167

Figure 6.35 Partitioning of Fe on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. 168

Figure 6.36 Partitioning of Mn on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M

NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv 169

Figure 6.37 Partitioning of Zn on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv 170

Figure 6.38 Partitioning of Al on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv 171

Figure 6.39 Correlation between the total amount of Cu retained on clinoptilolite with pore volumes 172

Figure 6.40 Percentages of partitioning of Cu in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizable compounds and residual fraction along the length of the column leaching cell 173

Figure 6.41 Percentage of partitioning of Fe in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizable compounds and residual fraction along the length of the column leaching cell. 174

Figure 6.42 Percentage of partitioning of Mn in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizing compounds and residual fraction along the length of the column leaching cell. 175

Figure 6.43 Correlations between the sum of amount of Zn from SSE with pore volumes 176

Figure 6.44 Percentage of partitioning of Zn in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxdies, oxidizable compounds and residual fraction along the length of the column leaching cell 177

Figure 6.45 Percentage of partitioning of Al in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizable compounds and residual fraction along the length of the column leaching cell 178

Figure 6.46 Correlations between mass loading and the amount of metals on soils 181

Figure 6.47 Relationship of the amount of metals retained on clinoptilolite to the metal concentrations in the effluent in column leaching cells 182

Figure 6.48 Illustration of the hypothetical problematic ARD scenario 185

Figure 6.49 Configuration of a clinoptilolite PRB system in a hypothetical problematic ARD scenario 186

Figure 7.1 Model predictions for 0.5 m/day, non-filtered ARD leaching column with treated clinoptilolite. 200

LIST OF TABLES

Table 2.1 Composition of mine drainage water from various types of mines (Ripley et al., 1978) 25

Table 2.2 The range in water quality, flow and discharge data for 2200 and 4100 discharges, and for Jane and Britannia Creeks (adapted from Price et al., 1995) 30

Table 2.3 Considerations in designing permeable reactive barrier systems 34

Table 2.4 Previous uses of permeable reactive barriers in metal contaminants removal 35

Table 2.5 Major elemental compositions from ICP analysis on clinoptilolite (Beck, 1996) 39

Table 2.6 Factors that could affect retention of metals and the mechanisms 42

Table 2.7 Functions of popular geochemical modeling programs (Source: Zhu and Anderson, 2002) 52

Table 3.1 Column leaching tests conducted and the design parameters 72

Table 3.2 Concentrations of metals in ARD of maximum design concentrations 73

Table 3.3 Difference in chemical composition between filtered and non-filtered ARD 73

Table 3.4 Reaction time of leaching cells for critical path analysis 74

Table 3.5 Reagents in selective sequential extractions and their purposes 77

Table 4.1 Chemical characteristics of ARD from the 4150 and 4100 Portal at the Britannia Mine, B.C. 80

Table 4.2 Major chemical composition and differences between natural (non-filtered) and filtered acid -rock drainage obtained from the 4150 Portal 81

Table 4.3 Concentrations of metal ions (mg/L) in natural ARD (pH 3.28) 82

Table 4.4 Chemical characteristics of the 4150 and the "adjusted" 4100 drainages 82

Table 4.5 Physio-chemical properties of clinoptilolite 83

Table 4.6 Trace minerals associated with the clinoptilolite sample 84

Table 4.7 Semi-quantitative analysis of the composition of major minerals in clinoptilolite from X-Ray diffraction 85

Table 4.8 Major elements in the clinoptilolite sample by X-Ray Fluorescence (XRF) and Inductive Coupled Plasma (ICP) Spectroscopy 88

Table 4.9 Hydraulic conductivity of clinoptilolite with various permeates 93

Table 5.1 Constant related to binding strength, *k* [L/mg], from Langmuir equation obtained in batch equilibirum adsorption tests in single and multiple-species solutions 100

Table 5.2 Percentage removal of metals in the natural Britannia copper mine drainage (pH 3.28) by the clinoptilolite (24-hour batch test) 105

Table 5.3 Ionization energies and ionic radii of Al^{3+}, Fe^{3+}, Cu^{2+} and Zn^{2+} ions 106

Table 5.4 Comparison of retention of Cu onto clinoptilolite using different methods of treatment 113

Table 6.1 Summary of the design parameters of the column leaching cell tests and the chemical characteristics of the leachates at equilibrium. 134

Table 6.2 Comparison of breakthrough volume at different flow rates 136

Table 6.3 Comparison of breakthrough volume between the filtered and non-filtered ARD at 0.5 m/day 139

Table 6.4 Summary of the partitioning of Cu expressed in % of the total from SSE in each fraction 148

Table 6.5 Summary of the partitioning of Zn expressed in % of the total amount obtained from SSE in each fraction 153

Table 6.6 Empirical relationships between the sum of the amount of Cu on clinoptilolite with the amount of leachate reacted 172

Table 6.7 Empirical relationships between the sum of the amount of Zn on clinoptilolite with the amount of leachate reacted 176

Table 6.8 Empirical relationships between the total amount of Cu and Zn retained on clinoptilolite with mass loading in the column leaching cell 182

Table 6.9 Costs associated with a clinoptilolite PRB in the hypothetical ARD scenario 187

Table 6.10 Costs associated with a water treatment facility for the hypothetical ARD scenario 188

Table 7.1 PHREEQC script to calculate the concentration of metals from outlet of a clinoptilolite leaching cell 198

Table 7.2 Comparison of the breakthrough volumes from geochemical model and experimental results 202

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CHAPTER 1 INTRODUCTION

1.1 Statement of Problems

Acid rock drainage (ARD) is considered to be one of the most serious environmental problems faced by the mining industry. Acid rock drainage occurs as a result of the natural oxidation of sulphide minerals contained in rock that is exposed to air and water. Subsequently, sulphuric acid is produced, lowering the pH of the contaminated drainage. In addition, at a certain pH level (~ pH 3.5), the process is accelerated by acid-generating bacteria, mainly *Thiobacillus ferrooxidans* and *Leptospirillum ferrooxidans*, which further lower the pH of the leachate from the exposed sulphide minerals and further mobilize and increase the metals in the drainage. Depending on geological factors and the mine site, the metals in the mining waste may include aluminum, cobalt, copper, cadmium, chromium, gold, iron, lead, manganese, silver and zinc. The pH of ARD may be as low as 2 in some geological environments, where there is no buffering capacity from other secondary minerals. At least 26 of the 1809 abandoned mining sites in British Columbia, Canada, have been identified as acid-generating and 20 additional sites have been identified as potentially acid-generating (EMCBC 1997). With high metal concentrations and low pH, ARD impacts the quality of the environment and the health of organisms in receiving water bodies.

Remediation options for the ARD include active treatment such as neutralizing the mine drainage with lime in a treatment plant, eliminating mobile cations in the effluent by precipitation, and passive treatment systems such as wetland and permeable reactive barriers. However, the cost for active treatment can be enormous and might not be feasible for ARD that contains metal concentrations too low for metal recovery but high enough to be toxic to aquatic life and to exceed the criteria for effluent disposal. Reactive barrier systems may be a suitable remediation option for areas where low metal concentrations and flow of ARD occur. Since ARD is characterized by high

acidity and metal concentrations, it is necessary that the reactive barrier material be able to attenuate the metal cations from the drainage and be able to neutralize the ARD plume as it passes through the barrier. In addition, the costs of using reactive barrier systems are lower than active treatment facilities due to the minimal maintenance (labor and consumables) required.

Zeolite has been found to have potential as an effective metal exchange medium in wastewater treatment (Blowes and Ptacek 1992; Zamzow and Murphy 1992; Robertson and Cherry 1995; Singer and Berkgaut 1995; Baker, Blowes et al. 1997; Vaca Mier, Lopez Callejas et al. 2001), acid rock drainage treatment (Vos 1992; Waybrant, Blowes et al. 1995; Beck 1996; Benner, Blowes et al. 1997; Gilbert, O'Meara et al. 1999) and as landfill liners (Singer and Berkgaut 1995). As a result, and since it is relatively inexpensive, it has the potential to be a good candidate as a reactive barrier material. However, no studies have been done to address the chemical integrity and multi-component attenuation of metal ions on clinoptilolite in low pH environments. There is also a lack of information on the hydraulic conductivity, partitioning of metals, and factors affecting the attenuation process of clinoptilolite in permeable reactive barrier systems.

Zeolites are tectosilicates consisting of three-dimensional frameworks of SiO_4^{4-} tetrahedral units, wherein all the oxygen atoms (O) of each tetrahedron are shared with adjacent tetrahedra. The most important characteristic of zeolites, from a water treatment perspective, is its net negatively charged structure, which results from isomorphic substitution of the Al^{3+} ion for Si^{4+} ion of the tetrahedra (Sherry 1971; Boles, Flanigen et al. 1977; Dixon and Weed 1989). Zeolites are also characterized by large void volumes (20% to 50%) and large internal surface areas of several hundred thousand square meters per kilogram, (Boles, Flanigen et al. 1977; Gottardi and Galli 1985; Dyer 1988; Dixon and Weed 1989) making it a good adsorbent. The other unique feature of zeolite is its ability to hydrate and dehydrate reversibly, and to exchange constituent cations without disrupting bonds (Dyer 1988). Each zeolite has its own arrangement and number

of channels, providing unique molecular sieve properties. Thus zeolites adsorb cations selectively according to the size and speciation of the cations.

Studies have been conducted using zeolite to remove and/or exchange metals with metals-contaminated water (Zamzow and Murphy 1992; Jacobs and Forstner 1999; Vaca Mier, Lopez Callejas et al. 2001). A study was done using zeolite amended with flyash in the supernatant for industrial wastewater treatment containing lead and cadmium (Singer and Berkgaut 1995). It was shown that zeolited flyash displayed high selectivity for $Pb^{2+}>Sr^{2+}>Cr^{2+}>Cd^{2+}>Zn^{2+}>Cs^{+}$ in competition with Na^{+}, especially at low concentration of these ions. Furthermore, the zeolite was effective in removing Pb^{2+} and Zn^{2+} from industrial wastewater of pH 7 (Singer and Berkgaut 1995).

Zamzow & Murphy (1992) found that clinoptilolite is efficient in taking up metal cations in copper-mine wastewater such as Al^{3+}, Cd^{2+}, Cu^{2+}, Fe^{3+}, Ni^{2+}, Pb^{2+} and Zn^{2+}, with relatively more Al^{3+} and Fe^{3+} removed than the other cations. This result is consistent with ion-exchange theory (Semmens and Seyfarth 1978; Yuan 1999), which states that the negative sites on crystal lattices have the highest affinity for trivalent ions, followed by divalent and monovalent ions respectively. In case of a series of metal cations of a given valence, the preference is correlated with the molecular size and the ionic radius of the cations. Zamzow & Murphy (1992) reported that Ca^{2+} and NH_4^{+} in wastewater interfered with the uptake of heavy metals, especially Ni^{2+}. Since sodium (Na^{+}) is the main exchangeable cation in the clinoptilolite, Zamzow & Murphy (1992) found that when the concentrations of metals are very high in the leachate, the amount of Na^{+} exchanged from the zeolite would start to build up to such a high level that no more ion exchange can take place. In that case, metal contaminants were not completely removed using the ion exchange sites on the zeolite alone.

Previous studies have shown that zeolite clinoptilolite has high retention capacity for heavy metals in ARD (Vos 1992; Gilbert, O'Meara et al. 1999). Vos (1992) conducted a study of

zeolite for treatment of ARD from the Britannia mine site, and recent research by Gilbert et al. (1999) using clinoptilolite in ARD remediation found that clinoptilolite is effective in removing metal cations from ARD. In a study by the United States Geological Survey (USGS) (Gilbert, O'Meara et al. 1999) on the adsorption capabilities of clinoptilolite in respect to mine drainage (pH 2-3), slight (120 μg of Al per gram of soil) dissociation of Al from the clinoptilolite-rich rock was observed. The leaching of Al ions from the clinoptilolite was not investigated further. An investigation has been conducted on the zeolite used in this study for the treatment of ARD from the Equity Silver Mine, B.C. (Beck 1996). It was found that the zeolite was effective in reducing the metals in the ARD (copper by 68%, zinc by 49%, arsenic by 97% and iron by 93%). However, test results on the adsorption were limited to the first 18 hours of reaction through a batch test in a static column, which may not represent the equilibrium condition on the zeolite. The stability of the zeolite, which may be affected by the acidity of the environment, was not investigated.

Zeolite clinoptilolite was used in this study. Clinoptilolite is a sub-category of the mineral zeolite. It is also the most abundantly found zeolite. Clinoptilolite is characterized by its high cation-exchange capacity, which is anticipated to have high-metal attenuation. Clinoptilolite also has the highest Si/Al ratio among all the other groups of zeolites, with Si/Al ratios ranging from 4.3 to 5.3 (Breck 1974; Meier and Olson 1978; Dixon and Weed 1989). Zeolites, which possess higher Si/Al ratios, have an advantage that when placed in low pH environments, its structure is less easily destroyed by the loss of Al from the framework to the environment (Boles, Flanigen et al. 1977; Gottardi and Galli 1985; Dyer 1988; Dixon and Weed 1989). The cage-like structure of zeolite clinoptilolite also allows it to have a high hydraulic conductivity compared to other minerals.

Clinoptilolite is found abundantly in sedimentary deposits (saline, alkaline lakes, deep-sea sediments, and low-temperature tephra systems). It can often be obtained at a reasonable cost

(Hay and Sheppard 2001; Dobelin and Armbruster 2003). An open-system zeolite clinoptilolite is found in Asp Creek and Sunday Creek in B.C.; Nye County in Nevada; John Day Formation in Oregon; Death Valley Junction in California, USA; and Yellow tuffs near Naples in Italy (Sheppard and Simandl 1999). The cost of the zeolite clinoptilolite, depending on the particle size and the quality of the clinoptilolite, ranges from CDN$100-200 per tonne. The formation of clinoptilolite in alkaline environments and its high pH may contribute in neutralizing the ARD through the course of treatment. The abundant availability of zeolite clinoptilonite in British Columbia and many parts of the world enable it to be easily accessible for use in permeable reactive barrier applications.

ARD is a serious global problem and a local issue in B.C., and the extent of the problem requires solutions to be economically feasible. In search of a suitable substrate for a permeable reactive barrier system, other than the chemical compatibility, attenuation ability for contaminants and its service life, it is also important for economic reasons that the barrier substrate be locally available. This is necessary because a large amount of substrate material would be needed in constructing a reactive barrier system. In view of the above criteria, the research focused on evaluating the performance, in terms of metal-attenuation ability and chemical stability of clinoptilolite as a permeable reactive barrier substract for ARD treatment. The results obtained from experiments are used to calibrate the parameters used in the geochemical model PHREEQC (Parkhurst and Appelo 1999; Parkhurst and Appelo 2003). The geochemical model will be used to predict the retention of metal ions on clinoptilolite, the breakthrough time, and hence the service life and thickness of the permeable reactive barrier.

Acid rock drainage from the Anaconda Britannia Mine was used in this study for the treatability of metals on the clinoptilolite. Mine drainage from the Britannia Mine was chosen because it is the most serious acid-generating site in B.C.(EMCBC 1997); it is also representative of typical chemical characteristics in acidic copper mine drainages. However, no study has been

conducted using clinoptilolite as a permeable reactive barrier substrate for removing metal ions from the ARD of the Britannia Mine.

In this study, clinoptilolite was first evaluated for its chemical stability in acidic environment at pHs of 0.5-3.0 and its metal attenuation ability using batch equilibrium adsorption tests. Once the suitability of the clinoptilolite was confirmed, clinoptilolite was tested for its performance in column leaching tests, which simulate the reactive wall situations using ARD from the Britannia Mine. Column leaching tests were conducted at various flow rates and concentrations of metals. Results from the column leaching tests provide information for the concentration profiles and breakthrough curves on the clinoptilolite. Partitioning of metals on clinoptilolite was determined by selective sequential extractions. A geochemical model was developed for predicting the breakthrough volumes of metals on the clinoptilolite.

1.2 Research objectives

The overall aim of this research is to explore the performance of clinoptilolite as a permeable reactive barrier substrate for acid-rock drainage. The specific objectives of this research are as follow:

- To evaluate the suitability of clinoptilolite as a reactive barrier substrate for acid rock drainage by examining its chemical stability (in terms of leaching of ions from the framework of the clinoptilolite structure) in acidic conditions commonly found in ARD environments;
- To examine the interactions and partitioning of heavy metals from ARD on the zeolite-clinoptilonite by conducting batch equilibrium adsorption tests and determination of metal adsorptivities;
- To determine the performance of the clinoptilolite as reactive barrier substrate in column leaching tests to simulate the on-site flow conditions. Column leaching tests

were conducted with the Britannia Mine ARD at natural and maximum design concentrations, and at various flow rates;

- To determine if pre-treatment of the clinoptilolite would improve effectiveness;
- To predict the transport, retention ability, and partitioning of heavy metals on the clinoptilolite in the barrier system using an existing geochemical model. Such a model is compared against experimental data and the model will be modified to meet the need for the stated application. Design requirements such as flow rates and influent concentrations will be defined in the algorithm to predict the performance of the clinoptilolite permeable reactive barrier.
- To provide design recommendations for engineers in using clinoptilolite as a permeable reactive barrier substrate.

1.3 Research Plan

To illustrate the objectives in this research, a research plan is presented in Figure 1.1, which consists of four major phases. The four phrases of the research plan are:

Phase 1: The selection and characterization of clinoptilolite and acid rock drainage.

Phase 2: Evaluation of the suitability and compatibility of the clinoptilolite as a reactive barrier substrate by examining the chemical compatibility (including chemical stability, permeability and neutralizing capacity) between the barrier substrate and the acid rock drainage and its retention ability for metal ions using batch equilibrium adsorption tests;

Phase 3: Investigate the performance of the clinoptilolite with the on-site flow conditions. The research also investigates the "worst" case scenarios that could be found on the site with maximum design concentration of metals in the ARD and at a high flow rate that could be encountered at the Britannia Mine site.

Phase 4: Apply results from the batch equilibrium adsorption tests and the column leaching tests for the validation of the geochemical model in predicting transport of metals in the clinoptilolite barrier system.

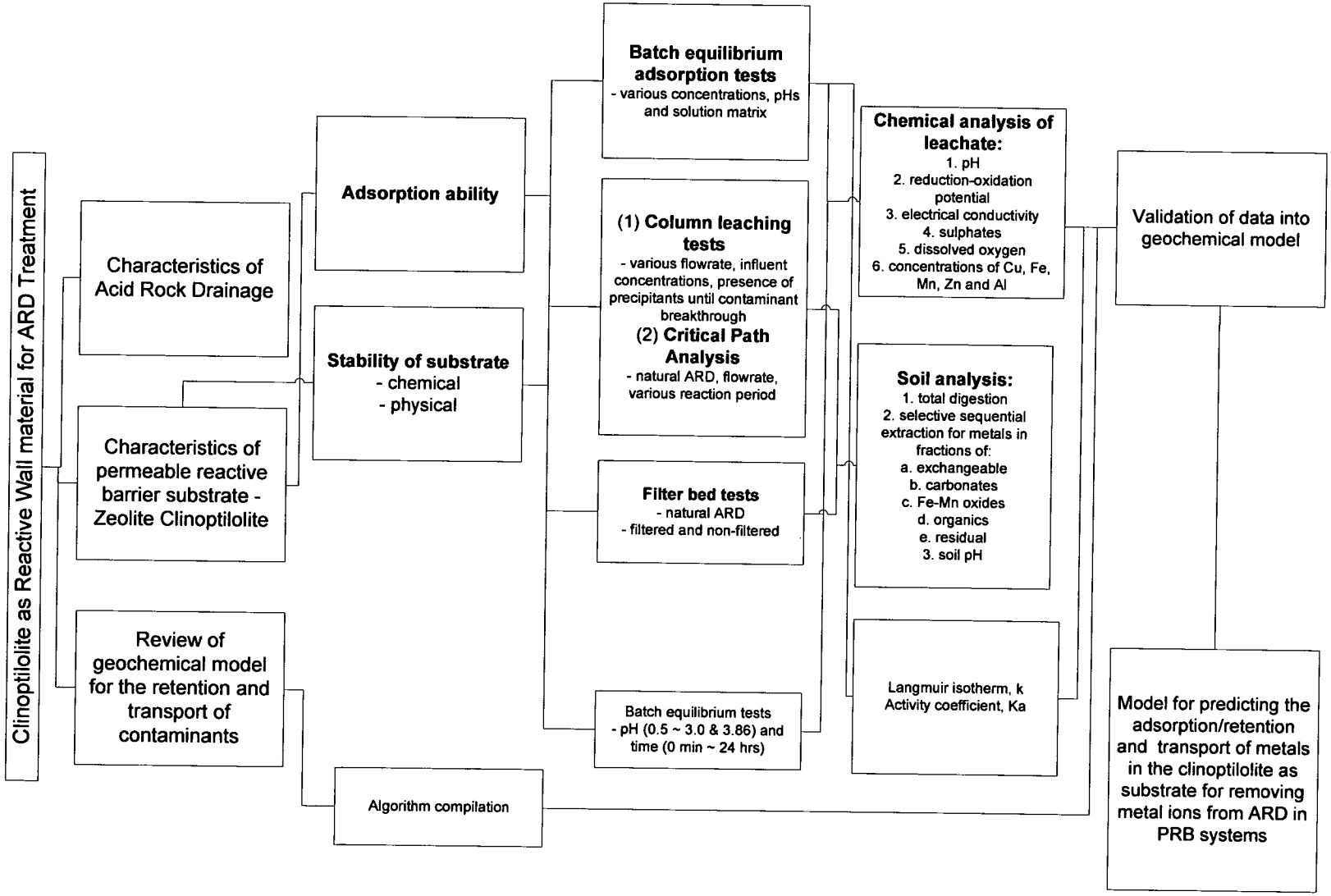

Figure 1.1 Research Plan Flowchart

1.4 Research Contributions

The contributions of this research include providing information on clinoptilolite as used for metal attenuation in ARD treatment and helping predict the performance of a clinoptilolite permeable reactive barrier (PRB) system with a contamination plume of similar source and chemical compositions. As a result of the study, the new knowledge on clinoptilolite to be revealed includes:

- Long-term study on the metal retention ability and physio-chemical stability of clinoptilolite in laboratory-scale column leaching tests for the simulation use of clinoptilolite as a permeable reactive barrier system;
- The effect of flow rates and ionic strength on the metal retention on clinoptilolite;
- The partitioning of metals on clinoptilolite after treatment of acid rock drainage.

The use of a clinoptilolite PRB system could benefit the mining and environmental industries by reducing costs for post-mine closure treatment and prevention operations for acidic drainages from exposed sulphide-bearing, acid-generating rocks. The use of locally available clinoptilolite should help promote the local mineral industry. In addition, determination of the pretreatment method for the substrate material helps in prolonging the service life of the permeable reactive barrier system.

The empirical and geochemical model can be used to predict the transport, breakthrough time and partitioning of metals in the reactive barrier system. Accuracy in the predictions of the transport of metals within the barrier system will help determine the most suitable scale of the reactive barrier system, thereby minimizing monitoring efforts and post-mine closure operating costs.

1.5 Organization of Thesis

In Chapter 1, statement of the problem of acid rock drainage has been addressed. The objectives of the research in the use of clinoptilolite in providing a possible treatment method for the heavy metals in ARD are listed. The research plan and the research contributions are outlined.

In Chapter 2, a literature review of the problem – Acid Rock Drainage, the proposed solution to the problem – Clinoptilolite permeable reactive barrier, and the possible interactions between the clinoptilolite and the ARD are illustrated.

The materials and methods used in the experiments are described in Chapter 3.

The results from the characterization of the clinoptilolite and the acid rock drainage used in this study are provided in Chapter 4.

Results of the batch adsorption and clinoptilolite stability tests, and discussions of the suitability of clinoptilolite for metal retention from acidic drainage based on its chemical stability and metals adsorptivities are presented in Chapter 5.

Provided in Chapter 6 are the results and discussion from the column leaching cell tests, the breakthrough of metals from various flow conditions, and the metal retentions on soil after ARD treatment. Also proposed in this chapter is a design for a permeable reactive barrier using the experimental results obtained in this study.

Outlined in Chapter 7 is the algorithm developed in a geochemical model to predict the transport of metals in the clinoptilolite leaching column.

In the last chapter, Chapter 8, of this thesis, conclusions made from the findings are reported; recommendations for further researches and possible improvements for the use of

clinoptilolite permeable barrier study are provided. Finally, research contributions are summarized.

CHAPTER 2 LITERATURE REVIEW

2.1 Acid Rock Drainage

Acid rock drainage (ARD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are reduced through exposure to air and water. When large quantities of rock containing sulphide minerals are excavated from an open pit or underground mine, the exposed sulphide minerals react with water and oxygen to create sulphuric acid. When the water reaches a certain level of acidity (about pH 3.5), a naturally occurring bacteria, *Thiobacillus ferroxidans,* may flourish, accelerating the oxidation and acidification processes, leaching even more trace metals from the waste rocks. Leaching of metals is accelerated in the low pH conditions. Heavy metal pollution results when metals such as arsenic, cobalt, copper, cadmium, lead, silver and zinc contained in the excavated rock are leached out and carried downstream as water washes over the rock surface.

Acidic drainage from the mine site can enter nearby streams, rivers, lakes and groundwater, severely degrading water quality, disturbing aquatic and wildlife habitat and making the water virtually unusable. This process could last for hundreds or thousands of years and has a great impact on the environment.

Acid rock drainage is a serious global problem and it exists at almost every location where mining activities occur. ARD problems are commonly found in Africa, China, and the Americas. In North America, there are many mining locations where environmental impacts have raised public concerns, such as the Sudbury Mine in Ontario, Canada, and the Iron Mountain Mine in California, U.S.A (Waybrant, Blowes et al. 1995; Dixit, Dixit et al. 1996; Keith, Runnells et al. 2001).

According to Environment Canada, acid drainage is considered to be the most serious environmental threat posed by the mining industry. The Canadian mineral industry generates 650 million tonnes of waste every year (one million tonnes of waste rock and 950,000 tonnes of tailings per day), which contains acid-generating sulphides, heavy metals and other contaminants, and is usually stored above ground in large free-draining piles (Government of Canada 1991).

The principal minerals and metals produced in British Columbia are coal, copper, crude oil and gold. The waste rock and exposed bedrock walls from which the mineral is excavated are the source of most of the metal pollution caused by mining in British Columbia (EMCBC 1997): Four main types of impacts from mining are acid rock drainage, heavy metal contamination and leaching, processing chemical pollution, erosion and sedimentation, which are interrelated. Among these impacts, acid rock drainage is of most concern because it causes the other impacts on the environment such as heavy metal contamination and leaching.

There are 1809 abandoned mine sites across British Columbia, a number of sites have been identified as acid generating and potentially acid generating. The known acid generating mines in B.C. as of 1997 included (EMCBC 1997):

- 12 historical mines: Anyox, Big Bull, Coast Copper, Giant Nickel, Mount Washington, Silver Standard, Baker, Britannia, Duthie, Mount Sicker, Silver Butte and Saint Eugene;
- 11 closed sites: Bell, Granisle, Equity, Goldstream, Premier, Samatosum, Johnny Mountain, Island copper, QR Gold, Sullivan and Kitsault;
- Three operating mines: Eskay Creek, Myra Falls, and Gibraltar.

The identified potential acid generating sites include:

- Three closed mines: Sable, Scottie Gold, Boss and Snip;

- Four operating mines: Elk, Quinsam, Huckleberry and South Kemess;
- 12 deposits, in advanced stages of development preparation: Harmony Gold, Prosperity (Fish Lake), Lexington, Mount Milligan, Red Mountain, Tulsequah Chief, Cirque, Kutcho Creek, Lumby Muscovite, Red Chris and Telkwa.

Due to both unacceptably high financial (high cost of remediation) and environmental liabilities, historical abandoned sites are frequently left untreated or without a proper closure program. This results in generation of untreated acidic and metal-containing effluents. There are many post-mining sites, as listed above, that have been left unattended once mining is completed. The problem of acid rock drainage has become most serious and costly to deal with and has already posed threats and hazards to the aquatic and wildlife in the receiving water bodies and surrounding areas. There are approximately 200 million tonnes of acid-generating tailings and 420 million tonnes of acid-generating waste rock in B.C. This is also increasing by 25 million tonnes per year (Feasby, Trembla et al. 1997).

As copper is the most abundantly mined metal in B.C., acid generation from copper mines is often a concern to the environment. The characteristics of copper mine ARD is that it contains high concentrations of copper, iron, zinc and aluminum. The pH of the rock drainages from copper mines ranges from 2.0 to 7.9.

Adequate environmental protection is needed at every hardrock mine site to prevent the runoff and leaching of the contaminants. The approaches for the protection at hardrock mines include rainfall management, surface water control, leak monitoring, reclamation and landscaping, and long-term monitoring. In practice, this protection was not conducted or mines were closed before any environmental criteria for the treatment of ARD were enforced.

Methods for treating ARD include active and passive treatments. Active treatment involves removing the metals and neutralizing the acidic drainage in a treatment plant. However, this

option is expensive in terms of construction and maintenance, and is only cost-effective for drainages with high flow rates and ones that contain high amounts of metals. Another option to prevent ARD generation is to stop rain water from infiltrating the waste rock pile (Blowes and Ptacek 1994). This option will prevent the oxidation of sulphides, and the release and transport of subsequent reaction products such as heavy metals. Other mitigation measures include conventional treatment of ARD which involves precipitation of Fe-oxyhydroxides by addition of lime. This approach can be effective but often involves high operating costs and produces large volumes of metal-rich sludge, from which metals may subsequently leach (Benner, Blowes et al. 1997).

For locations where acid rock drainage is detected, with metal concentrations insufficiently high for metal recovery but with enough toxicity to negatively impact aquatic life, permeable reactive barriers may present an effective and inexpensive option.

2.1.1 Generation of Acid Rock Drainage

Acid Rock drainage (ARD) is a natural process whereby sulphuric acid is produced when all three primary components (reactive sulphide minerals, air and water) for acid generation are present to react with each other.

When large quantities of rock containing sulphide minerals, such as pyrite (FeS_2, the most abundant sulphide containing mineral), are excavated from an open pit or in an underground mine, the rock reacts with water and oxygen to create sulphuric acid. The process is shown in the following chemical reaction:

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

At pH levels greater than 4 or 5, the ferrous iron (Fe^{2+}) is oxidized (or reacts with oxygen) to form ferric iron (Fe^{3+}) by chemical oxidation reactions:

$$Fe^{2+} + \tfrac{1}{4}\ O_2 + H^+ \rightarrow Fe^{3+} + \tfrac{1}{2}\ H_2O$$

In the early stages of ARD at pH levels above 3.5, ferric iron tends to precipitate out of solution as ferric hydroxide ($Fe(OH)_3$), a highly colored red precipitate. H^+ ions released during the reaction, lower the pH. The following equation summarizes the ferric hydroxide precipitate as Fe^{3+} ion reacts with water.

$$Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+$$

From the above three equations, it can be seen that the oxidation of one mole of pyrite will produce a net, four moles of hydrogen ion.

Bacterial activities involved in ARD

When the water or acid rock drainage reaches about pH 3.5, commonly occurring bacteria, *Thiobacillus ferrooxidans and Leptospirillum ferrooxidans,* accelerate the oxidation and acidification processes, leaching even more trace metals from the rocks. The reactions that occur in the presence of the sulphide oxidizing bacteria include: (1) oxidation of ferrous iron (Fe^{2+}) to ferric (Fe^{3+}); and (2) direct oxidation of reduced sulphur (S^{2-}) to form sulphuric acid (H_2SO_4). An illustration of the two oxidations reactions by *Thiobacillus ferrooxidans* is shown in Figure 2.1.

$$FeS_2$$

$$Fe^{2+} = Fe^{3+} + e^-$$

&

$$Fe^{3+} + 3H_2O = Fe(OH)_3 + 3H^+$$

$$2S^- + 3O_2 + 2H_2O = 2\,H_2SO_4 + 2e^-$$

Figure 2.1 Bacterial activities of *Thiobacillus ferrooxidans*

Thiobacillus ferrooxidans is an chemo-autotrophic bacterium, which derive energy from oxidation of either iron or sulphur of pyrite containing rocks. In the case of ARD, the bacteria utilize the liberated electron (e^-) from the oxidation of ferrous to ferric iron for the reduction of

carbon dioxide into new cell material. Hence, these bacteria can grow in a minimal nutritional environment since all of the minimal requirements are readily available in the natural acid rock drainage.

When *Thiobacillus ferrooxidans* is oxidizing the reduced sulphur compounds, as well as ferrous iron to the ferric iron state, it increases the rate-limiting step of ferric iron generation. Acid is produced microbiologically as a result of direct oxidation of reduced sulphur compounds. The acid will leach from the rock as long as the source rock is exposed to air and water, and until all sulphides are exhausted. Other bacterial species that participate or are capable of accelerating the oxidation of sulphide minerals, include *Thiobacillus thiooxidans* and *Sulfolobus* (Edwards, Bond et al. 2000).

Effect of temperature on oxidation of pyrite

The effect of temperature on the biological and chemical oxidation of pyrite is illustrated in Figure 2.2. The maximum biological oxidation occurs at 36°C for mesophillic bacteria and at 55°C for thermophillic bacteria. The chemical oxidation rate increases with increasing temperature. In general, both chemical and biological oxidation rates accelerate with an increase in temperature. Since the oxidation process is exothermic, the process generates heat and further increases the temperature in the environment. However, in cold-temperature regions, where temperatures are below 0°C, chemical oxidation is considered insignificant.

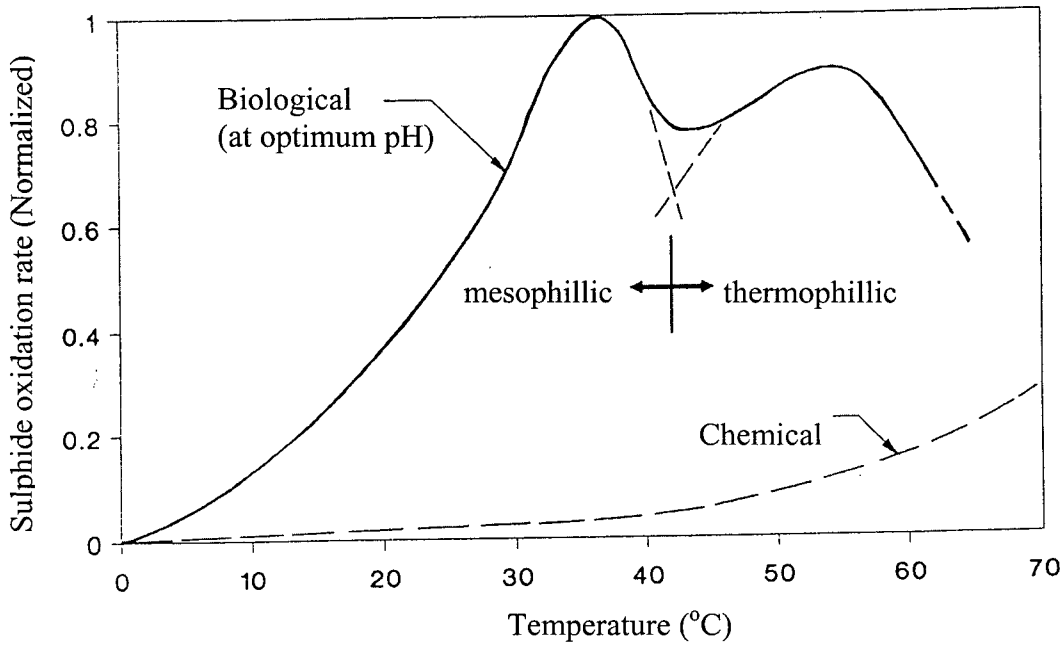

Figure 2.2 Effect of temperature on biological and chemical oxidation rate (adapted from *Guidelines for Acid Rock Drainage Prediction in the North*, Indian and Northern Affairs Canada, 1993)

Effect of pH on oxidation of pyrite

The effect of pH on the biological and chemical oxidation of pyrite at acidic pH is illustrated in Figure 2.3. The maximum biological oxidation occurs at a pH around 2.5. Chemical oxidation is insignificant below pH 5.2 compared to the biological oxidation. However, above pH 5.2, biological oxidation ceases and chemical oxidation becomes dominant. Biological oxidation of sulphide below pH 1 becomes insignificant while chemical oxidation below pH 1 starts to increase with decreasing pH.

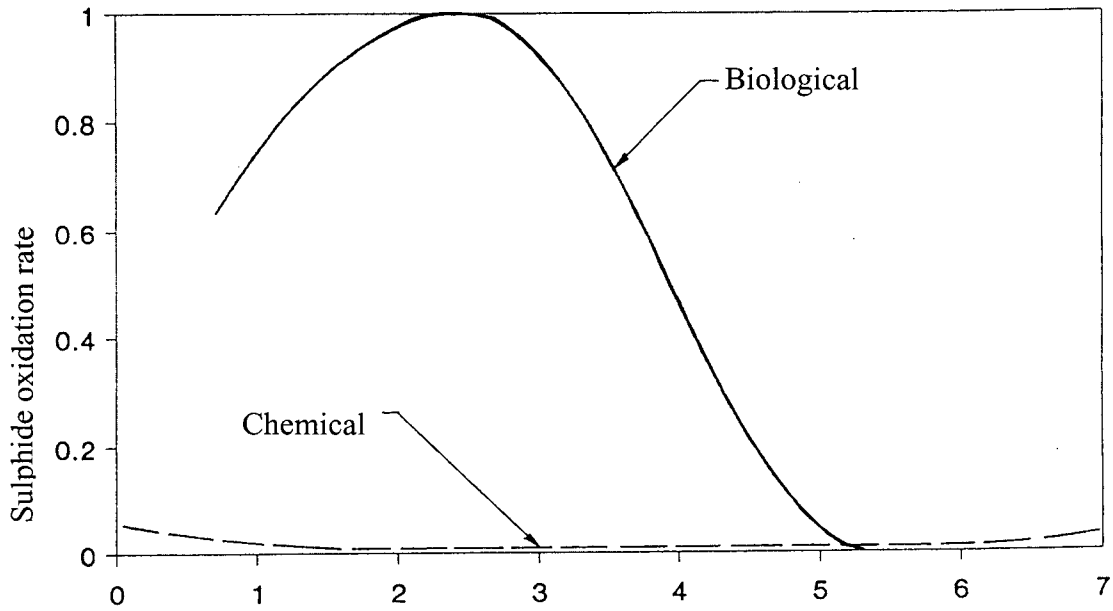

Figure 2.3 Effect of pH on biological and chemical sulphide-oxidation rate (adapted from *Guidelines for Acid Rock Drainage Prediction in the North*, Indian and Northern Affairs Canada, 1993)

Geochemistry and Neutralization of ARD

Following the oxidation of the sulphide mineral, the resulting acid products may either be immediately flushed away by infiltrating water or removed from solution while in contact with an acid-consuming mineral. The acid-consuming mineral may neutralize the leachate and remove a portion of the acidity and iron from the solution and raise the pH.

In evaluating the generation of ARD, it is important to know that not all sulphide minerals are equally reactive nor is acidity equally produced. The ability of a particular rock sample to generate net acidity is a function of the balance between the potentially acid-producing sulphide minerals and the potentially acid-consuming (or neutralizing/acid consuming) material.

Geologists determine both the acid-producing and acid-neutralizing mineral contents of samples from a mine site and analyze the results by a method called Acid-Base Accounting (ABA). If the buffering capacity of the minerals in the deposit is exhausted before the acid-generating capacity, acidic drainage will occur. Conversely, when the buffering capacity of the rock is greater than its acid-generating capacity, then acidic drainage will not occur. In that situation, metals will precipitate out of the solution.

The approach in estimating the likelihood of the acid generated from waste rock being consumed is through the Neutralization Potential (NP) (Lawrence and Scheske 1997). The interpretation of NP values involves the consideration of mineralogical composition of the waste, and a system of classifying neutralizing minerals according to their relative reactivity. It is based on the contribution of carbonate minerals and the more reactive silicate minerals that can react with acidic drainage under conditions found in mine waste. For example, calcite, dolomite, brucite, and magnesite dissolve at pH 5 and have a relative reactivity of 1; comparing this to the intermediate weathered minerals such as phyllosilicates (chlorite, talc, etc), which have a relative reactivity of 0.02, and clay (vermiculite, montmorillonite, etc) with a relative reactivity of 0.01. Hence, carbonate-based mineral, like calcite, have a much higher neutralizing capacity for acidic drainages.

Sulphate ions are stable over a wide range of pH, therefore, the concentration of sulphate in the drainage can be used as an indicator of the extent of acid generation even after neutralization by acid-consuming mineral has occurred.

The most common acid-consuming mineral is calcite ($CaCO_3$), which consumes acidity by reacting with the H^+ ions to produce calcium and bicarbonate ions (HCO_3^-), as summarized in the following equation:

$$CaCO_3 + H^+ \rightarrow Ca^+ + HCO_3^-$$

As neutralization occurs, metallic ions such as Fe^{2+}, Cu^{2+}, Zn^{2+}, Pb^{2+}, and As^{2+} will precipitate in the hydroxide form. However, metallic ions in the acid rock drainage also precipitate with sulphates, carbonates, and their hydrated and/or hydroxy-complex forms. Beside calcite, dolomite is also a commonly found acid neutralizing mineral. Calcite and dolomite are capable of raising the pH of the water passing through the soil to around 6.5. Ferrous carbonate ($FeCO_3$) has a capability of buffering drainage water to pH around 5.5, aluminum hydroxide in clay minerals, e.g. gibbsite, could buffer the drainage to pH around 4.0 through the dissolution of aluminum silicates. Ferric hydroxide, $Fe(OH)_3$, which could occur from precipitation of the ferric ions from the naturally occurring acid rock drainage, could buffer the pH of the drainage to around pH 3.0 (Sherlock, Lawrence et al. 1995; Nordstorm and Alpers 1997).

Different minerals can neutralize acid drainage at different rates and in different pH ranges. Many ore deposit types in Canada have little or no buffering capacity (AQUAMIN 1996). Therefore, if these deposits are exposed at the surface, or if wastes from the mining of these deposits are exposed, acidic drainage can result.

Processes in the development of ARD

The generation of ARD could be viewed as 3-stage process defined by the pH of the water that is in contact with the sulphide. Illustrated in Figure 2.4 are the three stages that occur in the process.

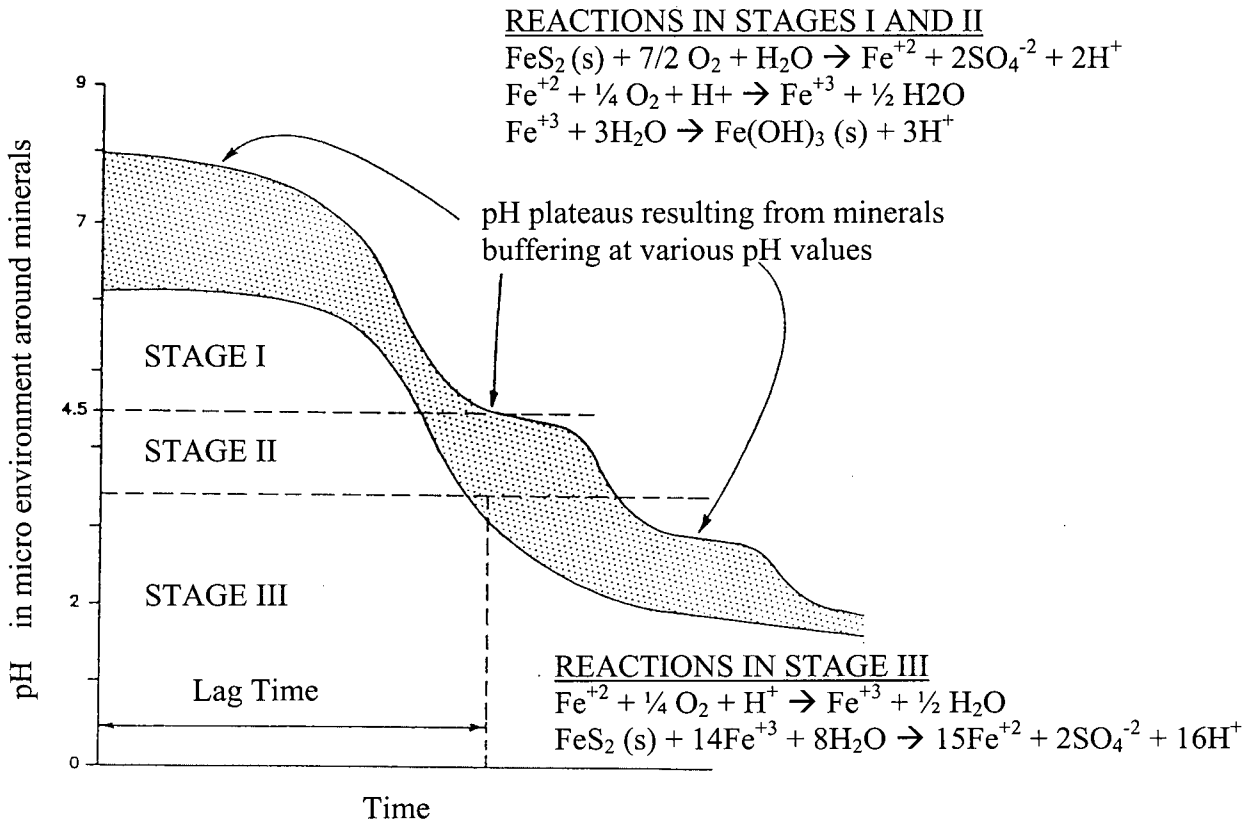

Figure 2.4 Stages in the formation of acid rock drainage (Adapted from Guidelines for ARD prediction in the North, Indian and Northern Affairs Canada, 1993)

In the initial stage (Stage 1) of oxidation, the pH is nearly neutral. When oxygen and water first come into contact with the sulphide-containing mineral, the exposed sulphide mineral produces ferric hydroxide as a precipitate and sulphuric acid. This stage is carried out by chemical oxidation. However, in this stage, any calcium-based carbonate acid-neutralizing compound, such as calcite in the rock, would neutralize the amount of acidity produced and maintain the leachate at the neutral pH level (pH~7). Ferric iron is precipitated from solution as a hydroxide, and the rate of pyrite oxidation is controlled at a low rate by the loss of ferric iron from the solution. Therefore, drainage from this stage is affected by the acid-neutralizing capacity of the waste rock and the rate of flushing, regardless if it has enough time for the neutralization to occur. The drainage at this stage is also characterized by having an elevated level of sulphate because the H^+ ions are taken up by the buffering agent, such as carbonates.

If ARD generation continues and the acid-neutralizing compound is exhausted,. the process moves towards the second stage (Stage 2) of the ARD development. When pH in the environment decreases towards 4.5, both chemical and biological oxidation reactions occur. Once biological oxidation is introduced below about pH 4.5, the oxidation of sulphide increases rapidly. Therefore, the pH of the drainage would also drop progressively. The drainage at this stage is weakly acidic with elevated ferrous iron and sulphate concentrations. The acidity can increase to relatively high levels even though the metal concentration in solution may be low.

The acid generation continues when oxygen, water and sulphide-bearing mineral are in contact. When the alkali minerals are consumed or become unavailable, or when acidity is produced at a faster rate than alkalinity, the pH becomes more acidic and the sulphide-oxidizing reaction becomes dominated by biological activities. Ferrous ion is produced from the sulphide oxidation reactions, and biologically oxidized to ferric iron, which, in turn, replaces oxygen as the primary oxidant. The rate of oxidation in this stage is more rapid than in stage 1, whereas in stage 1 the oxidation occurs chemically. The decrease in pH also accelerates the rate of oxidation. The drainage from this stage (Stage 3) is acidic and contains high levels of sulphate and metals in solution (Edwards, Bond et al. 2000). Iron in the solution occurs primarily as ferric iron after biological oxidation.

The acid generation continues until the sulphide has been completely oxidized, which depends on the sulphide content in the rock. The pH of the leachate decreases until the rock becomes essentially inert and the ambient pH of the water is not affected. This could take days to hundreds of years and is dependent on the factors required for acid generation, namely the reactivity/solubility of the sulphide-bearing material, the oxygen concentration and the availability of water. For example, in cold-temperature regions, the low temperature would

retard the onset of rapid oxidation and thus extend the time scale of the various stages of acid generation.

2.1.2 Characteristics of ARD

Depending on geological factors and the type of mine at the site, the metals found in mining waste may include arsenic, antimony, cobalt, copper, cadmium, chromium, gold, iron, lead, molybdenum, silver and zinc. These metals tend to dissolve and mobilize more easily in the acidic waters associated with acid rock drainage. For many rock types, metal leaching will only be significant if the pH drops below pH 5.5. However, elements like molybdenum, zinc, cadmium, antimony and arsenic remain soluble at neutral or alkaline pH values (Price and Errington 1997). Concentrations of the metals found in the acid rock drainage vary largely at every mine and with the type of mine. Typical metal concentrations found in the drainage in the different kinds of mines are shown in Table 2.1. The drainage from copper and uranium mines appear to be the most acidic and contain the highest concentrations of metals.

Table 2.1 Composition of mine drainage water from various types of mines (Ripley, Redmann et al. 1978)

	Copper	Copper-Lead-Zinc	Copper-Nickel	Copper-Molybdenum	Gold	Iron Ore	Mercury	Uranium
PH	3.8	2.0-7.9	7.5	7.7	7.6	6.4	11.5	2.3
Suspended solids, mg/L		10-690	15		68			
Dissolved solids, mg/L		700	1300		1460			1680
Aluminum, mg/L					0.6			
Arsenic, mg/L		0.002-0.03					0.005	
Calcium, mg/L		120			240			52
Cadmium, mg/L				0.002				
Cobalt, mg/L			0.1	0.004			0.008	416
Chromium, mg/L	0.1			0.002				
Copper, mg/L	0.01-83	0.005-76	0.15	0.02	0.24	0.1		3.6
Iron, mg/L	0.08-48	8.2-3200	1.2	0.21	3.6	1.3		30-3200
Mercury, mg/L							0.001	
Magnesium, mg/L		4						106
Manganese, mg/L	0.27	0.4		0.43				5.6
Molybdenum, mg/L				0.04				
Sodium, mg/L		16			101			
Nickel, mg/L			1.0	0.01	0.22	0.1		
Lead, mg/L	0.006	0.02-90		0.01		0.1	.01	0.7
Uranium, mg/L								67
Zinc, mg/L	0.01-91	0.04-1600	0.1	0.13	0.06	0.1	0.01	11
Sulphate, mg/L		320-1660	300		810	320		360-7400

2.2 Background of Britannia Mine

Among the numerous abandoned mine sites in British Columbia, the Anaconda Britannia Mine is one legacy of B.C.'s mining industry. The Britannia Mine is located at Britannia Beach on the east shore of Howe Sound, approximately 48 km north of Vancouver, British Columbia, Canada. Britannia Copper Mine, one of the largest copper producers in North America, operated from the 1920's. Mining operations were stopped and the concentrator was closed in the 1970's. The site has been generating ARD since the mine first operated. A regional location map of the Britannia Mine site is presented in Figure 2.5.

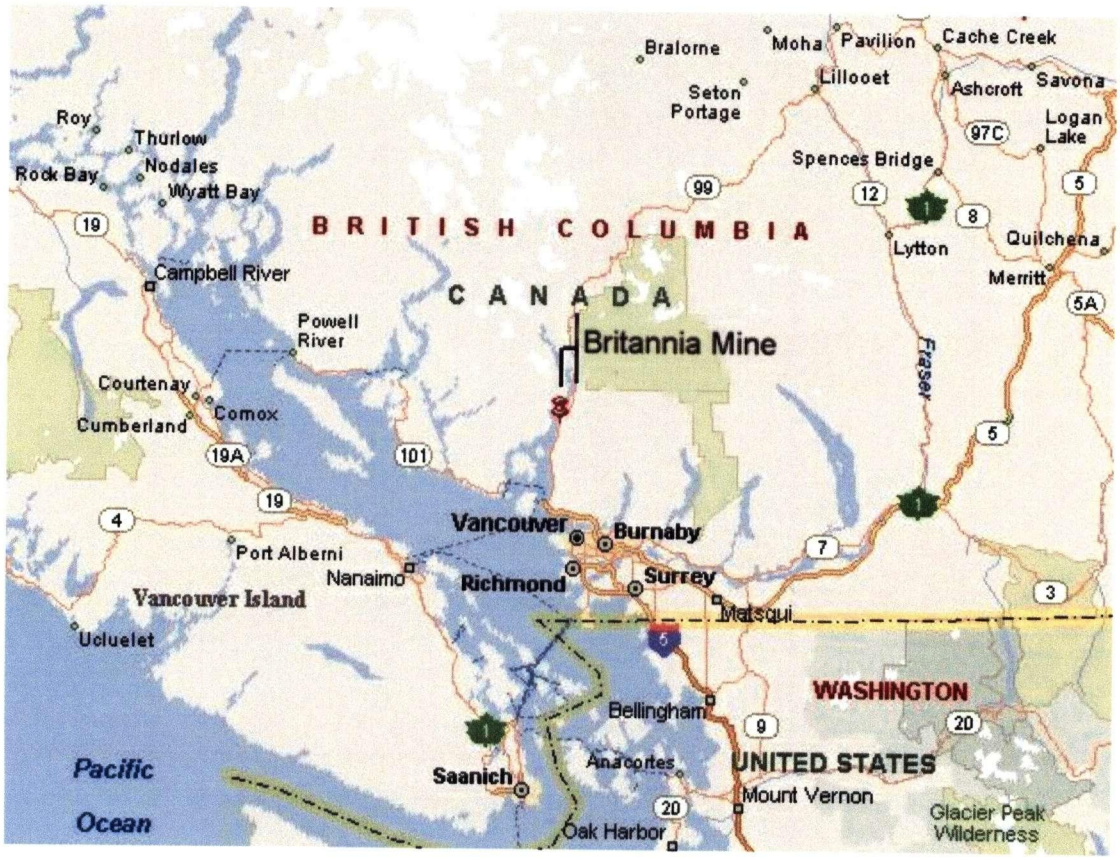

Figure 2.5 Regional location map of the Britannia Mine site

The problem of the acid rock drainage is significant (extremely low pH and high heavy metals concentration) partly due to the large exposure of sulphide-bearing rocks from open pit mining. This has created large basins, trapping heavy snows and rain, and funneling the water

to the mine. The other reason for the low pH in the ARD is that the rocks in the west coast of the Canadian region have very low acid-neutralizing capacity. The runoff rate from surface excavations is approximately 400 to 600 m^3 per hour. The two main pathways of drainage from the Britannia Mine site are the 2200 Portal and the 4100 Portal (Figure 2.6).

ARD flows from the 2200 Portal into Jane Creek, a tributary of Britannia Creek, and ultimately into Howe Sound.. Since the water in the creek is warmer and fresher than the water in Howe Sound, the creek water tends to float on the upper layer of the Howe Sound water. This harms and kills the salmon, which live in and are attracted to brackish water and sheltered inlet areas such as found in Howe Sound (Price, Schwab et al. 1995).

All mine drainages are directed to the 4100-Portal by a 6-km-long adit (Figure 2.7). The drainages from the 4100-Portal then flows into Howe Sound through a 27-m deep outfall at the mouth of the Britannia Creek. The purpose of the deep outfall is to reduce the impact of ARD on the surface water. Figure 2.8 shows a pond created by a large puddle of water downstream of the 4100 Portal. The picture was taken in October 1997. The dark-reddish-orange color shows a large amount of iron precipitate in the water.

2.2.1 Geological characteristics at the Britannia Mine

The geological strata of the ore bodies mined at Britannia consist of sulphides, widely disseminated or concentrated in stringers and along bedding planes. The principal economic mineralization in the area is associated with quartz mineralization, and consists of pyrite and chalcopyrite, with important concentrations of sphalerite in certain areas of the deposits. The main mineralogy of ore bodies is simple and fairly constant. Pyrite is by far the most abundant mineral, with less chalcopyrite and sphalerite and minor erratically distributed galena, tennanite, tetrahedrite and pyrrhotite. The main nonmetallic minerals include quartz and muscovite (chlorite), anhydrite and siderite (MEMPR 1991).

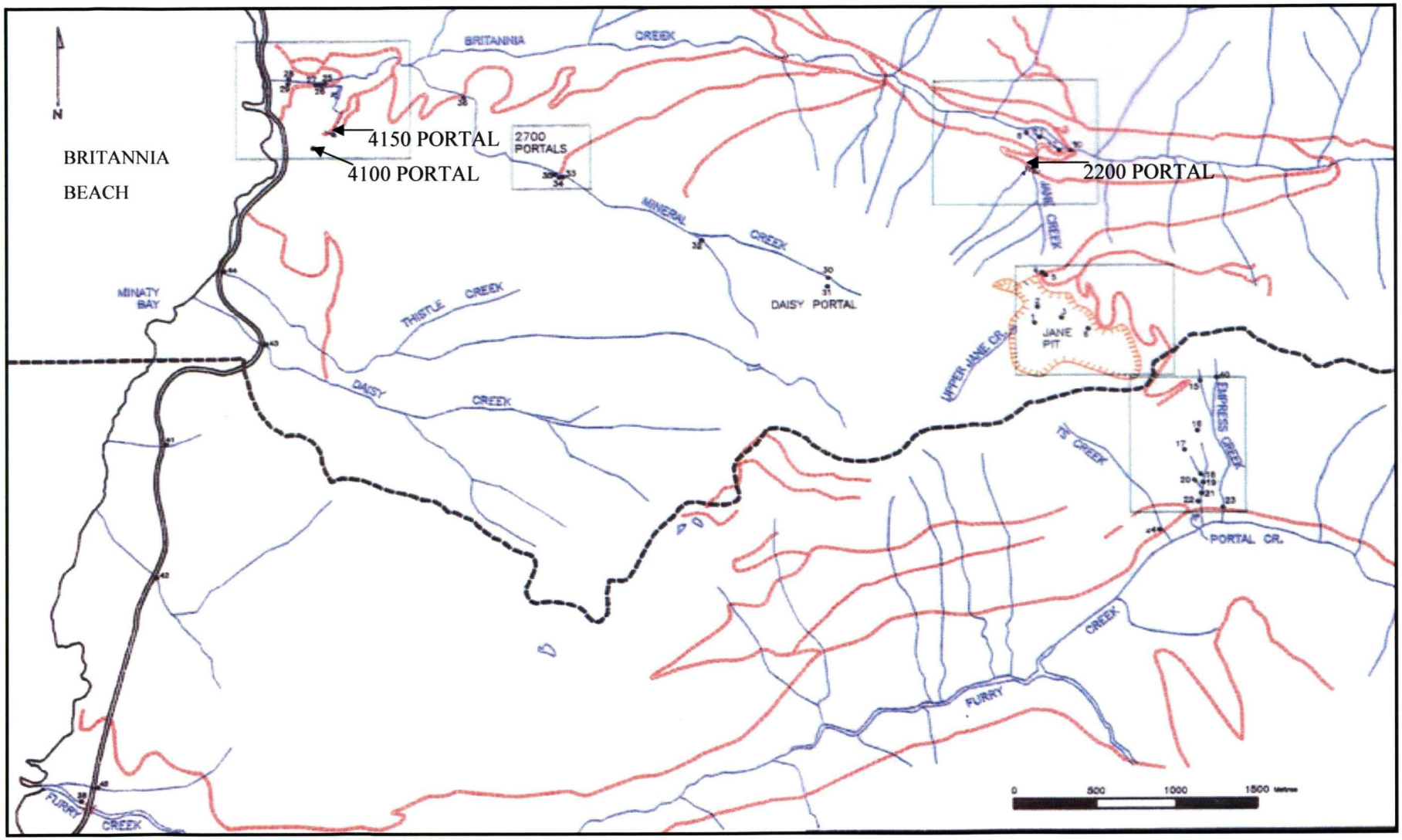

Figure 2.6 Regional map showing sampling sites at the Britannia Mine (adapted from Price et al., 1995)

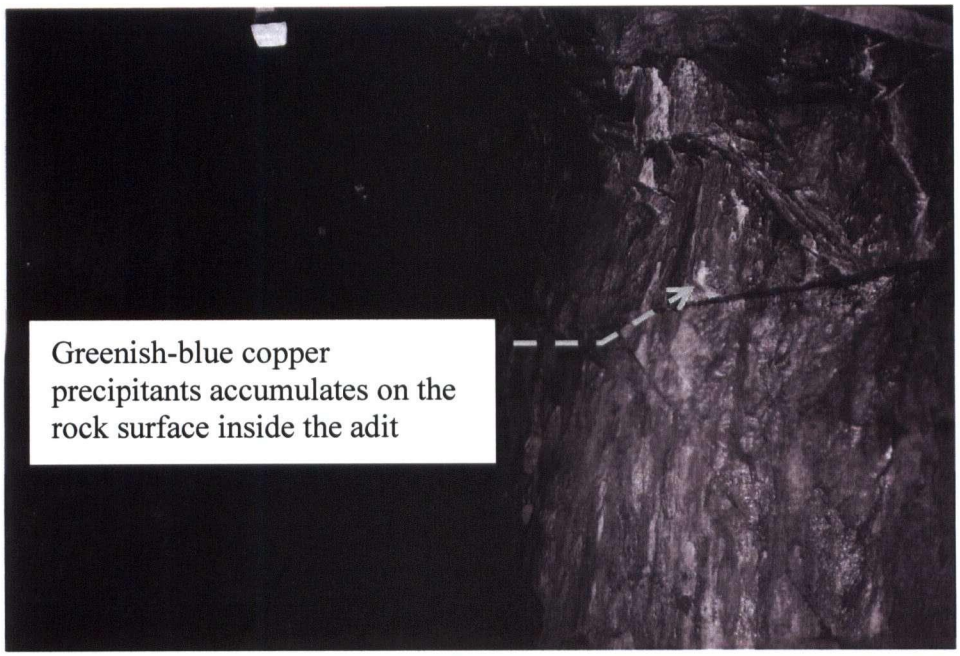

Figure 2.7 Interior of the adit at the Britannia Mine

Figure 2.8 Water containing high iron precipitates ponding at downstream of 4100 Portal, Britannia Mine site

The water quality of the ARD from the 2200 level and the 4100 level are summarized in Table 2.2. The pH of the drainage from the 2200 level and the 4100 level is as low as 2.7, concentration of copper can reach as high as 115 mg/L, zinc can reach up to 48 mg/L, iron up to 55 mg/L and aluminum up to 74 mg/L. The concentrations of these metals far exceed the BC metal mine effluent limits which are: for copper 0.05-0.3 mg/L; zinc 0.2-1.0 mg/L; iron 0.3-1.0 mg/L; aluminum 0.5-1.0 mg/L; and pH limit of 6.5-8.5. The metals are toxic to aquatic life at those concentrations. However, the metal concentrations in the mine drainages are too low for economical metal recovery. Therefore, there is a need to find a cost-effective method to deal with the metal concentrations in the drainage. Reactive wall for ARD treatment is one of the potential solutions.

Table 2.2 The range in water quality, flow and discharge data for 2200 and 4100 discharges, and for Jane and Britannia Creeks (adapted from Price et al., 1995)

	2200 Drainage	Jane Creek		Britannia Creek			
		Before 2200	After 2200	Before the 2200 Area	Before Main 4100 Input	After Main 4100 Input	4100 Drainage
Flow, L/s	0-20	4.2-5.6	4.2-69	58-1030	426-2284	-	42-160
pH	2.7-4.6	5.9-7.4	4.0-7.6	5.3-7.0	4.4-6.0	3.6-4.9	3.2-4.5
Cu, mg/L	0.2-115	0.4-4.0	0.1-28	0.001-0.015	0.17-1.9	0.8-3.3	14-31
Zn, mg/L	1.3-48	0.7-1.6	1.1-13	0.006-0.029	0.20-0.70	1.3-3.4	22-27
Al, mg/L	4-74	0.2-2	0-21	0-0.1	0.1-0.9	0.7-3.0	20-32
Fe, mg/L	0.4-55	0.1-5	0.1-16	0.0	0.1-0.9	0.2-1.2	2-34
SO_4,mg/L	200-1950	46-93	62-545	3-6	14-5	112-238	1140-1900

2.3 Permeable Reactive Barrier Systems

Passive treatment technologies use natural materials to facilitate chemical and biological processes. This cost-effective treatment is obtained by manipulating environmental conditions in the treatment system so that particular contaminant removal processes are optimized by utilizing locally sourced substrates. As a result, neither the materials nor the products of the vast majority of passive treatment are hazardous. Some passive systems, such as permeable

reactive barriers and wetland systems, are designed to operate for years with minimal requirement for operator intervention and/or costly maintenance (Younger, Banwart et al. 2002).

A permeable reactive barrier (PRB) is a passive in-situ treatment zone of reactive material that degrades or immobilizes contaminants as groundwater flows through it. PRBs could be installed as permanent, semi-permanent or replaceable units across the flow path of a contaminant plume. The transport of contaminants is carried out by natural gradients, through the strategically placed treatment media. The media, or substrate of the barrier system, retain the metals or other pollutants by degradation, sorption, precipitation and/or other retention mechanisms. The barriers may also contain reactants for degrading volatile organics, chelators for immobilizing metals, or other agents to enhance the performance (U.S.EPA. 1999). A schematic diagram of a permeable reactive barrier is presented in Figure 2.9.

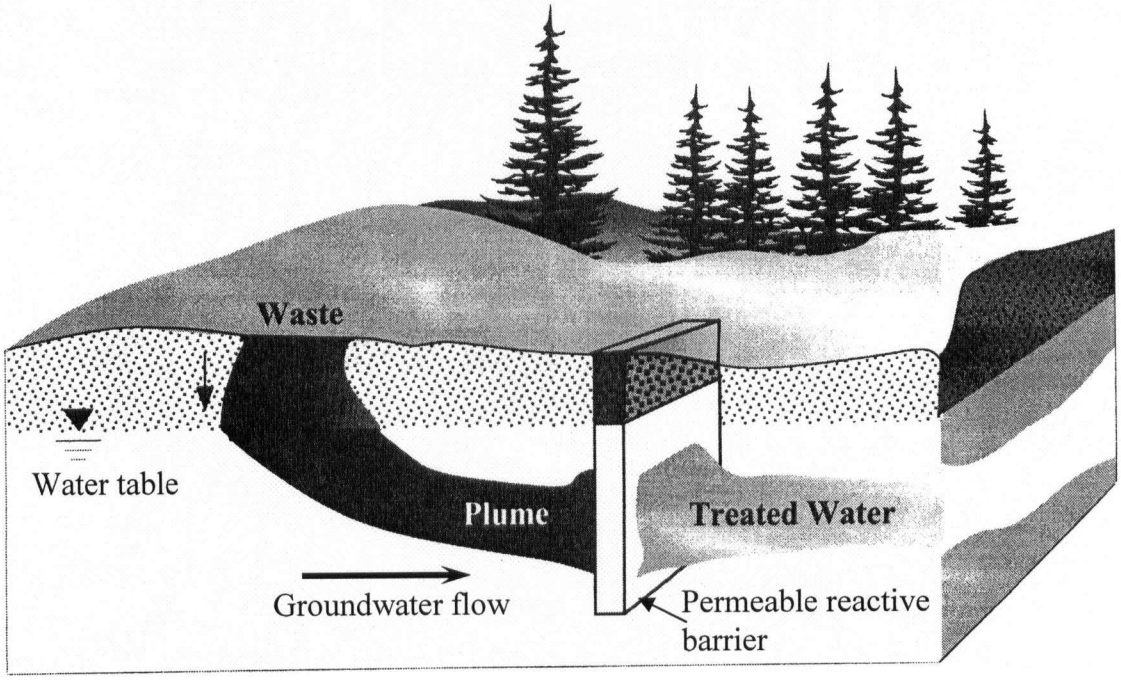

Figure 2.9 Schematic diagram of a permeable reactive barrier with contaminant plume (Adapted from Puls et al. (1998))

The goal of the permeable reactive barrier is to minimize the possibility that a contaminant plume can move toward and endanger sensitive receptors, such as through drinking water, or

discharge into surface waters. Rather than to constrain plume migration, permeable reactive barriers are designed as conduits for the contaminated groundwater flow (Puls, Powell et al. 1998). As contaminated water passes through the reactive zone of the PRB, the contaminants are either immobilized or chemically transformed to a more desirable state (e.g. less toxic, etc.).

Passive treatment systems are now sufficiently numerous in North America (and increasingly in Europe) that is possible to identify some of the key pros and cons of the technology. The advantages of the passive treatment system include low operating and capital costs and their ability to work unattended for long periods. Passive systems can often be directly integrated with surrounding ecosystems and be more pleasant in appearance than active treatment systems. However, reliable expertise, research and field-scale practices of passive treatment technology are still scarce. In addition, since day-to-day intervention in the treatment processes is precluded in the operation, precise control of the treatment effluent quality is not feasible at this point. In cases where the flow rate of the contaminant plume is high, large land-area, which may not be available in all the problem locations, is likely necessary for the treatment system.

2.3.1 Design requirements

Substrates used in a permeable reactive barrier should be compatible with the subsurface environment. The substrate should not cause adverse chemical reactions or by-products when reacting with constituents in the contaminant plume, and should not itself act as a possible source of contaminant.

In order to minimize the cost of a permeable reactive system, it is required that the substrate be able to persist over a long period of time, maintaining its reactivity and integrity during its service life. The substrate material ideally should also be readily available at a low cost or be locally available. In addition, the substrate material for the permeable reactive barrier should

maintain a hydraulic conductivity that does not constrain groundwater flow. This could be achieved by using substrates with a wide range of grain sizes, which would prevent blocking of inter-granular spaces.

Most PRBs are installed in either the funnel-and-gate, or the continuous trench configuration (Figure 2.10). The funnel-and-gate system employs impermeable walls to direct the contaminant plume through a gate, or treatment zone containing the reactive media. A continuous trench is installed across the entire path of the plume and is filled with reactive media.

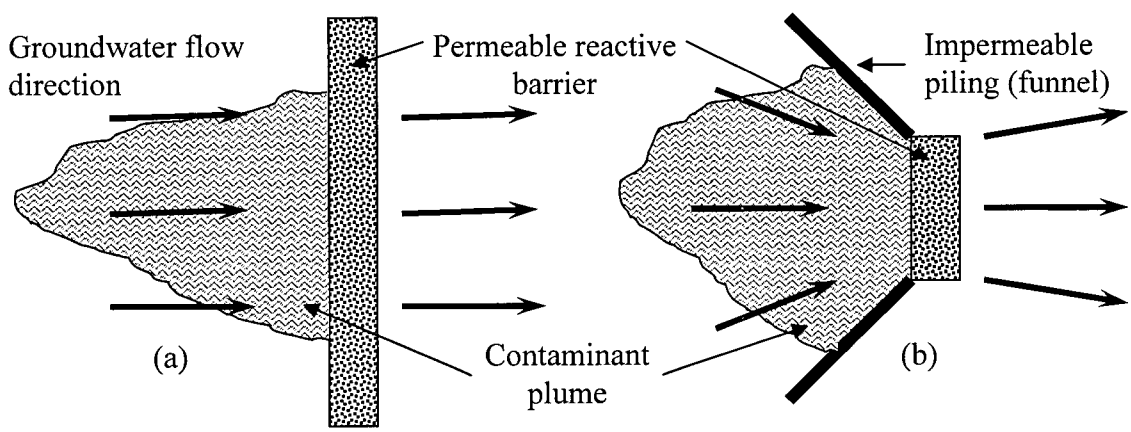

Figure 2.10 Schematic plan layouts of permeable reactive barriers: (a) continuous trench, and (b) funnel-and-gate

There are no established rules for sizing the length of permeable reactive barriers in the direction of flow through the reactive substrate (Younger, Banwart et al. 2002) . However, a few considerations are suggested in the selection of the permeable reactive barrier substrate (Table 2.3):

Table 2.3 Considerations in designing permeable reactive barrier systems

Design parameter	Continuous wall	Funnel-and-gate
Method of flow	Water passes through the barrier under its natural gradient and at its natural flow velocity	▪ Funnels direct groundwater towards permeable treatment zones or "gates". The funnel portion of the design is engineered to completely encompass the path of the contaminant plume ▪ the overall design must prevent the contaminant plume from flowing around the barrier in any direction.
Cross-sectional area	The PRB covers an area comparable to the cross-sectional area of the plume	Up- and down-gradient surface areas of the aquifer material contacting the PRB should be approximately the same to minimize disruption in the natural groundwater flow relative to the funnel-and-gate design
Groundwater flow velocity	Groundwater flow velocity through the PRB is similar to the velocity in the aquifer	Groundwater velocity within the gate should be higher than those resulting from the natural gradient
Hydraulic conductivity	To prevent underflow of the contaminated groundwater, hydraulic conductivity of the aquifer should be less than that of the PRB	▪ Funnel should be made of low permeability material to direct groundwater to the gate. The funnel typically consists of sheet piling, slurry walls, or some other material and is "keyed" into an impermeable layer to prevent contaminant underflow. ▪ Hydraulic conductivity of the reactive material must be equal to or greater than the aquifer permeability to minimize flow restrictions.
Depth	The PRB should be built to a depth that over-encompasses the vertical and horizontal dimensions of the contaminant plume	The bottom of the "gate" should be built into an impermeable zone/strata to mitigate the potential for contaminant underflow
Thickness	▪ The thickness of barrier should be sufficient to remediate the contaminant of concern to the established concentration goals, i.e. sufficient contact, or residence time between the reactive material and the contaminant. ▪ Since the reaction mechanism associated with retention of contaminants in PRB are surface area, cation exchange capacity dependent, the amount of reactive material needed should be proportional to the mass flux of contaminant requiring treatment	

In the actual field implementation of PRBs, it is possible that additional substrates be required than that estimated from theoretical calculations, particularly if the plume is very broad and requires a relatively long PRB. In this case, there is a need to be certain that the PRB has no un-reactive gaps or flow paths throughout its length to maintain full coverage of the plume. There will also be some limiting thicknesses that have to be maintained to assure the integrity of the PRB throughout its volume. The cost of PRBs would depend on the depth, width and saturated thickness of the plume, which controls the overall dimension of the system. The major components for the capital cost of a PRB are the reactive materials, "funnel" material (if installing a funnel-and-gate system), and installation cost.

2.3.2 Uses of permeable reactive barrier systems

Permeable reactive barriers have been investigated and used in contaminants including chlorinated solvents, metals and inorganics, fuel hydrocarbons, nutrients, radionuclides and other organic contaminants. Some examples of previously studied full and pilot-scale PRBs for metals contaminants are listed in Table 2.4.

Table 2.4 Previous uses of permeable reactive barriers in metal contaminants removal

Location	**Targeted metal contaminants**	**Reactive media**
Nickel Rim Mine Site, Sudbury, Ontario, Canada	Ni, Fe, sulphate	Organic carbon: Reactive mixture of municipal compost, leaf compost and wood chips. Pea gravel was added to increase hydraulic conductivity. PRB installed using cut-and-fill technique.
Tonolli superfund site, Nesquehoning, PA, USA	Pb, Cd, As, Zn, Cu	Limestone groundwater trench.
U.S. Coast Guard Support Center, Elizabeth City, NC, USA	Cr^{+6}	Continuous trench wall of zero-valent iron (Fe^0).
LEAP Permeable Barrier Demonstration Facility, Portland, OR, USA	Cr^{+6}	Surfactant-modified zeolite (SMZ) permeable reactive barrier hung in the center of the simulated aquifer.

In this study, zeolite clinoptilolite was selected as the substrate material for a permeable reactive barrier system. An evaluation and the suitability of clinoptilolite to be a substrate material are discussed in the following Section 2.4.

To be a good permeable reactive barrier material, it has to satisfy the following criteria:

- have enough adsorption capacity to hold target contaminants in the contaminated groundwater plume
- be chemically stable so that under acidic conditions, the barrier material is able to maintain its structure chemically, that the cations within the framework of the chemical structure not dissociate nor that any of the ions leach into the environment
- be physically stable and be able to maintain the required hydraulic conductivity to handle the flow of groundwater in the field condition, avoiding underflow of the contaminated plume to the aquifer

In the design of the permeable reactive barrier, field conditions must be defined in order to achieve the treatment goal efficiently. Such parameters include:

- flow rates
- concentrations and type of contaminants in the contaminated plume
- width or horizontal spread of the contaminated plume
- depth of the contaminated plume
- anticipated service life of the PRB system
- required effluent concentration from PRB system

Once the field conditions are defined, the thickness of the PRB could be determined using the equation:

Thickness = mass / (width * depth)

Where mass = mass flux of contaminant in influent / contaminant retention capacity of substrate

2.4 Properties of zeolite

Zeolites are tectosilicates, that is they consist of three-dimensional frameworks of SiO_4^{4-} tetrahedra wherein all the oxygen (O) of each tetrahedron is shared with adjacent tetrahedra. The zeolite structure would be electrically neutral if each tetrahedron were to contain Si as its central cation. However, in isomorphic substitution, the Si^{4+} ion is replaced by Al^{3+} ion, which leads to a deficiency of a positive charge in the framework. From the structural view of zeolite, each O atom is shared between two tetrahedra with no mobile anions present. The resulting zeolite structure has a net negative charge due to the presence of Al-centered tetrahedra, these negative charges are counter-balanced by the presence of alkali and alkaline earth cations (such as Na^+, K^+ — monovalent cations; Ca^{2+}, Mg^{2+}, Sr^{2+}, Ba^{2+} — divalent cations) within the existing pores elsewhere in the structure (Sherry 1971; Boles, Flanigen et al. 1977; Dixon and Weed 1989).

The zeolite structures can be visualized as linking the primary building units of SiO_4 and AlO_4 tetrahedra into secondary building units (SBUs) in simple geometrical forms. The SBUs range in complexity from simple rings of 4 or 6 tetrahedra (4-rings or 6-rings) to cubo-octahedra (8- or 12- rings). SBUs may be linked together in a variety of ways, giving rise to a crystal structure possessing a unique set of physical and chemical properties. For example, the structure of clinoptilolite is based on a complex linkage of 4- and 5- rings of tetrahedra. These hydrated aluminosilicates consisting of tetrahedral framework of O atoms, surrounding either a Si or an Al atom, extended in a three-dimensional network provide structural channels (Boles, Flanigen et al. 1977; Gottardi and Galli 1985; Dyer 1988; Dixon and Weed 1989). Since each zeolite has its own arrangement and number of channels, making its unique molecular sieve properties, it will adsorb cations selectively according to the size and the speciation of the cations.

Zeolites are also characterized by the large void volumes of 20% to 50% and the large internal surface areas of several hundred thousand square meters per kilogram, which are the requirements of a good adsorbent. The other unique feature of zeolite is its ability to hydrate and dehydrate reversibly, and to exchange constituent cations without disrupting the bonds of the framework (Dyer 1988).

Clinoptilolite, a sub-category of zeolite, which means "*oblique feather stone*" in Greek, received its name because it was thought to be the monoclinic (or obliquely inclined) phase of the mineral ptilolite, as in "*oblique ptilolite*". But ptilolite was later found to be the earlier named mineral mordenite; consequently ptilolite is no longer in use. Clinoptilolite is very closely related to heulandite and is currently being considered for disuse itself as it may just be a variety of heulandite. It differs from heulandite significantly only in its enrichment in potassium and slightly higher silica content, and it is argued that a separate mineral is not needed. The name clinoptilolite is widely recognized and used among zeolite industries, mineral collectors and mineralogists and recognized as a legitimate, distinct mineral (Breck 1974).

2.4.1 Minerological properties of Clinoptilolite

The representative unit-cell formula for clinoptilolite is $(Na_3K_3)\{Al_6Si_{30}O_{72}\}\bullet 24H_2O$. The Si/Al ratio is 4.3-5.3 (Dixon and Weed 1989). In this type of zeolite, the net negative charge created by the replacement of Si^{4+} by Al^{3+} cations in isomorphic substitution, is balanced by the exchangeable cations K^+ and Na^+. A summary of the major elemental composition in the zeolite clinoptilolite is shown in Table 2.5. The Si/Al ratio of clinoptilolite used in this study is 5.4.

Table 2.5 Major elemental compositions from ICP analysis on clinoptilolite (Beck, 1996)

Element	Concentration (μg/g or ppm)
Aluminum	110,000
Potassium	40,000
Iron	36,000
Sodium	18,000
Zinc	210
Copper	71

2.4.2 Stability in low pH

One of the concerns of the use of zeolite as a reactive material with ARD, is its resistance to low pH. It is often assumed that zeolites have a low resistance to mineral acids. Since zeolites are mainly made up of silica and aluminum (in the tetrahedra and octahedra layers), they are susceptible to partial dissolution by either acidic or basic environments. This ease of dissolution can be linked to the readily removed aluminum from tetrahedral site frameworks where Si:Al is 1:2. The leached aluminum hydrolyses to a variety of species in which the metal is hexa-coordinated. However, at higher Si:Al ratio, even though the framework aluminum was leached by the mineral acids, zeolitic structures can still be retained due to the high ratio of silica in the framework (Dyer 1988).

If the zeolite is infiltrated with a chemical that would destroy the structure of the zeolite itself, or cause dissociation of the zeolite, the purpose of retaining the contaminant or the metal cations would not be served. For example, leachates of very low pH can dissolve aluminum, iron, alkali metals and alkaline earths; bases dissolve silica, depending on the resistance of the mineral (Gottardi and Galli 1985). The solubility of the zeolite depends on the nature of the

acid, the acid concentration, the acid to clay ratio, and the temperature and duration of the treatment (Grim 1968).

The loss of Al from the zeolite framework will cause a consequent loss of capacity and ultimately collapse of the framework. The limit of acid resistance of zeolite is usually about pH 3-4 (Dixon and Weed 1989). When the pH drops even lower, zeolite with Si/Al ratio in the range of 1-2 will readily lose Al from their framework. The leached Al is readily hydrolyzed to a variety of species in which the metal is hexa-coordinated (Dyer 1988). For higher Si:Al ratio zeolites, such as clinoptilolite (Si/Al ratio ranges 4.3-5.3) (Boles, Flanigen et al. 1977; Gottardi and Galli 1985; Dyer 1988; Dixon and Weed 1989), the effect of mineral acid is that Al leaches from the framework, and decomposes to an aqueous aluminosilicate gel. In some instances, a zeolitic structure can be retained when there is more Si than Al ions in the framework, because the structure is less easily destructed by the loss of Al.

Clinoptilolite has been shown to retain crystal habit and integrity even after six months of exposure to 8 M nitric acid. Leaching can be promoted by agents other than mineral acids and the same effect can be attained by treatment, for example, with ethylenediamine tetra-acetic acid (H_4EDTA), silicon tetrachloride, fluorosilicates, organic acids and even acetyl-acetone, which form stable Al complexes. It has been claimed that clinoptilolite can be stripped of all aluminum to leave a silica pseudomorph of each structure. Studies on the reaction of zeolites with moderate acid molarities demonstrate that the first stage of the leaching occurs by a cation exchange, whereby hydronium ions (H_3O^+) replace the indigenous cations (Dyer 1988).

De-cationated forms of clinoptilolite were obtained by Barrer and Coughlan (1968) by treatment with 0.25, 0.5, 1 and 2 N acid solutions with the contemporaneous removal of 42%, 67%, 93%, and 100% of the original Al, whose charges in the framework are substituted by 3 H^+, whereas the charges of the leached extra framework cations are substituted by H_3O^+. The

acid treated material, even with 2N HCl, retains the original x-ray powder pattern of clinoptilolite, with only minor variations (Gottardi and Galli 1985).

In a recent study by the USGS (Gilbert, O'Meara et al. 1999) on the adsorption capabilities of clinoptilolite to mine drainage (pH 2-3), a slight (120μg per gram of soil) desorption of Al in the clinoptilolite-rich rock had been observed. This could be explained by the displacement of Al in the zeolite framework by the H^+ ion in the acidic solution.

2.4.3 Adsorption capability

An earlier study on the adsorption of heavy metals from ARD was conducted on the clinoptilolite sample used in this research (Beck 1996). It was found that zeolite is effective in reducing Equity Silver's ARD's copper by 68%, zinc by 49%, arsenic by 97% and iron by 93%. However, the test results only revealed the adsorption in the first 18 hours of reaction, and the stability of the zeolite, which may be affected by the acidic environment, had not been investigated.

A study conducted by Vos (1992) in using zeolite for treatment of ARD from Britannia mine, and recent research done by Gilbert et al. (1999) in using clinoptilolite for ARD remediation has found that clinoptilolite is effective in removing metal cations such as aluminum, iron, lead, cadmium and copper in the ARD.

The US Geological Survey tested three Clinoptilolite-Rich Rocks (CRR): sodium-rich, calcium-rich and potassium-rich, for their ability to exchange copper, lead and zinc in the presence of low concentrations of calcium and potassium, which compete with metal ions in the zeolite exchange process. Samples were exposed to acidified solutions of pH 2.1 containing 1.2 mg/L copper, 1.3 mg/L lead, 15 mg/L zinc, and 2 mg/L calcium repeatedly. The sodium-rich CRR tested was able to removed approximately 65% of the zinc, 55% of the copper, and 95% of

the lead from solution and was more effective at removing copper and zinc from solution than the calcium- and potassium-rich CRR. Another experiment was conducted using a solution with a pH of 2.6 and containing 100 mg/L copper, 0.31 mg/L lead, 19 mg/L zinc, 3.1 mg/L calcium, 3.3 mg/L potassium, and 15 mg/L sodium. Again, sodium-rich CRR removed more copper and zinc from solution than the calcium- and potassium-rich CRR (Desborough 1997; Virta 1997)

However, these results were based only on batch adsorption tests and short term monitoring. The chemical compatibility to clinoptilolite and its stability in the ARD environment was not investigated.

2.4.4 Surface Sorption Phenomena

Retention mechanism at a surface is termed as sorption, which includes adsorption, surface precipitation and polymerization. Factors that could affect retention of metals include ion association, gas-water reaction, ion exchange reactions, sorption and mineral-solution reactions. The mechanisms of the factors are listed in Table 2.6.

Table 2.6 Factors that could affect retention of metals and the mechanisms (Adapted from Sparks, 1995)

Factor	**Mechanism**
Ion association reactions	Ion pairing, complexation (inner and outer sphere), and chelation type reactions in solution
Ion exchange reactions	Electrostatic ion replacement reactions on charged solid surfaces
Sorption	Simple physical adsorption, surface complexation (inner- and outer- sphere), and surface precipitation reactions
Mineral-solution reactions	Precipitation/dissolution reactions involving discrete mineral phases and coprecipitation reactions by which trace constituents can become incorporated into the structure of discrete mineral phrase

Electrostatic ion reactions

Clay crystals carry a permanent net negative charge as a result of isomorphous substitution. The net negative charge is compensated by cations, which are located on the layer surfaces. In the presence of water, these compensating cations have a tendency to diffuse away from the layer surface since their concentration is smaller in the bulk solution. On the other hand, they are attracted electrostatically to the charged layers. The result of these opposing trends is the creation of a distribution of the compensating cations in diffuse electrical double layer on the exterior layer surfaces of a clay particle. Theses cations between the layers are confined to the narrow space between opposite layer surfaces. The compensating cations act as the counter-ions of the double layers, like all counter-ions, they are exchangeable for other cations (Mohamed and Antia 1998).

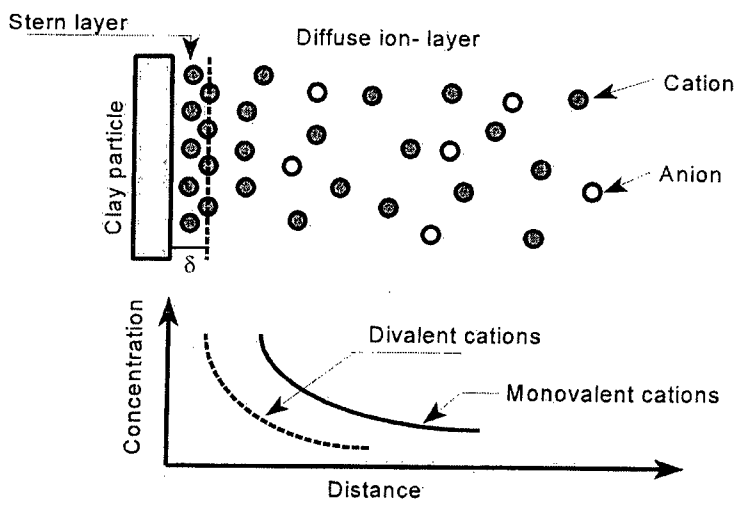

Figure 2.11 The diffuse-ion layer (Adapted from Mohamed and Antia,1998)

The first layer of ions (Stern layer) is not immediately at the surface, but at a distance away from it. The counter-ion charge is separated from the surface charge by a layer of thickness (δ) in which no charge exists. A simple model relating the density of charge on the surface to the electrical potential across the double layer was developed by Gouy (1910) and Chapman (1913).

The model was based on the assumptions that: (1) the adsorbent surface is a uniform plane of charge density; (2) the adsorptive ions are point species that interact mutually and with the adsorbent through the Coulomb force. Their only mechanism of adsorption is the diffuse-ion layer; and (3) the aqueous solution phase is a uniform continuum of dielectric constant in which the point-ion adsorptive is immersed. The relationship between the thickness of the double layer ($\frac{1}{\kappa}$) and the ion concentration in the equilibrium solution as described by the Gouy-Chapman theory is presented as follows:

$$\kappa^2 = \frac{8\pi n e^2 z^2}{\in kT} cm^{-2}$$

where

$\frac{1}{\kappa}$ = thickness of the double layer

n = counter ion concentration in the equilibrium solution (ions/cm^3)

= molarity × 10^{-3} × Avogardo's number

K = Boltzmann constant (kT = 0.4×10^{-13} ergs at room temperature)

T = absolute temperature

Z = valences of ions

e = elementary charge (4.80×10^{-10} esu)

$\in$ = dielectric constant (80)

The Guoy-Chapman theory predicts that double-layer thickness ($\frac{1}{\kappa}$) is inversely proportional to the product of ion concentration and valency of the electrolyte in the external solution (Sparks 1995). It is also noted that the actual thickness of the electrical double layer cannot be measure, but it is defined mathematically as the distance of a point from the surface where the change of potential (ψ) with distance (x) is 0 ($d\psi / dx = 0$).

Adsorption

Adsorption is the net accumulation of masses at the interface between a solid phase and an aqueous solution phase (Sposito 1984). Adsorption can include the removal of solute molecules from the solution, solvent from the solid surface, and attachment of the solute molecule to the surface (Stumm 1992). Both physical and chemical forces are involved in adsorption of solutes from solution.

Physical forces include: van der Waals forces (e.g. partitioning) and electrostatic outer-sphere complexes (e.g. ion exchange). Chemical forces result from short-range interactions that include inner-sphere complexation that involves a ligand exchange mechanism, covalent bonding, and hydrogen bonding (Stumm and Morgan 1981; Sparks 1986).

Surface functional groups is "a chemically reactive molecular unit bound into the structure of a solid at its periphery such that the reactive components of the unit can be bathed by a fluid" (Sposito 1984). Surface functional groups may be organic (e.g. carboxyl, carbonyl, phenolic) or inorganic molecular units. The major inorganic surface functional groups in soils are the siloxane surface associated with the plane of oxygen atoms bound to the silica tetrahedral layer of a phyllosilicate and hydroxyl groups that are associated with the edges of inorganic minerals such as kaolinite, amorphous materials, and metal oxides, oxyhydroxides, and hydroxides.

When the interaction of a surface functional group with an ion or molecule present in the soil solution creates a stable molecular entity, it is called a surface complex and the reaction is referred to as surface complexation. There are two types of surface complexes that can form: (1) outer-sphere and (2) inner-sphere (Sparks 1995). An outer-sphere surface complex is defined as the complex that is obtained when at least one water molecule is interposed between the surface functional group and the ion or molecule it binds. Outer-sphere surface complexes involve electrostatic coulombic interactions and bonding mechanisms, and thus are less stable than inner-sphere complexes in which the binding is covalent or ionic. Outer-sphere

complexation is usually a rapid process that is reversible, and the adsorption via this mechanism is affected by ionic strength of the aqueous phase. Adsorption by outer-sphere complexation occurs only on surfaces that are of opposite charge to the adsorbate. This type of adsorption is called non-specific adsorption (Sposito 1984; Mohamed and Antia 1998). An inner-sphere surface complex is defined as the complex that is obtained when no water molecule is interposed between the surface functional group and the ion or molecule it binds. The inner-sphere surface complexes involve either ionic or covalent bonding, or some combination of the two. The interaction is usually slower and often not reversible and adsorption by this mechanism is weakly affected by the ionic strength of the aqueous phase. Inner-sphere complexation can increase, reduce, neutralize, or reverse the charge on the sorptive regardless of the original charge. Adsorption of ions via inner-sphere complexation can occur on a surface regardless of the surface charge. Since covalent bonding depends significantly on the particular electron configurations of both the surface group and the complex ion, inner-sphere surface complexation is termed specific adsorption (Sposito 1984; Mohamed and Antia 1998). It is also noted that outer- and inner-sphere complexation can, and often do, occur simultaneously (Sparks 1995).

If a solvated ion does not form a complex with a charged surface functional group, but instead neutralizes surface charge, it is said to be adsorbed in the diffuse-ion layer. This adsorption mechanism involves ions that are fully dissociated from surface functional groups and are free to move in the soil solution. The diffuse-ion layer involves electrostatic bonding. There is only a weak dependence on the electron configuration of the surface group and the adsorbed ion. This type of adsorption is also called non-specific adsorption (Mohamed and Antia 1998).

Surface precipitation

As the amount of metal cation or anion sorbed on a surface increases to a high surface coverage, a precipitate of the cation or anion can form with the ions of the mineral and is know as surface precipitation. It is the process whereby a three-dimensional growth mechanism occurs on the solid. There is a continuum between surface complexation (adsorption) and surface precipitation as shown in Figure 2.12 (Sparks 1995). At low surface coverage, surface complexation dominates and as surface coverage increases, nucleation occurs or distinct entities or aggregates occur on the surface. As surface loading further increases, surface precipitation becomes the dominant mechanism. When the precipitate covers the entire surface, it is referred to as a "surface precipitate". When the precipitate grows away from the surface before covering it, it is referred to as a "surface cluster" (Stumm 1992; Sparks 1995).

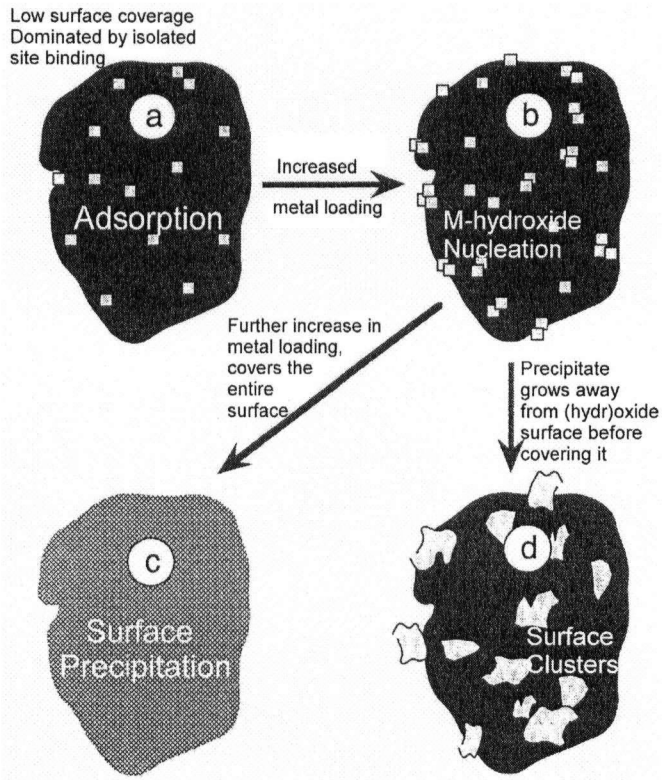

Figure 2.12 An illustration of metal ion sorption on (hydr)oxide (Adapted from Sparks, 1995)

Relative strengths amount sorption mechanisms

The relative affinity that a given metal cation has for a soil adsorbent depends in a complex manner way on the soil solution composition. But as a first approximation, the selectivity of a soil for an adsorption metal cation can be rationalized in terms of inner-sphere and outer-sphere surface complexation, and diffuse-ion layer concepts. The relative order of increasing interaction strength among these three adsorption mechanisms is: diffuse-ion layer > outer-sphere complex > inner-sphere complex.

For the diffuse-ion layer only the metal cation valence and surface charge are critical in determining adsorption affinity. The outer-sphere complex is intermediate, in that valence is probably the most important factor (Mohamed and Antia 1998). Hence, the relative affinity of a soil adsorbent for a free metal cation will increase with the tendency of the cation to form inner-sphere surface complexes.

Effect of ionic radii

In case of a series of metal cations of a given valence, the tendency is correlated positively with the ionic radius(Mohamed and Antia 1998). The first reason is that metal cations with larger ionic radii will create a smaller electric field (since ionic potential = valence/ionic radius) and be less likely to remain solvated for complexation by a surface functional group. The second reason is that metal cation, which has a larger ionic radius implies a larger spread of the electron configuration in space and a greater tendency for a meal cation to polarize in response to the electric field of a charged surface functional group, which polarization is a necessary prerequisite for the distortion of the electron configuration leading to covalent bonding (Mohamed and Antia 1998). Given the above considerations, the relative adsorption affinity series, or so-called the selectivity sequence, of the metal cations found in this study based on ionic radius is:

$K^{+}>Na^{+}>Zn^{2+}$

With respect to transition metal cations, ionic radius is not adequate as a single predictor of adsorption affinity because electron configuration plays a very important role in the complexes of these cations (e.g. Mn, Fe, Ni). The relative affinities of the transition metal cations found in this study are listed as follow, and tend to follow the Irving Williams order (Mohamed and Antia 1998): $Cu^{2+}>Fe^{2+}>Mn^{2+}$.

Effect of pH

As pH increases, surface charge decreases toward negative values, and the electrostatic attraction of a soil adsorbent for a metal cation is enhanced. If a soil is reacted with a series of aqueous solutions containing a metal cation at the same initial concentration but having an increasing valence, the amount of metal cation adsorbed will increase with pH (Mohamed and Antia 1998).

2.4.5 Availability of the substrate material

In search of a suitable substrate for a permeable reactive barrier system (other than the chemical compatibility, attenuation ability for the contaminants and its service life), it is also important that the barrier substrate be locally available for economical purposes, as a large amount of substrate material could be needed in constructing and the placement of the reactive-barrier system. Clinoptilolite may be found in large quantities from sedimentary deposits (saline, alkaline lakes, deep-sea sediments, and low-temperature tephra systems). Therefore, it may be obtained at a competitive price (Hay and Sheppard 2001; Dobelin and Armbruster 2003).

Open-system zeolite clinoptilolite is found at Asp Creek, Sunday Creek in B.C.; Nye County in Nevada, John Day Formation in Oregon, Death Valley Junction in California, USA; and Yellow tuffs near Naples in Italy (Sheppard and Simandl 1999). Depending on the quality

and specification, the price of clinoptilolite ranges between 50 and 300 US$ per ton (Armbruster 2001).

2.5 Geochemical models

Geochemical models have been used widely in field-based environmental problems of contamination and water-resources studies. Common practices in using geochemical model for contamination problems include determining the concentrations in groundwater for risk assessment, to evaluate feasibility of remedial alternatives, and to demonstrate potential migration of regulated chemical species or other adverse environmental impacts in applying for permits for mining or waste disposal/storage facilities.

In maximizing the performance of a permeable reactive barrier, it would be an advantage to have the knowledge and predictions of the solute concentrations in space and time within the barrier system. Knowing the fate of the contaminants in the barrier system, one could predict the extent of contamination and to predict the service life of a barrier system. Predictions of how the contaminants react with the substrate can be used to make estimates of the amount of substrate needed for the barrier system. This in turn, minimizes the cost and maximizes the use of the substrate material.

Several equilibrium thermodynamic computer programs, such as MINTEQA2, PHREEQC and EQ3/6, are available for modeling soil solution and solid phase chemistry by providing information on the thermodynamic possibility of certain reactions to occur. In addition, some models, such as MINTEQA2 and PHREEQC also provide information on cation-exchange reactions and metal-ion adsorption, as well as the transport of cations. The geochemical models are used to:

- Calculate the distribution of free metal ions and metal ligand complexes in soil solution.

- Predict the fate of metals added to soils by providing a listing of which precipitation and adsorption reactions are likely to be controlling the solution concentration of metals, and
- Provide a method for evaluating the effect that changing one or more soil solution parameters, such as pH, redox, inorganic and organic ligand concentration, or metal concentration, has on the adsorption/precipitation behavior of the metal of interest.

Geochemical models have been extensively reviewed in the literature (Nordstorm and Ball 1984; Appelo and Postma 1993; Paschke and Heijde 1996), and as such only a brief description of the geochemical models will be covered in this thesis. Generally, geochemical models may be divided into three categories: speciation-solubility models, reaction-path models, and reactive-transport models. Speciation-solubility models predict the concentrations and activities of the ionic and molecular species in an aqueous system. They contain no spatial or temporal information. Reaction-path models simulate the successive reaction steps of a system in response to the mass or energy flux. Some temporal information is included in terms of reaction progress, but no spatial information is contained. Coupled reactive-mass-transport models contain both temporal and spatial information about chemical reactions. However, they are too complicated and expensive to use because of the large information database and data requirements.

Reaction-path models calculate a sequence of equilibrium states involving incremental or step-wise mass transfer between the phases within a system, or incremental addition or subtraction of a reactant from the system. The calculated mass transfer is based on the principles of mass balance and thermodynamic equilibrium. A summary of the functions available for some of the most popular geochemical model is presented in Table 2.7.

Table 2.7 Functions of popular geochemical modeling programs (Source: Zhu and Anderson, 2002)

Functions		MINTEQA2	PHREEQC	EQ3/6	GWB
Types of reactions	Aqueous speciation	✓	✓	✓	✓
	Precipitation/dissolution	✓	✓	✓	✓
	Solid solutions		✓	✓	
	Ion-exchange	✓	✓		
	Surface complexation				
	Constant capacitance	✓			✓
	Double layer	✓	✓		
	Triple layer	✓			✓
Activity coefficient	Davis	✓	✓	✓	✓
	B-dot		✓	✓	✓
	Pitzer			✓	✓
Redox	Disequilibrium		✓		✓
Gas Phase		✓	✓	✓	
Reaction path models	Mixing/titration		✓	✓	✓
	Flow through		✓	✓	✓
	Flush		✓		✓
	Dump option		✓		✓
	Fixed activity		✓	✓	✓
	Slide activity		✓		✓
	Change of temperature		✓	✓	✓

In terms of selecting a model, one should choose a model that includes the types of reactions that could be involved in the scenario to be predicted. MINTEQA2 is an equilibrium model and does not consider the kinetics and transport of cations in the reactions. Such models are also limited by the accuracy of the thermodynamics database available. PHREEQC is a computer program written in the C programming language that is designed to perform a wide variety of aqueous geochemical calculations. PHREEQC is based on an ion-association aqueous model and has the capabilities for speciation and saturation-index calculations, batch-reaction and one-dimensional transport calculations. Calculations involving aqueous, mineral, solid-solution, surface-complexation and ion-exchange equilibria are included and can be defined. GWB is a collective of the other geochemical models but purchase of the software was required, therefore, PHREEQC was chosen in this study because it was free through the USGS and it contains the necessary functions that are required for the transport and speciation. In addition, Langmuir isotherm constants, k, related to the binding strength of the metal ions

could be applied in the algorithm. PHREEQC is also one of the most commonly used programs by government agencies and geochemical model developers.

The purpose of using PHREEQC for column simulation is to assess the ability of the transport and the geochemical capabilities of the program to simulate the leaching of metal and breakthrough time in the column leaching tests, and to compare with the experimental results obtained. This type of transport prediction model (TPM) is an essential tool in the decision-making process for regulatory agencies and practitioners in: (a) assessment and evaluation of attenuation competence of soil-engineered barriers or soil substrate; (b) prediction of continued progress of pollutant plumes; and (c) risk assessment. These models are designed to provide analyses and predictive performance characteristics of pollutant plumes in transport through the soil medium. The problems addressed include those dealing with evaluation of the capability of soils to function as natural attenuation barrier systems over the period of leachate generation and transport in the substrate, generally from 1 to 50 years or more. An important factor in successful development of TPMs is their ability to represent the many interacting relationships governing transport of pollutants in the soil-water system (Yong 2001).

However, there are some limitations of the program that may affect the accuracy of the prediction. Such limitations include a lack of kinetic data for critical environmental and geochemical processes, and the large discrepancy between laboratory and field-derived rate constants (Zhu and Anderson 2002). Other limitations include characterizing the effective surface areas of the sorbents and the applicability of laboratory data to the field. Therefore, the focus on TPMs is in the direction of the capability of the TPMs to fully accommodate or account for the phenomena resulting from the various interactions between pollutants and soil fractions (Yong 2001).

PHREEQC uses a mixing-cell approach to simulate advection. At the beginning of transport simulation, the equilibrium aqueous and solid-phase compositions are computed for each cell. Then, transport is simulated by "shifting" the aqueous contact of each cell to the adjacent downstream cell where any specified mixing is done and water is equilibrated with the solid-phase components. The sequence of shifting, mixing and equilibration is repeated for each cell until the total numbers of shifts are completed. In this approach, the advective transport and chemical equilibrium are computed separately and, before simulating the transport, each model computes an equilibrium aqueous and solid-phase composition for each cell in the column. The thermodynamic database used in PHREEQC is the same as the thermodynamic database used in WATEQ4F.

The geochemical model was simulated using the data obtained from the experiments for the prediction of contaminant transport and attenuation. In the geochemical model, the characteristics of the substrate are first defined. They include the type of substrate of the column leaching cell, porosity, amount of cation-exchange capacity site, types of exchange sites and amount of substrates. The setup of the experiment such as flow rates, flow direction, residence time and the composition of the leachate are defined subsequently. The background information on the characteristics of the materials used was obtained from the experiments as discussed in Sections 3.1 and 3.2. Specifications of the column leaching cell tests, as discussed in Section 3.2.4, were used and defined in the geochemical model for the predictions.

CHAPTER 3 MATERIALS AND METHODS

This section describes the methods and procedures taken in carrying out the studies. The two main components of the experiments are acid rock drainage (ARD), and zeolite clinoptilolite.

3.1 ARD sampling

The experiments were conducted using ARD from the Anaconda-Britannia Mine, Britannia Beach, B.C. ARD samples were taken from the 4100 and the 4150 Portal at the mine site. Two phases of ARD sampling were carried out. The first of the sampling was conducted on January 9, 2002. The ARD sample was obtained from the 4150 Portal at the Britannia Mine site. Since the 4100 Portal was plugged for maintenance and monitoring as of October 2001, ARD was obtained from the next portal downstream of the 4100 Portal. 4150 Portal is the closest source of ARD and is most representative of the ARD in the adit in terms of chemical composition and water quality after the 4100 Portal. Mine drainage was taken at the u-notch outlet at the 4150 portal (Figure 3.1).

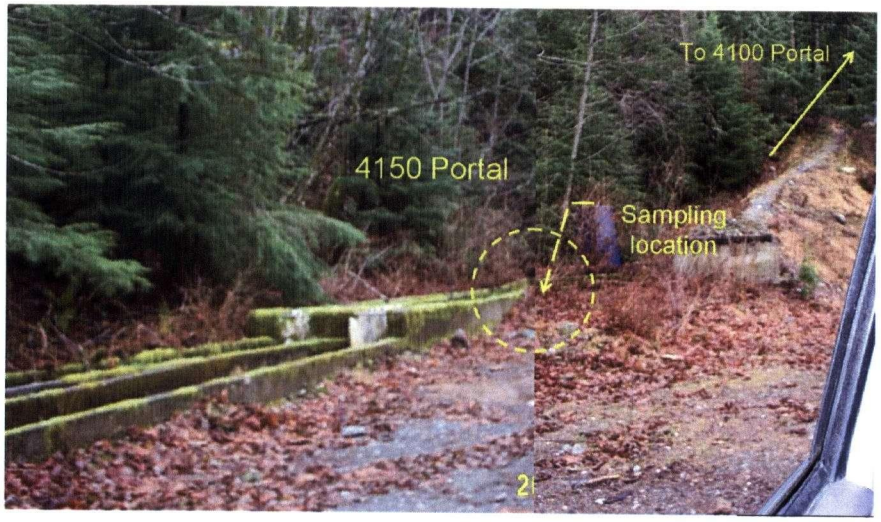

Figure 3.1 Sampling location at the 4150 Portal, Britannia Mine

The second phase of ARD sampling was conducted on March 12, 2003. ARD sampling was taken from the 4100 Portal. The 4100 Portal collects acid drainage directly from the adit in the mine site, and discharges to Britannia Creek. Drainage obtained from the 4100 Portal was used, as it is the closest location for sampling water from the adit. Mine drainage was collected from a hose directed from the adit (Figure 3.2). The drainages from the 4100 and 4150 Portals were analyzed and compared.

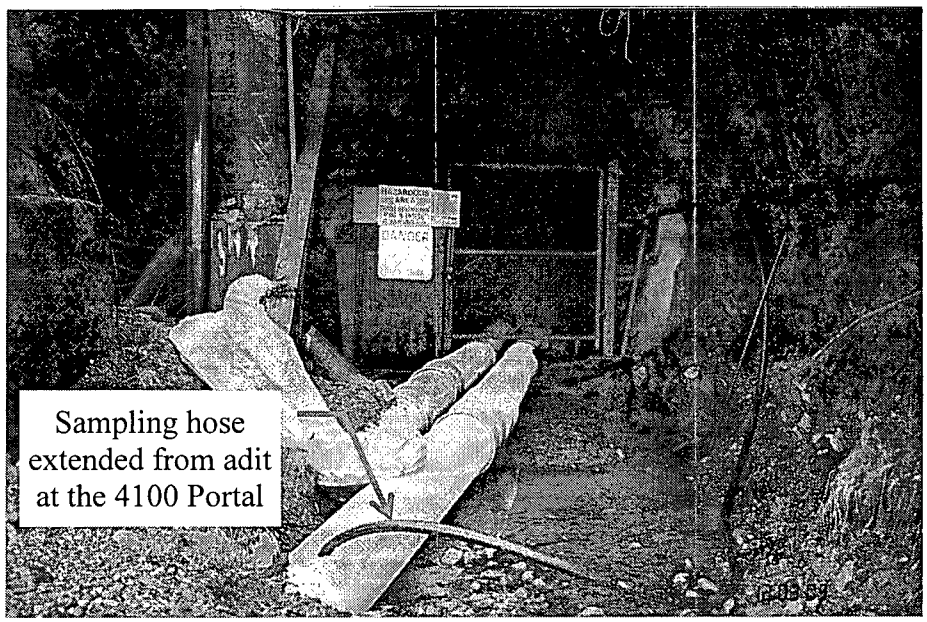

Figure 3.2 Sampling location at the 4100 Portal, Britannia Mine

Mine drainage water samples were collected for on-site chemical analyses for their pH, reduction-oxidation potential, and electrical conductivity. Waters samples were collected and preserved (acidified with 1:1 concentrated nitric acid: water solution) for chemical analyses in the lab.

3.2 Laboratory investigation of zeolite clinoptilolite

The zeolite clinoptilolite used in this study was provided by Canmark International Resources Inc. from cores recovered during the drilling program at their Sunday Creek mine site near Princeton, B.C. The zeolite was shipped in 15 kg sample bags. Physio-chemical characterization of the clinoptilolite was conducted as described in the following sections. The major elemental composition of the studied clinoptilolite is shown in Appendix C (Beck 1996).

3.2.1 Physical-chemical characteristics of zeolite clinoptilolite

Soil pH

The pH of clinoptilolite was measured using two methods (Sheldrick 1984): (1) 1:2 soil:0.01M calcium chloride ($CaCl_2$) ratio, and (2) 1:1 soil:deionized distilled water ratio. The measurement of soil pH in 0.01M $CaCl_2$ is the preferred method for most purposes as suggested by Peech (1965). By using the 0.01M $CaCl_2$, the pH measurement is almost independent of dilution over a wide range and the concentration of soluble salt present in non-saline soils. The pH was measured using an Orion model 420A pH meter and VWR Symphony pH electrode.

Cation exchange capacity and surface area

Clinoptilolite samples passing a standard nomenclature no.100 mesh sieve were used for the cation exchange capacity and surface area determination. The total surface area of the sample was determined by using the ethylene glycol monoethyl ether (EGME) method (Jackson 1956). The test involves saturating a soil sample with EGME and then removing the excess EGME in a vacuum desiccator, until the EGME forms a monomolecular layer on the soil surface. The specific surface area (SSA) of clinoptilolite was obtained by dividing the total surface area by the dry sample weight with units of m^2/g. The cation exchange capacity (CEC)was determined based on the sum of exchangeable cations of sodium (Na^+), potassium

(K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). The above cations were determined by displacing them from the sample with 1M NH_4OAc (Sheldrick 1984). The concentrations of Na, K, Ca and Mg were measured by atomic absorption spectrophotometer (Perkin Elmer Model 306, Perkin Elmer Instruments Inc., Wellesley, MA, USA) and the NH_4^+ concentration was measured by the Ammonium Acetate Method (pH 7.0) in an Automated Ion Analyzer, model QuikChem Flow Injection Analysis (FIA+) 8000 series (Lachat Instruments, Milwaukee, WI, USA).

Carbonate content

The carbonate content of the clinoptilolite was determined, using a gravimetric method, by estimating the carbonates ($CaCO_3$) from the resulting loss of CO_2 in reacting with 4 M hydrochloric acid as described in Sheldrick (1984).

Particle size analysis

The particle size distribution of the bulk clinoptilolite samples was determined using dry sieving procedures as described in ASTM D422-63 (ASTM 1991). Particle sizes were determined by dry sieving method using a series of brass sieves of mesh opening ranging from 4.60 mm to 74 μm (W.S. Tyler Company, Cleveland, Ohio, U.S.A.). The particle size distribution of particles smaller than 74 μm was determined by using x-ray gravitational sedimentation analyzer Sedigraph 5100 (Micromeritics in North Gosford, NSW, Australia).

Specific gravity

The specific gravity was determined by the standard test method for specific gravity of soils as described in ASTMD854-83 (ASTM 1991). Specific gravity of the sample was used to calculate the pore volume of the substrate when packed in the leaching columns.

Hydraulic conductivity

The hydraulic conductivity (k) of the barrier substrate was determined using both variable head and constant head permeameter tests (Lambe 1991), with two different permeants – tap water and natural ARD from the Britannia Mine.

Constant head permeameter tests were conducted in permeameters that have a dimension of 55 cm in length, and 4.3 cm inner diameter. Each permeameter was set to a certain hydraulic head relative to the reservoir and permeants flow in an upward direction from the bottom of the permeameter. The permeameters were packed with dry clinoptilolite with an optimum dry density (ρ_d = 1440 kg/m^3), the permeants were introduced and saturated within the column. Hydraulic conductivity of the material is calculated according to the hydraulic head and the rate of flow from the permeameter, experiments were repeated and recorded until the results were within 5% difference.

Variable-head permeameter tests were also conducted in permeameters with 16 cm in length and 3.8 cm inner diameter, the length of the standpipe was 100 cm long and 0.71cm in diameter (Figure 3.3). Permeant wash from the top of the permeameter to the overflow pan, located at the bottom of the column. The hydraulic conductivity of the barrier material was measured over a period of three months in the variable-head permeameter as a long-term observation for further changes on the hydraulic conductivity of the barrier material.

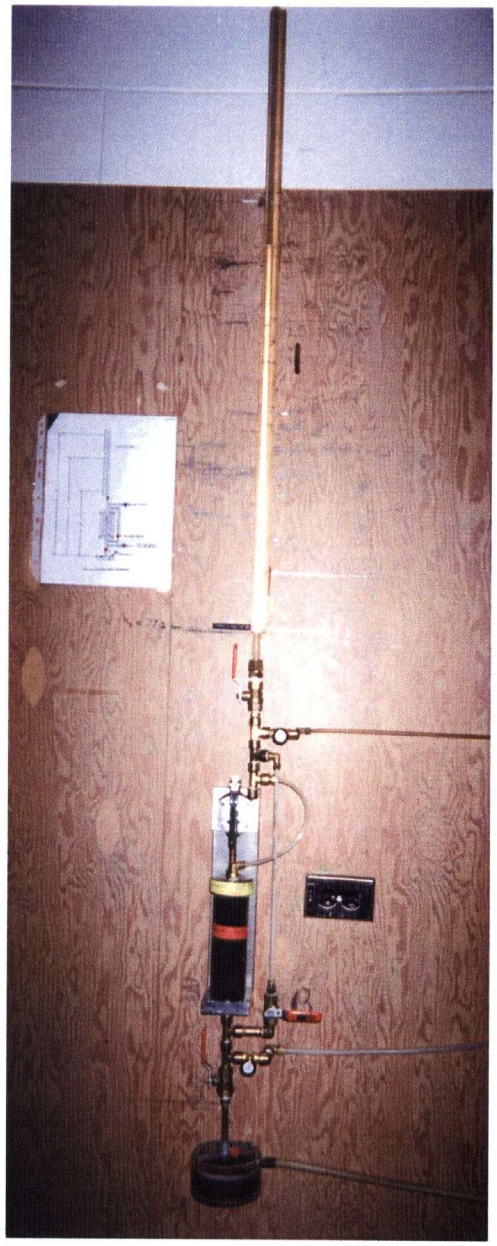

Figure 3.3 Setup of the variable-head permeameter

3.2.2 Minerological characteristics of zeolite clinoptilolite

X-ray Diffraction

X-Ray diffraction (XRD) analysis was conducted on the zeolite clinoptilolite under three different conditions: (i) its bulk condition provided by the supplier; (ii) after immersion in water

for three months and; (iii) after immersion in ARD for three months. The diffractograms of the XRD were compared and analyzed.

Each of the soil samples was separated into three particle sizes for XRD analysis by centrifugation, sedimentation and decantation (Jackson 1956): (a) < 2 μm, (b) 2 - 50 μm, and (c) > 50μm in particle size. Preparation of the XRD slides followed the procedures as described in Kittrick and Hope (1963). The XRD analysis was conducted over a range of 3-33° 2θ with CuKα radiation (Siemens D5000 Bragg-Brentano Diffractometer and the Siemens Kristalloflex, Germany).

Scanning Electron Microscopy

Morphology of clinoptilolite in 3 different conditions: (i) its bulk condition provided by the supplier; (ii) after immersion in water for 3 months and; (iii) after immersion in ARD for 3 months, were observed from the images from the Philips XL30 Scanning Electron Microscope (SEM) (Philips Industrial and electro-acoustic systems, Holland) equipped with a Princeton Gamma-Tech Energy-Dispersion Spectrometer (EDS) (Princeton, NJ, USA).

Geochemical Analyses

(1) X-Ray Fluorescence (XRF) Analysis

X-Ray fluorescent analysis was obtained from Canmark International Resources Inc. (Beck 1996). The samples were prepared as fused disks using a lithium tetraborate flux and scanned in a range of 2 degrees to 37 degrees using a X-ray fluorescence spectrometer (Siemens model 200 Sequential X-Ray Fluorescence Analyzer) with a Cr tube.

(2) Whole sample major and trace element analyses

Whole rock chemical of the clinoptilolite analyses were conducted by ACME Analytical Laboratories Ltd. Samples were placed in an oven and heated to 1025°C for 25 minutes. The

molten sample was dissolved in 5% HNO_3 and supernatant was extracted. Sample solutions were aspirated into an ICP emission spectro-graph (Jarrel Ash AtomComp Model 975) for the determination of major oxides and elements. Trace elements were determined by an ICP mass spectrometer (Perkin-Elmer Elan 6000). Loss on ignition (LOI) was determined by igniting 1 g sample at 950°C for 90 minutes, followed by measurement of the weight loss. Total carbon and sulphur were determined by using the LECO carbon analyzer (Model CR-412, LECO Corporation).

3.2.3 Adsorption capacity and chemical stability

The adsorptivity of metal ions from the ARD onto the clinoptilolite was determined by following the USEPA (1987) batch adsorption test procedures to obtain: (1) adsorption isotherms in background matrices of ARD and distilled water, and (2) adsorption of metals in different pH conditions with natural ARD and its natural chemical compositions.

The adsorption isotherms of the metals copper, iron, aluminum and zinc on clinoptilolite were obtained in multiple species solutions with background matrix of: (1) natural ARD from the Britannia Mine, and (2) distilled water. Metals concentrations ranging from 0 to 1000 mg/L (0, 100, 200, 500, 750 and 1000 mg/L) were added to the background matrix solutions. The pHs of the prepared solutions were 3.28.

The adsorption of heavy metals affected by pH was tested in the ARD from Britannia Mine (pH. 3.28) and the ARD was adjusted to pHs of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.86.

The samples were prepared in a mixture ratio of 1:10 soil:solution, i.e. 40 ml of contaminant solution was used with 4 grams of soil sample. Samples were shaken for 24 hours using a reciprocal shaker at 29 rotations/min at room temperature to reach equilibrium conditions USEPA (1987). The supernatant of the sample was separated by centrifuging for 15 minutes at

3500 rpm (2800 x *g*) and was analyzed for copper, cadmium, iron, zinc and aluminum by Atomic Adsorption Spectrophotometer (AAS) (Thermo Jarrell Ash Video 22, TJA Solutions, Franklin, MA, USA). The concentration of potassium was determined by an Atomic Emission Spectrophotometer (AE) (SpectrAA 220FS). The pH values of the initial and equilibrium solutions were measured. The amount of metals adsorbed on the zeolite from the solution was calculated based on the differences between concentrations of metals in the initial and final solution.

Stability at low pH environment

Chemical stability of the structure of clinoptilolite was tested against a low pH environment (pH levels of 0.5 - 3.0), which are commonly found in copper mine ARD. The sample was also tested over a range of times of acid treatment.

Low pH ARD was prepared by adjusting the pH of the Britannia Mine ARD. After the acid treatment, the amount of Al^{3+} and K^{+} present in the supernatant was determined. pH stability tests were conducted in 50-ml polyethylene bottles, loaded with 4 g of air-dried zeolite and 40 ml of nitric acid/distilled water with pH levels of 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0. The durations of acid treatment were 2 hours, 1 day, and 3 days. For pHs of 2.5 and 3.0, the duration of acid treatments were extended to 1 week and 2 weeks to observe long-term effects. After the acid treatment, the clinoptilolite and the supernatant were separated by centrifuging at 3500 rpm (2800 x g) for 15 minutes.

The concentrations of Al were determined by atomic adsorption (AA) and the concentrations of K and Si were determined by atomic emission (AE) (SpectrAA 220FS Atomic Adsorption Spectrometer, Varian Scientific Instruments manufactured in Mulgrave, Victoria, Australia). The changes in the concentration of the Al^{3+} and K^{+} were compared with time and pH of the treatment solution.

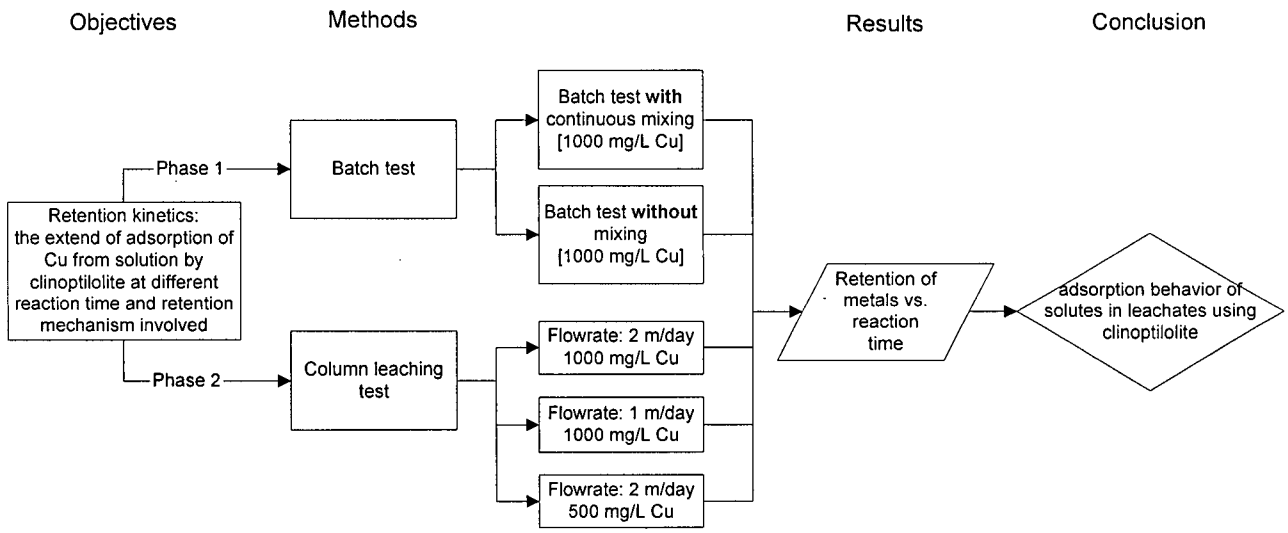

Figure 3.4 The work plan of the retention kinetics study of copper onto clinoptilolite

Synthetic ARD was used in this study. The synthetic ARD was prepared in order to simulate the reaction of clinoptilolite in a pH environment and copper concentration similar to that of the natural ARD. Synthetic ARD was chosen over natural ARD because natural ARD contains metal cations other than copper, as well as a large amount of sulphate, which would affect the reactions between copper and clinoptilolite.

Synthetic ARD used in the batch adsorption test contained 1000 mg/L of copper with a background of nitric acid/distilled water mixture of pH 3.28. pH level were selected based on that of the ARD from the Britannia Copper Mine in British Columbia. Copper concentrations were selected to provide an adequate source of copper for various reactions.

Batch adsorption test for adsorption kinetics: Batch adsorption test involves two techniques: i) mixing a batch of solution with soil (dynamic), and ii) allowing the soil and solution to react without mixing after addition of the permeant (static).

In the first set of the batch adsorption test, the adsorptivity of heavy metal cations from the ARD onto the clinoptilolite was determined by following the batch procedures for estimating soil adsorption of chemicals as detailed in Roy et al. (1991). The samples were prepared with a 1:10 soil:solution ratio, i.e. 40 ml of solution was used to react with 4 grams of clinoptilolite sample. Samples were placed in a rotary shaker (at rate of 29 rpm) and were shaken at room temperature for 0, 15, 30 minutes, 1, 2, 4, 6, and 24 hours respectively. The supernatant solutions were filtered using 0.45μm pore-size membrane filter papers and analyzed for copper concentrations using a Thermo Jarrell Ash Video 22 Atomic Absorption Spectrophotometer (TJA Solutions, Franklin, MA, USA). The pH values of the initial and final solutions were measured. The amount of heavy metal retained on the clinoptilolite from the solution was calculated based on the differences in concentrations in the initial and final solution per mass of soil.

The second set of the batch adsorption test does not involve shaking of the soil and solution. The preparation of the samples and the ratio of mixture of soil:solution is identical to that in the mixing batch method. The procedure started with filling 50-ml centrifuge tubes each with 4 grams of clinoptilolite sample, then addition of 40-ml of 1000 mg/L of Cu permeant.

The clinoptilolite and solution were mixed and left to stand at room temperature for 0, 5, 10, 15, 20, 30 minutes, 1, 2, 4, 6, and 24 hours respectively. The supernatant was filtered after each timed reaction and analyzed for copper concentration. A schematic diagram of the procedures of the non-mixing batch adsorption test is shown in Figure 3.5.

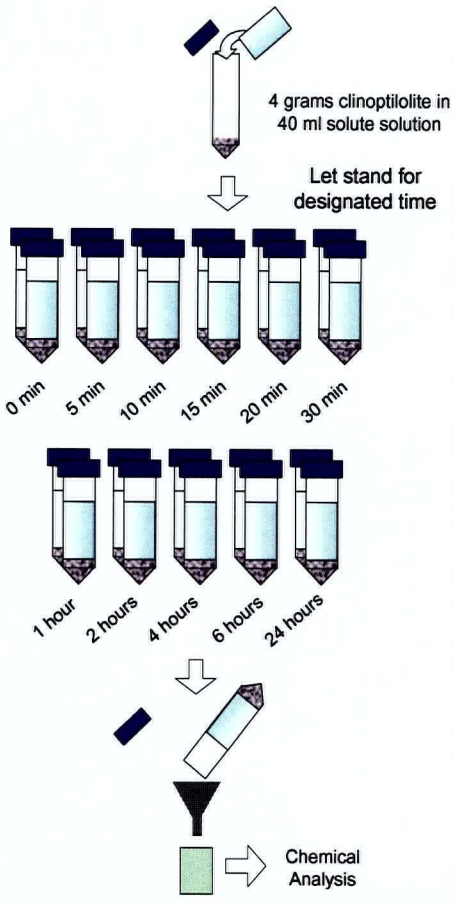

Figure 3.5 Schematic diagram of the procedures for non-mixing batch adsorption tests for retention kinetics

Mini column leaching test for retention kinetics: The column leaching test was conducted with the identical soil:solution ratio and amount of soil used (4 grams) in the batch adsorption test. Leaching solution fed through the column cell from the bottom, in an upward direction, with recycling flow (Figure 3.6 and Figure 3.7).

Leaching cells, 6-cm long and 1-cm inner diameter were filled with 4 grams of clinoptilolite. 40 mL of 1000 mg/L Cu solution was used to leach through the column at linear flow rates of 1m/day and 2m/day. These flow rates were chosen to simulate the maximum and minimum flow rates, which could be found at the Britannia mine site. An experiment using

leaching solution with 500 mg/L of Cu was also conducted at 2 m/day in the column leaching cell to determine any concentration effect on the performance of the clinoptilolite.

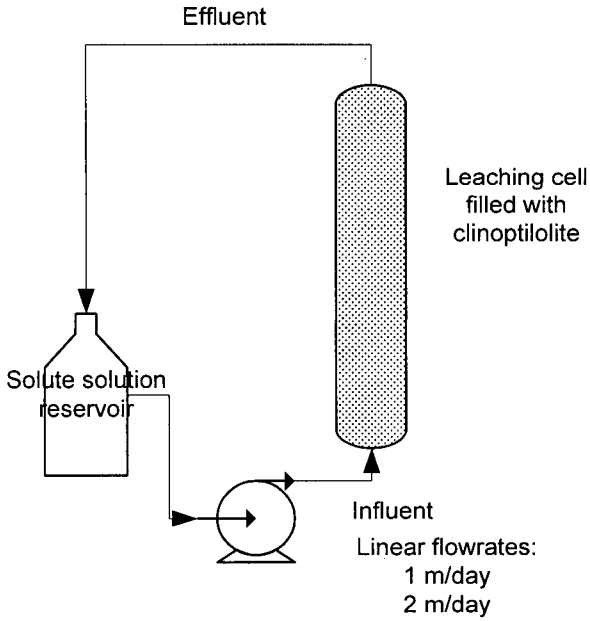

Figure 3.6 Schematic diagram of the experimental setup of mini-column-leaching cell

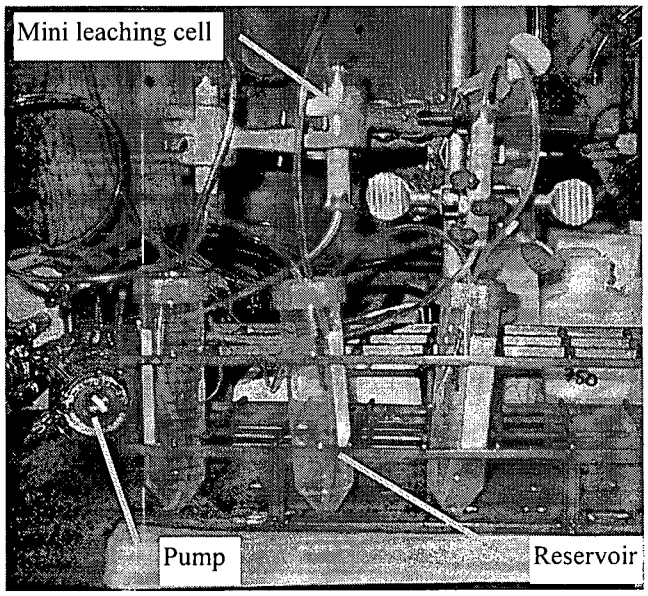

Figure 3.7 Setup of mini-column leaching cell

Liquid samples from the reservoir (Figure 3.6 and Figure 3.7) were taken at 0, 5, 10, 15, 20, 30 minutes, 1, 2, 4, 6, and 24 hours for chemical analysis.

3.2.4 Column leaching tests

Column leaching tests were conducted in two phases. The first phase of the column leaching tests was carried out with various flow rates of influent, metals concentrations and filtration. The leaching cells were monitored until the breakthrough of chemicals at the outlet, then clinoptilolite within the column was extracted for soil chemical analyses. The second phase of the column leaching tests was carried out with the natural ARD in its unfiltered form and flow rate that occurs at the mine site. Column leaching cells were conducted in replicates; one leaching cell was stopped at each designated time interval and soil was extracted for

analyses. Changes of metal retention by the soil were recorded for each time interval until breakthrough.

Configuration of the column leaching cells

Column leaching cells were made of clear PVC pipes of inner diameter 4.1 cm and 55 cm in length. Influent was pumped into the bottom of the column leaching cell by a peristaltic pump (System model 7553-70, 6-600 rpm, manufactured by Cole-Parmer Instrument Co., Chicago, IL, USA)(Figure 3.8 to Figure 3.10). The diameter of the column cells were chosen to minimize the wall effects caused by the radial distribution of porosity. The particle-to-column ratio (mean particle size/column diameter) is recommended to be greater than 30 in order for the wall effects to be negligible (In this study, the mean particles size of clinoptilolite used is 0.85 mm, hence, the minimum size of the column should be 2.55 cm in diameter). Sampling ports were located at 11-cm intervals along the column. At each end of the column, a porous plate made of inert material was placed to ensure uniform flow of leachate and to prevent soil loss from the leaching cell. The rubber fitting and the plastic ring sandwiched the porous plate to minimize leakage and leveled the porous plate inside the end-cap (Figure 3.9). A schematic diagram of the column leaching cell and the respective dimensions are shown in Figure 3.11.

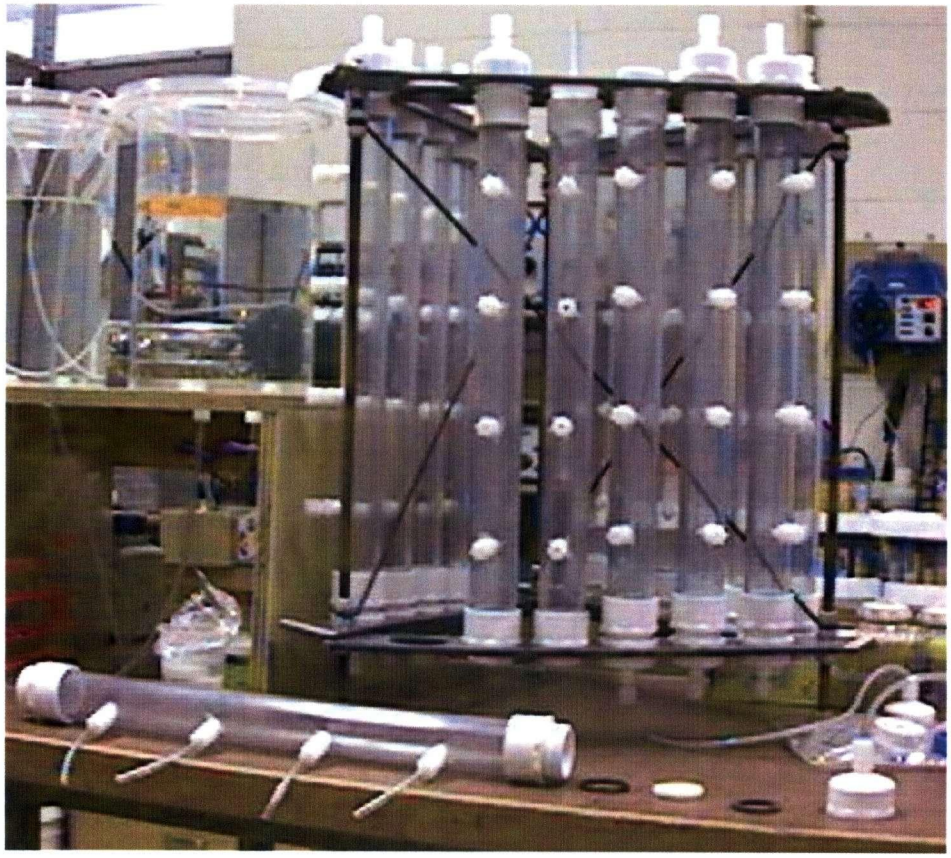

Figure 3.8 Configuration of column-leaching cells

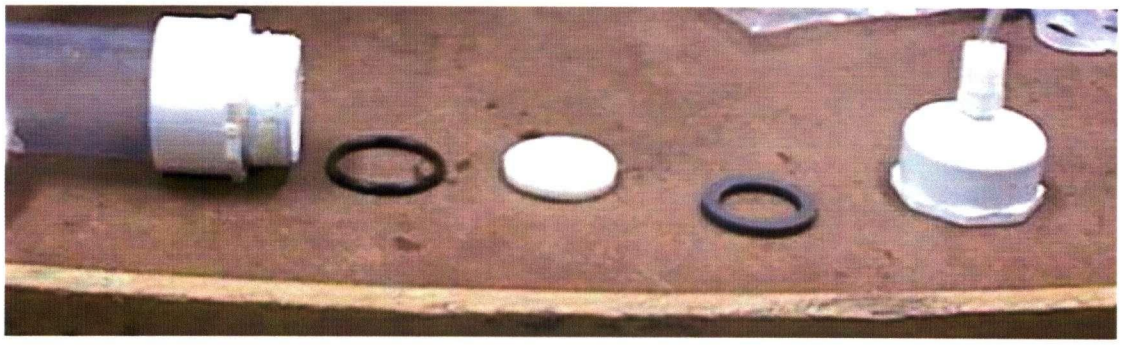

Figure 3.9 Assemblage at the end-caps

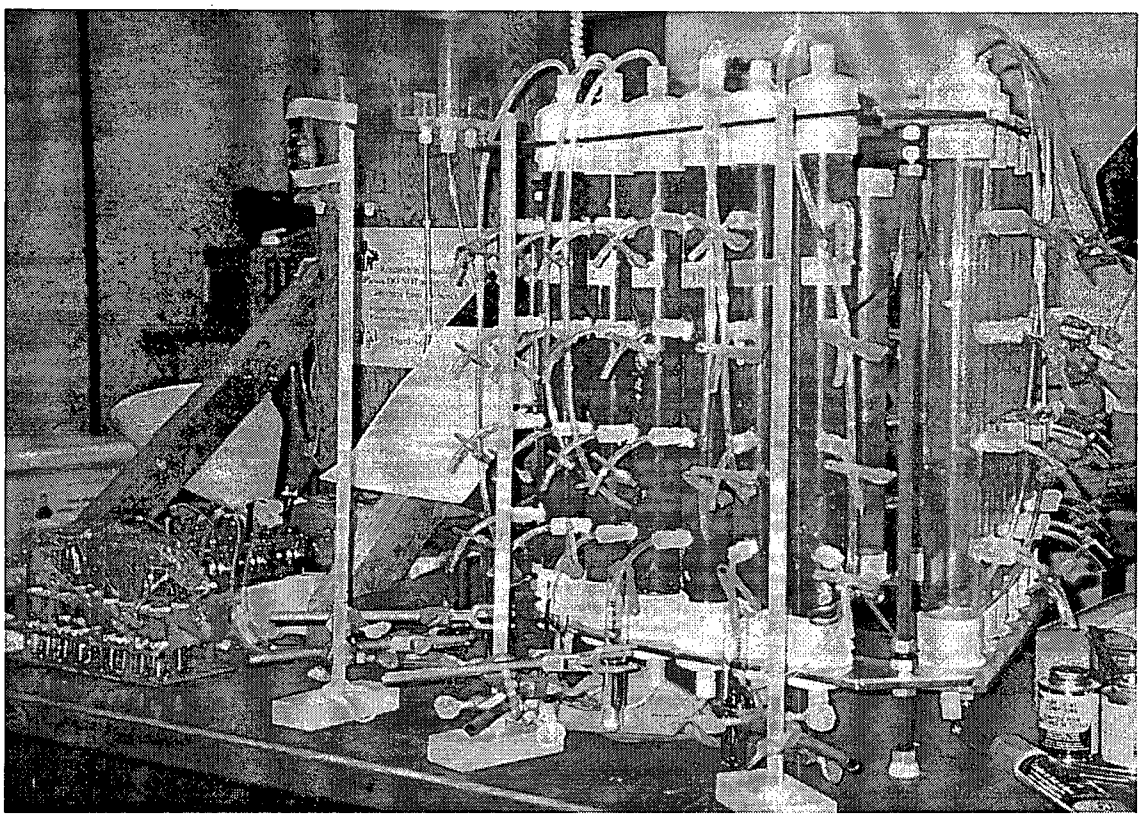

Figure 3.10 Setup of column leaching cells

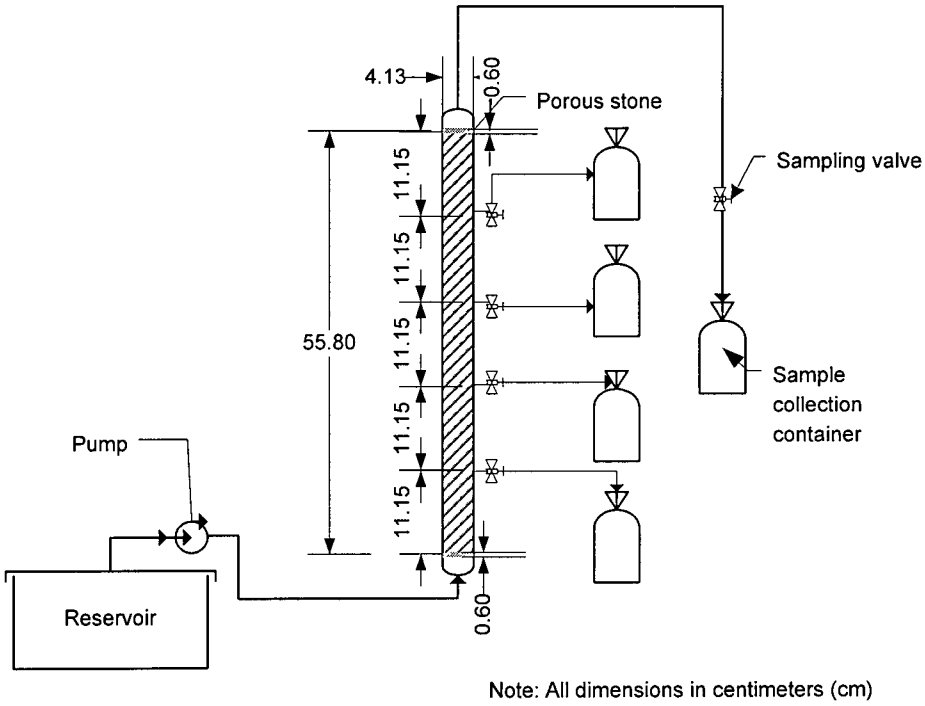

Figure 3.11 Schematic diagram of the column leaching cell

Leaching tests of various parameters

Laboratory column tests are useful in determining contaminant removal rates under conditions that more closely approximated the operating conditions anticipated in the field, such as flow velocity and ionic strength of the leachate. The flow velocity was selected to approximate the velocity expected in the field-scale treatment zone (Bratty and Lynn 1998). Contaminant concentrations were measured at the inlet, outlet, and sampling ports along the column every 1.5 to 4 pore volumes (one pore volume is equal to the total volume of liquid within the column) until breakthrough and a steady-state concentration profile was achieved (i.e. concentrations at a point remain relatively constant over time). pH and Eh profiles were also measured during the test period.

Column leaching tests were conducted using the natural ARD sample collected in January, 2002 from the 4150 Portal (as opposed to the previous column tests, which were conducted using ARD sample collected in the September 2000 from the 4100 Portal). Chemical characteristics of the ARD samples will be discussed in Section 4.1.

Preparation of clinoptilolite leaching cells

Clinoptilolite samples were packed into the column leaching cells on a vibrating table (Model VP86B1; Syntron Division, Homer City, PA, USA). Approximately 850 grams of clinoptilolite is compacted into the 55-cm long column leaching cell of 4.13-cm diameter to a dry density of approximately 1100 Kg/m^3 at 2.8 % water content (porosity of 0.439). The clinoptilolite leaching cell has a pore volume of approximately 323 ml (Appendix C-4). The hydraulic retention time of the contaminating plume ranges from 4 to 12 hours (retention time = length of column/linear flowrate), depending on the design flow rates of the respective leaching experiment. The compaction curve of the clinoptilolite is obtained by using the Standard Proctor Test as described in Lambe (1991) and is presented in the Appendix C-3. A sample

calculation for the compaction of the material and its compaction properties are presented the Appendix C-4.

The column leaching test was conducted using a flow rate of ~1.5 m/day (linear flow rate). Samples were taken at each 11 cm interval along the column leaching cells and were analyzed for the concentrations of copper, iron, manganese, zinc and aluminum. pH, oxidation-reduction potential (Eh) and electrical conductivity (EC) of the samples were also measured. Water samples were taken until the concentration of the effluent sample reached that of the influent. The soil column was taken apart and soil at depths of each 11 cm was taken out, followed by selective sequential extraction and metal analysis. The changes in the major ion composition in the effluent and water from the sampling ports were determined.

Column leaching tests have been conducted on the clinoptilolite samples of the following combinations of testing parameters are shown in Table 3.1.

Table 3.1 Column leaching tests conducted and the design parameters

Pretreatment	Contaminant concentration	Flowrate	ID
--	Natural ARD (non-filtered)	1 m/day	NTNFC1
1M NaCl	Natural ARD (non-filtered)	1.5 m/day	PTB1C1
1M NaCl	Max design conc. (filtered)	1.5 m/day	PTB3, 4
1M NaCl	Natural ARD (filtered)	1.5 m/day	PTB5, 6
1M NaCl	Natural ARD (filtered)	0.5 m/day	PTB8,9
1M NaCl	Max design conc.(filtered)	0.5 m/day	PTB 11,12
1M NaCl	Max design conc. (non-filtered)	0.5 m/day	PTB13,14
1M NaCl	Natural ARD (non-filtered)	0.5 m/day	PTB 15
1M NaCl	Natural ARD (filtered)	Bed reactor	PTB 17
1M NaCl	Natural ARD (non-filtered)	Bed reactor	PTB 18

Leaching cells were leached with either natural ARD or ARD artificially adjusted to the maximum design metal concentrations. Maximum design concentration of the ARD was determined based on the maximum detected metals concentrations found at the Britannia mine

site (Bratty and Lynn 1998). The maximum design concentrations of metals are listed in Table 3.2.

Table 3.2 Concentrations of metals in ARD of maximum design concentrations

Chemical species	Concentration (mg/L)
Aluminum	74
Copper	115
Iron	56
Manganese	9.2
Zinc	49
pH	Min 2.7, max 4.5

Filtered and non-filtered ARD were used to compare the influence of the precipitates in the mine water. The filtered ARD was filtered prior to leaching through the column cells to reduce clogging by any precipitates, as well as to remove any debris from the ARD as taken from the sampling site. The chemical composition of the filtered ARD was very close to that of the non-filtered ARD, except that ~90% of iron was removed, which was from the iron-oxide and -sulphate portion in the sampled solution from the field. The metal concentrations were all within 4% for the different samples used in the experiments. The chemical composition between the filtered and non-filtered ARD, and their differences are presented in Table 3.3.

Table 3.3 Difference in chemical composition between filtered and non-filtered ARD

Chemical species	Concentration in natural ARD as sampled (non-filtered), mg/L	Concentration in natural ARD (filtered), mg/L	% difference in concentration
Sulphate	1210	1200	-0.83%
Aluminum	39.7	40.3	1.51%
Copper	36.8	37.9	2.99%
Iron	17	1.06	-93.76%
Manganese	3.88	3.96	3.03%
Zinc	24.9	25.7	3.21%
PH	3.09	3.09	-
Eh (mV)	+678.3	+677.2	-
EC (mS/cm)	2.05	2.05	-

Note: "-" value not applicable

Column Leaching Test – Changes on clinoptilolite with time

Column leaching tests were carried out with the natural ARD in its unfiltered form and flow rate that occurs at the mine site. Column leaching cells were conducted in eight replicates. Water samples were taken at 10 cm intervals along the column approximately every 24 hours (~1.5 pore volume) for metals concentrations, pH, redox potential, electrical conductivity, and dissolved oxygen measurements. At each designated time interval (approximately 10 pore volumes increments), the leaching cell was stopped and soil was extracted for analyses. Leachate was collected every 24 hours and metals concentrations were recorded until breakthrough. Soils extracted from the column were subjected to total digestion and selective sequential extraction for metals. The time expressed in number of pore volumes when leaching cells were terminated are listed in Table 3.4.

Table 3.4 Reaction time of leaching cells for critical path analysis

Leaching cell ID	**CPA 8**	**CPA 7**	**CPA 6**	**CPA 5**	**CPA 4**	**CPA 3**	**CPA 2**	**CPA 1**
Reaction time (approx. # of pore volumes)	15	26	38	45	57	73	85	96

3.2.5 Chemical analyses for clinoptilolite and water sample after column leaching tests

As the chemical composition of the effluent reaches that of the influent, it indicates that the leaching cell system (the clinoptilolite) is at equilibrium with the leaching solution (ARD). In order to find out the total amount of metal present and the partitioning of metals on the clinoptilolite, acid digestion for metals and selective sequential extractions (SSE) were conducted. A comparison of the recovery, evaluated by comparing each metal concentration with the sum of the five individual fractions from the selective sequential extractions, are reported in the results and discussion section.

Total digestion of clinoptilolite

Acid digestion of clinoptilolite was conducted using microwave sample digestion (MDS-81D Microwave Digestion system). The microwave-digestion system was modified for use with a pressure controller, 120-ml Teflon PFA vessels with pressure relief valves, and two-ported cap with sealing ring provided by the Soil Chemistry Laboratory of the Department of Soil Science, UBC. Microwave digestions procedures were carried out at described in Gilman (1988). Samples were digested with 1:1 nitric acid:distilled water solution in a soil:solution ratio of 1:20. Samples were placed in 120-ml Teflon PFA vessels, which are specifically made for microwave ovens and were heated for 15 minutes at 50% power (300 Watts), followed by 30 minutes at 100% power (600 Watts). The mixture of soil and acid was removed from the vessels, the supernatant and residual solid were separated by centrifugation.

Selective sequential extraction (SSE) metals and materials

The partitioning of particular metals in clinoptilolite was determined using a selective sequential extractions (SSE) technique. The basic use of selective sequential extraction (SSE) is its use of appropriate chemical reagents in a manner that releases the different heavy metal fractions from the soil solids by destroying the bonding between the metals and the soil solids in a series progressively. The basis is strength (enthalpy) of the bonding within the various mineral components from electrostatic to covalent.

The analytical procedure involves chemical extractions for metals partitioned in five fractions: (1) exchangeable, (2) bound to carbonates, (3) bound to Fe-Mn oxides, (4) bound to organic matter, and (5) residual fraction by using the appropriate chemical reagents as described in Tessier et al. (1979) and Yong (1993). Modification of the procedures for the specific type of tests in this study included appending an initial rinse with distilled water prior to the extraction for exchangeable ions. The purpose of the initial rinse is to rinse off free ions (soluble salts)

within the pore water. In addition, in the last step of the SSE, microwave sample acid digestion replaced the conventional hot-plate acid digestion. A list of the chemicals used and their purposes are provided in Table 3.5. Details of the chemical reagents used and the procedures are shown in Appendix A-1.

Note, the purpose of the weak acid extraction, weak acid extraction/complexing agent and the strong acid extraction for oxidizing fractions were to remove most, if not all trace minerals and help to clean up the samples. These two procedures should not affect appreciably the zeolites and phyllosilicates, nor quartz and feldspars. These extractions only dissolve the non-crystalline/amorphous components in the zeolite mixture. Only the microwave residual extraction destroys the crystalline components of the zeolite.

The SSE is an operationally defined method and does not necessarily denote that the chemical phases are present in the clinoptilolite. It should be noted that this method of analysis is not precise, but provides a qualitative appreciation of the capability of the various soil constituents to retain heavy metals (Mohamed and Antia 1998).

Table 3.5 Reagents in selective sequential extractions and their purposes

Type of extraction	Reagent	Purpose
(1) Exchangeable	1M Potassium nitrate	Remove metals in the exchangeable phase and non-specifically adsorbed and ion exchangeable, i.e. they can be replaced by competing cations.
(2) Weak acid extraction	1M NaOAc adjusted to pH 5.0 with HOAc	Dissolves exchangeable carbonates and phosphates. However, due to the nature of the clinoptilolite, there is very little or no carbonates in the soil itself. The weak acid extraction was targeted to and should remove minerals and amorphous materials that are dominantly ionically bounded, e.g. gypsum and other salts.
(3) Weak acid extraction and complexing agent	Hydroxylamine hydrochloride: 0.04 M $NH_2OH{\cdot}HCl$ in 25% v/v HOAc (pH4.2)	Remove metals associated with metal oxides (hydroxide-oxide phase). Metals that are attached to amorphous or poorly crystallized Fe, Al, and Mn oxides.
(4) Strong acid extraction/oxidizing	Hydrogen Peroxide, nitric acid (pH 2.0), ammonium acetate ▪ 0.02 M HNO_3 ▪ 30% H_2O_2 adjusted to pH 2 with HNO_3 ▪ 3.2M NH_4OAc in 20% v/v HNO_3	The strong acid extraction should remove oxidizable elements and minerals, e.g. sulphides to sulphates fractions in the sample.
(5) Residual	1:1 concentrated HNO_3: distilled water solution	Remove metals fraction within the lattice of silicate minerals. (refractory minerals could remain in a final residue)

Water sample analyses

Water samples were analysed for pH, reduction-oxidation potential, electrical conductivity, dissolved oxygen, sulphates, and the metals Cu, Fe, Mn, Zn, and Al. Details of the procedures of the methods used are shown in Appendix A-2.

3.3 Application of the geochemical model

The geochemical modeling program PHREEQC was used in this study to assess the transport and the geochemical capabilities of the barrier material and to simulate the breakthrough of the leachate (ARD) in the column-leaching cell experiments for the prediction of the transport of metal cations in permeable reactive barriers. The use of the model PHREEQC in this study include calculating the distribution of aqueous species using an ion-association aqueous model and a reaction transport model which simulates transport (advection, diffusion and dispersion) and chemical reactions as water moves through an one-dimensional column with 5 cells, which corresponds to the 5 sections of the sampling ports.

Reactions taken into account include:

- EXCHANGE & EXCHANGE_SPECIES– Defining the exchanger and the exchange species– composition of the Ca^+, Na^+, Mg^{++}, and K^+ ions on the exchanger (clinoptilolite) for cation exchange reactions.
- SOLUTION 1-5 -- Equilibrate with initial solution (pretreatment solution) in the column
- SURFACE, SURFACE_SPECIES & SURFACE_MASTER_SPECIES– Defining the surface of the clinoptilolite, the surface areas and the number of moles of each type of surface which corresponds to certain type of cations for the surface complexation reactions. The surface of the clinoptilolite used in the algorithm utilized the constants and maximum adsorption values obtained from the Langmuir adsorption isotherms in the multiple metal species batch equilibrium adsorption tests
- SOLUTION 0 – Defining chemical composition of leaching solution
- TRANSPORT – which includes advection, diffusion and dispersion in the leaching column. The number of cells and the length of each cell of the column are defined.

The retention time/flow rate are defined in this data block. The diffusion coefficient is set to minimal and the dispersivity is directly proportional to the d_{10} of the clinoptilolite sample.

By defining the parameters in the data block, along with the results obtained from the adsorption isotherm, the algorithm could be validated.

CHAPTER 4 CHARACTERISTICS OF CLINOPTILOLITE AND ACID ROCK DRAINAGE AND THEIR COMPATABILITY

4.1 Characteristics of Britannia Mine Acid Rock Drainage

The chemical characteristics of ARD from the Britannia Mine were determined. The major chemical components of the mine drainages obtained from the 4150 and the 4100 Portals are summarized in Table 4.1.

Table 4.1 Chemical characteristics of ARD from the 4150 and 4100 Portal at the Britannia Mine, B.C.

	4150 Portal	**4100 Portal**
PH	3.07	3.28
Eh (mV)	+512	+392
EC (mS/cm)	1.84	2.30
Cu (mg/L)	36.4	23.6
Fe (mg/L)	13.1	5.15
Mn (mg/L)	3.83	4.69
Zn (mg/L)	24.2	22.5
Al (mg/L)	39.5	30.0
Sulphate (mg/L)	1140	1480
Temperature	4.8°C	4.6°C
Sampling date	January 9, 2002	March 12, 2003

In the mine drainage samples obtained from both portals, it was observed that precipitates were present in the water sample. In order to differentiate the effect of the presence of precipitates in non-filtered from filtered mine drainages on the performance of clinoptilolite barrier and to minimize the clogging of the inter-granular spaces and analytical instruments by precipitates, some mine drainages were filtered prior to feeding the column leaching cells. The chemical characteristics of the natural (non-filtered) and the filtered mine drainages are summarized in Table 4.2. A detailed list of chemical characteristics of the ARD is presented in Appendix B.

Table 4.2 Major chemical composition and differences between natural (non-filtered) and filtered acid -rock drainage obtained from the 4150 Portal

Chemical composition (mg/L)	Natural (non-fitlered) ARD	Filtered ARD	% difference
Sulfate	1210	1200	-0.83%
Aluminum	39.7	40.3	1.51%
Copper	36.8	37.9	2.99%
Iron	17	1.06	-93.76%
Manganese	3.88	3.96	2.06%
Sulphur	396	443	11.87%
Zinc	24.9	25.7	3.21%

Filtered mine drainage had a significant decrease in iron. In the natural ARD, the iron concentration seems to be contributed by the iron precipitate in the mine drainage. ICP/MS was performed on the oven-dried residue from the filtration to find out the amount of iron that was present in the precipitate. The results are presented in Appendix B-2. This precipitate contains 64% iron, as ferric oxide (Fe_2O_3) and 32.6% as loss on ignition material, and a small amount of aluminum oxide (Al_2O_3) and silicon oxide (SiO_2), 1.5% and 1.2%, respectively. The loss of ignition portion may include a minimal water content as the sample was pre-treated by oven-drying at 110°C, organic carbon species, carbonates, and sulphates. During the loss of ignition determination process, any carbonates present decompose with the loss of carbon dioxide; sulphates decompose with the loss of sulphur trioxide. Copper was found in the residue in the amount of approximately 1260 mg per Kg of precipitates. However, the difference in the concentration of copper in the filtered and non-filtered mine drainage is insignificant (< 3%).

4.1.1 Chemical characteristics of ARD used in batch equilibrium adsorption tests

ARD water was obtained from the 4100 Portal for batch-equilibrium-adsorption tests. The mine-drainages were adjusted to pH 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 3.86 to simulate the

adsorptivity of the metals in a range of pHs which the ARD could occur. The concentrations of metal ions in the natural mine drainage (at pH 3.28) are listed in Table 4.3.

Table 4.3 Concentrations of metal ions (mg/L) in natural ARD (pH 3.28)

Metal	Concentration (mg/L)
Al	23.73
Cd	0.283
Cu	19.48
Fe	3.23
K	1.13
Zn	38.3

4.1.2 Chemical characteristics of ARD used in column-leaching tests

Mine-drainage samples from the 4150 and 4100 Portals were used in column-leaching tests. Since concentration of copper is significantly lower in the 4100 drainage samples, adjustment to the concentration of copper was made to the 4100 drainage to simulate that in the 4150 drainage. Chemical characteristics of the 4150 drainage and that of the "adjusted" 4100 drainage are shown in Table 4.4.

Table 4.4 Chemical characteristics of the 4150 and the "adjusted" 4100 drainages

	4150 Portal	4100 Portal	"adjusted" 4100 drainage
pH	3.07	3.28	3.27
MV (mV)	+512 mV	+392 mV	+560.5
EC (mS/cm)	1.835	2.30	2.31
Cu (mg/L)	36.4	23.6	37.99
Fe (mg/L)	13.1	5.15	0.323
Mn (mg/L)	3.83	4.69	3.475
Zn (mg/L)	24.2	22.5	19.20
Al (mg/L)	39.5	30.0	30.17

Results of the "adjusted" 4100 drainage indicated that concentration of Fe was decreased after the adjustment. The decreased concentration of free Fe ions in the solution may be a result of Fe precipitation in which operating pH (pH > 2) where Fe-oxides or hydroxides ions would precipitate.

4.2 Physio-chemical, physical and mineralogical properties of clinoptilolite

The physio-chemical properties, physical and mineralogical properties of the clinoptilolite used in this study are presented in the following subsections.

4.2.1 Physical-chemical properties

The physio-chemical properties of the clinoptilolite used in this study are given in Table 4.5. The pH of the clinoptilolite is 7.58 using 1:2 soil:$CaCl_2$ pH determinations. The cation exchange capacity of the clinoptilolite is 121.5 cmol/Kg and the major exchangeable cations are calcium, sodium and magnesium. It is noted that the percent base saturation of the clinoptilolite is 96.2%, and that the difference is contributed by the soluble salts as the pH of the clinoptilolite is greater than 7. It is also noted that the soil pH from the 1:1 soil:deionzed water determination is greater than 8, which suggests that presence of free $CaCO_3$ is present in the clinoptilolite (Dixon and Weed, 1989). The specific surface area is 63.84 m^2/g and the specific gravity of the clinoptilolite is 2.00.

Table 4.5 Physio-chemical properties of clinoptilolite

Properties		
Soil pH	1:2 soil:$CaCl_2$	7.58
	1:1 soil:deionzed water	8.34
CEC (cmol/kg or meq/100g)		121.52
Exchangeable cations (cmol/kg or meq/100g)		
	Ca^{2+}	45.66
	Na^{+}	44.13
	Mg^{2+}	2.76
	K^{+}	24.30
	$\sum$ exchangeable cations	116.9
% Base saturation		96.2 %
Specific Surface area (m^2/g)		63.844
Carbonate content (% by weight)		1.538

4.2.2 Mineralogical properties

X-ray diffraction analyses were conducted on the clinoptilolite sample. Majority (about 65% to 75%) of the sample is made up of the mineral heulandite-clinoptilolite. Accessory feldspar, quartz and mica were also present. The presence of 14Å (Angstrom), or 1.4 nm, peaks in the diffractograms, indicates that vermiculites were also present. Results indicated that trace amounts of auxiliary minerals associated with the clinoptilolite mineral, such as oxides/hydroxides, carbonates, chlorides, fluorides, phosphates, sulphates, sulphides and compounds etc., were also present. A list of these trace minerals is presented in Table 4.6.

Table 4.6 Trace minerals associated with the clinoptilolite sample

Type of auxiliary minerals	Minerals	Chemical formula
Oxide & hydroxides	Diaspore	$AlO(OH)$
	Akaganeite	$Fe^{3+}(O, OH, Cl)$
	Boehmite	$AlO(OH)$
Carbonates, chlorides, fluorides, phosphates, sulphates, sulphides, etc. compounds	Sylvite	KCl
	Fluorite	CaF_2
	Jarosite	$KFe^{3+}{}_3(SO_4)_2(OH)_6$
	Gypsum	$CaSO_4{\cdot}2(H_2O)$
	Rozenite	$Fe^{2+}SO_4{\cdot}4(H_2O)$
	Fluor-hydroxy- & carbonate-apatites	$Ca_5(PO_4,CO_3)_3F$ $Ca_5(PO_4,CO_3)(OH)$ $Ca_5(PO_4)_3F$ $Ca_5(PO_4)_3(OH)$
	Birnessite	$(Na,Ca,K)_x(Mn^{4+},Mn^{3+})_2O_4 \cdot 1.5(H_2O)$
	Pyrite	FeS_2

This study, due to the complexity and low occurrence of the associated minerals, only focused on the clay minerals or phyllosilicates, and other silicates such as heulandite-clinoptilolite, feldspar, quartz and mica. Detailed X-Ray diffractogram interpretation is presented in Appendix C-1.

Clinoptilolite samples that underwent water treatment and ARD treatments were also investigated for changes in mineral composition. It was found that there were no changes in the

mineral composition of the clinoptilolite fraction, within the sample of particle size greater than 50 μm. Semi-quantitative analyses of the approximate percentage of minerals present in the clinoptilolite sample were conducted and the results are illustrated in Appendix C-1 and summarized in Table 4.7.

Table 4.7 Semi-quantitative analysis of the composition of major minerals in clinoptilolite from X-Ray diffraction

Particle size range	<2μm		2-50μm		>50μm
Treatment type	*Bulk*	*water/ARD treated*	*Bulk*	*water/ARD treated*	*Both water/ARD treated*
Quartz	10%	10%	5%	5%	10%
Clinoptilolite + mica	65%	20%	65%	65%	75%
Feldspar	10%	10%	15%	15%	10%
Vermiculite	-	40%	10%	10%	-
Other	15%	20%	5%	5%	-

Vermiculite was observed in the water or ARD treated clinoptilolite of particle size <2μm. It was noted that vermiculite was not detected following ARD treatment. The operational observation of the appearance of the vermiculites in the quantitative analysis can be expressed by the following:

- Vermiculite-like mineral appeared after ARD treatment. From XRD analysis, vermiculite can be identified by having a 14Å → 12.8Å peak in the x-ray diffractogram. There may be another mineral, or possibly a combination of other types of minerals present, which appeared to be a vermiculite-like in the quantitative analysis.
- Vermiculite couldt have been transformed from mica after ARD treatment when hydrated exchangeable cations replaces the potassium ions in the K-bearing micas. The transformation of micas to expansible 2:1 minerals may be represented by the following equation:

$$\text{Micas} \xrightarrow{-\,K + \text{hydrated exchangeable cations}} \text{Expansible 2:1 minerals (vermiculites)}$$

This is termed a "simple transformation" because a considerable portion of the mica structure (the 2:1 layer) is retained intact as a transformation product.

The structure transformation has been viewed to take place by layer weathering and edge weathering (Dixon and Weed 1989) as shown in the following figure:

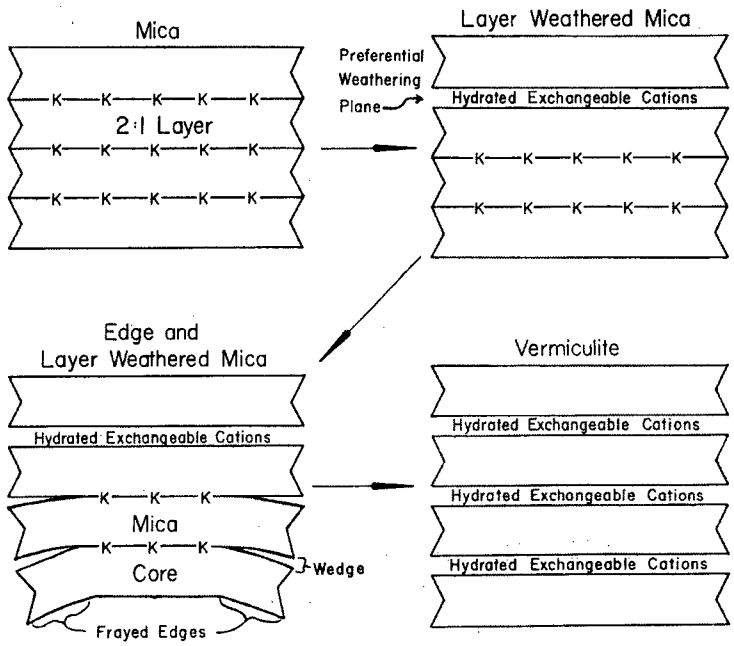

Figure 4.1 Diagrams illustrating layer-weathering and edge-weathering of micas by exchanging interlayer potassium with hydrated exchangeable cations. Mica particles would normally be much wider in relation to thickness than the zone represented in the diagram. (Adapted from Dixon and Weed, 1977)

After ARD treatment, some soluble or amorphous coatings on the surface of the vermiculites, which may have negatively affected the quantification of vermiculite, might have been removed. Hence the peaks of the vermiculite mineral appeared in the ARD-treated sample from the X-ray diffractograms.

X-Ray Fluorescence (XRF) and Inductive Coupled Plasma (ICP) spectroscopy were conducted for the measurement of major and minor elements in the clinoptilolite sample. The

results of ICP spectroscopy, following digestion of the zeolite clinoptilolite sample, indicated that the major element in the clinoptilolite after silicon is aluminum. The presence of aluminum may be a result of isomorphic substitution of Al in the SiO_4^{4-} of the tetrahedra framework (Dyer 1988; Dixon and Weed 1989). Sodium is the most abundantly present exchangeable cation in the zeolite sample, followed by iron, potassium and calcium. The Si/Al ratio of the sample is 5.4.

Results from the XRF and ICP rock analyses are shown in Table 4.8. Results from experimental analysis and that provided by Canmark Resources (Canmark Int'l Resources Inc. 1993) showed that the clinoptilolite sample contains 67% SiO_2 and 12% Al_2O_3, and a Si/Al ratio of 5.4, which agrees with that obtained from the ICP rock digestion. Note, that the data is presented by a convention of the XRF analysis to express the elemental analysis in oxide forms.

Table 4.8 Major elements in the clinoptilolite sample by X-Ray Fluorescence (XRF) and Inductive Coupled Plasma (ICP) Spectroscopy

Element*	unit	Bulk clinoptilolite (ICP)	1M NaCl treated (ICP)	Clinoptilolite ore** (XRF)	Clinoptilolite ore** (ICP)
SiO_2	%	67.14	68.27	66.53	66.37
Al_2O_3	%	12.45	12.6	12.30	12.07
Fe_2O_3	%	2.56	2.61	2.41	2.73
MgO	%	0.84	0.8	0.72	0.76
CaO	%	2.49	1.94	2.08	2.04
Na_2O	%	2.6	3.36	3.38	2.78
K_2O	%	2.35	2.35	2.27	2.21
TiO_2	%	0.26	0.25	0.25	0.22
P_2O_5	%	0.06	0.05	0.05	0.03
MnO	%	0.04	0.04	0.05	0.04
Cr_2O_3	%	< .001	< .001	n/a	n/a
Ba	ppm	1689	1687	1633	1933
Ni	ppm	34	41	n/a	n/a
Sc	ppm	3	3	n/a	n/a
LOI	%	8.6	7.7	n/a	n/a
TOT/C	%	0.09	0.11	n/a	n/a
TOT/S	%	0.03	0.04	n/a	n/a
TOTAL	%	99.58	100.16	90.21	89.44

*The data is a convention of the XRF analysis, to express the elemental analysis in oxide forms.
**XRF and ICP results were provided by Canmark Resources Inc. on the ore body.
n/a – Result was not available

From the wide Si/Al ratio and the abundance of potassium and sodium ions in the sample, it was concluded that the sample is dominated by clinoptilolite (which is characterized by a Si/Al of 5.4 or higher, as a differentia from the heulandite group of the zeolite mineral), as suggested in the X-Ray diffraction analysis.

Table 4.8 provides the composition of the major elements in the clinoptilolite sample, other than the Si and Al. It was found that the amount of Na_2O increased from 2.6% to 3.36% after 1M NaCl pretreatment. At the same time, the amounts of MgO and CaO decreased. This indicated that the NaCl pretreatment is effective in replacing Mg and Ca cations on the clinoptilolite for a more homogenic surface.

Shown in Figure 4.2 is the morphology of the studied clinoptilolite. The morphology of clinoptilolite occurs in almost auhedral masses, with only rare crystal faces or edges, similar to those presented by Dixon and Weed (1989). These natural (untreated) clinoptilolite materials occur as laths and plates, and displays the characteristic of tabular morphology typical of basalt-vug heulandites (Dixon and Weed 1989). The scanning electron microscope (SEM) analyses were conducted on samples of particle size ranges from 2 to 50μm; however, some laths longer than 50μm in length were found. The reason for the misplacement of the larger particle sample may have been due to the shape of the clinoptilolite. During sieving, the shorter axis of the elongated clinoptilolite particle may have passed through the mesh of the sieve. However, the other reason is that there are variations in the sizes of mesh openings in aged sieves. Misuse of the aged sieves may have caused slightly larger particles to pass through during the separation procedures.

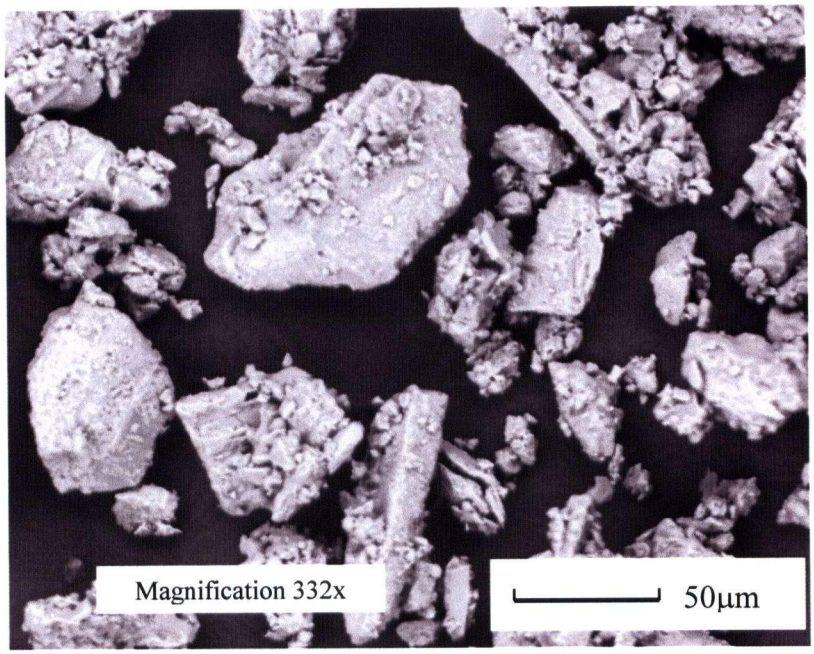

Figure 4.2 Scanning electron microscopic image of bulk clinoptilolite (particle size 2-50 μm)

4.3 pH Stability tests

In determining whether a material is suitable for use as a substrate for a permeable reactive barrier for ARD treatment, it is important that the substrate be chemically stable in acidic environments. The indices for the chemical stability of the clinoptilolite were indicated by the leaching of Al^{3+} and K^{+} from the clinoptilolite after acid treatment for varying time periods.

4.3.1 Chemical stability

The results of the pH stability tests are given in Figure 4.3. The results indicate that Al^{3+} was leached out from the clinoptilolite structure under acid treatments. In the acid environment of initial pH 0.5, Al^{3+} ions were found to be leaching continuously over the study period of 3 days, reaching a concentration of 7000 μg Al per gram of clinoptilolite, which is approximately 6.36% of Al in the clinoptilolite structure. The leaching of Al decreases as the solution becomes less acidic. For pH levels of 2.5 and 3.0, 1- and 2- week stability tests were

conducted; there were no increase in Al^{3+} leaching from the clinoptilolite. For example, at the end of the 2-week acid treatment with a solution of pH 3.0 (which is about the pH level of the ARD that was used in the study), only 0.01% of the Al^{3+} from the clinoptilolite was leached out.

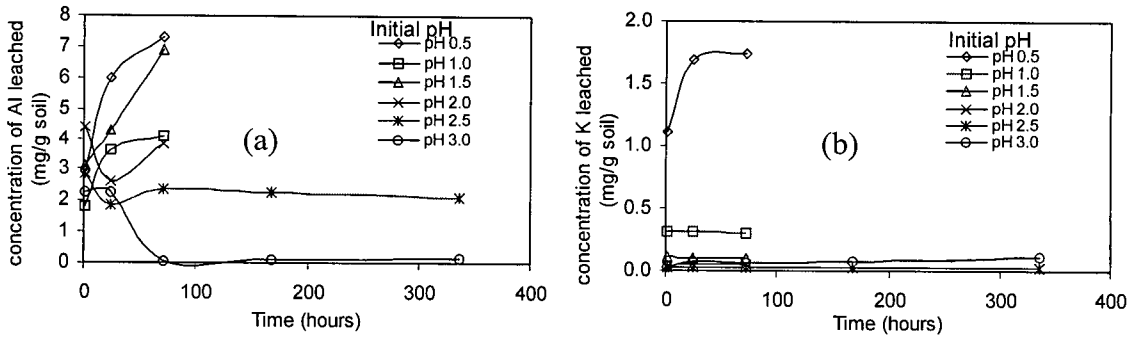

Figure 4.3 Leaching of ions from clinoptilolite acid treatment at various initial pHs with time: (a) Amount of Al ions leached; (b) Amount of K ions leached

Figure 4.3b indicates that 1700 μg of K^+ per gram of clinoptilolite (about 4.25% of the K^+ in the clinoptilolite structure), was leached at the end of the 3-day acid treatment by a solution of pH 0.5. With acid treatments using pH 1.0 to pH 3.0 solutions, less than 1% of the K^+ was leached, the amount of K^+ leached also increased at a very slow rate (~ 0.035% per day).

It is noted that the indicated pH values were the initial pH of the leaching solutions. In Section 4.4, neutralization capability of clinoptilolite will be discussed and changes of pH in the leaching solution may occur at the end of the experiment. Utilizing the initial pH values in the estimation would provide a more conservative prediction of the chemical stability of clinoptilolite.

Figure 4.4 indicates that there is a strong correlation between the amount of Na^+ and Al^{3+} leached. At pH 2.0, 2.25 g of Na^+ leaching was detected with each gram of Al^{3+} leached, whereas at pH 3.28 (the pH level of natural ARD), only 0.667 g of Na^+ leaching was detected with each gram of Al^{3+} leached. This relationship indicated that the leaching of Na^+ happened more rapidly when compared to that of Al^{3+} as pH of the solution decreases. This may be a result of the weaker affinity of Na^+ ions to the surface of the clinoptilolite than that of Al^{3+}, due to the valency of the cations and the "structural" role of Al.

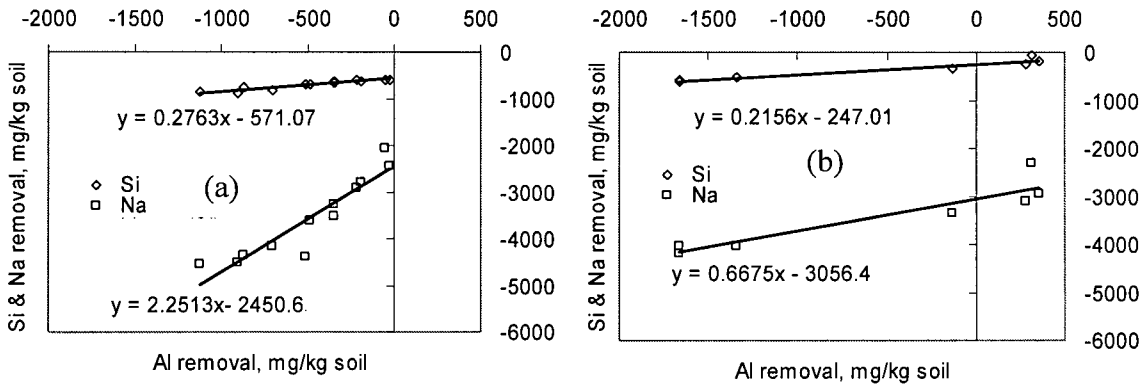

Figure 4.4 The leaching of Si and Na relative to Al in multiple species solutions with background matrix of: (a) nitric acid, pH 2; (b) natural ARD, pH 3.28

In both nitric acid (pH 2) and natural ARD (pH 3.28) solutions, the ratio of Si^{4+} to Al leaching is very similar. Approximately 0.2 g of Si^{4+} was leached with each gram of Al leached. This might be due to the solubility of Si^{4+}, which dissolves more readily at high pH levels (~pH 12); hence, in low pH solutions such as ARD, Si^{4+} is considerably more stable.

From the results of the leachability of the major cations (Al^{3+} and Si^{4+}) from the framework of clinoptilolite, it was concluded that clinoptilolite is chemically stable in low pH environments and is a candidate in the application of ARD treatment.

4.3.2 Physical stability – hydraulic conductivity

The material in the reactive barrier must maintain a hydraulic conductivity that is sufficient to accommodate the groundwater flow in order to prevent the increase in hydraulic gradient upstream of the barrier and possible re-routing of the ARD.

A series of constant head permeameter tests have shown that the hydraulic conductivity of the material maintains a level of 10^{-3} cm/s or higher for a period of three months, when permeated with acid rock drainage obtained from the Britannia Mine. However, when clinoptilolite was permeated with water, the hydraulic conductivity decreased with time. This corresponds to the observations of Oweis and Khera (1998), that an increase in chemical concentration/ionic strength, such as being in the ARD environment, will lead to a suppression of the thickness of the double layers of the particle and triggers flocculation. This in turn inhibits swelling and results in a higher hydraulic conductivity.

The results presented in Table 4.9 indicate that the hydraulic conductivity of the clinoptilolite permeated with water is in the range of 3.2×10^{-4} cm/s (or 2.74 m/day), and that permeated with ARD is 2.2×10^{-3} cm/s (19 m/day). When ARD is permeated subsequent to water, the hydraulic conductivity of the material remains in the 3.1×10^{-4} cm/s levels, which is lower than the hydraulic conductivity when clinoptilolite was initially permeated with ARD (which has a high ionic strength and acidity).

Table 4.9 Hydraulic conductivity of clinoptilolite with various permeates

Permeant	**Hydraulic conductivity, k (cm/s)**
Water (90 days)	3.17×10^{-4}
ARD (90 days)	2.20×10^{-3}
Water (30 days) → ARD (60 days)	3.10×10^{-4}

In general practice, the barrier material is placed in a location in the field where it is in direct contact with ARD. The results indicate that clinoptilolite is able to maintain a hydraulic conductivity sufficient for groundwater to pass through without creating backpressure in the up-gradient area. The average groundwater flowrate (specific discharge) at the Britannia Mine is approximately 0.7 to 1.0 m/day. Therefore, clinoptilolite will be able to handle the flow of ARD contaminated plume if used as a permeable reactive barrier material at the Britannia Mine.

4.3.3 Mineralogical changes

Clinoptilolite samples were scanned using X-ray diffraction to observe changes in the mineralogical properties. Three samples were scanned: (i) without any treatment, (ii) after three months of water treatment (distilled water of pH 5.25), and (iii) after three months of natural ARD treatment (pH 3.28).

Effects of acid treatment on the crystallinity of clinoptilolite

Details of the X-Ray diffractograms of the clinoptilolite samples with the respective particle size fractions are given in Appendix C-1. Results indicated that the crystallinity of clinoptilolite particle <50 μm increased after water treatment, and further increased after acid treatment. Increased crystallinity was interpreted in the X-ray diffractograms by some of the "impurities" or amorphous materials on the particles <50 μm likely washed away during the treatment, hence the clinoptilolite minerals exhibited a sharper peak in the diffractograms. In contrast, clinoptilolite particles >50 μm were found to have decreased in crystallinity, as measured by the sharpness of peaks on the diffractograms. This may be a result of the dissolution of the surface particles during water and acid treatments.

Effects of acid treatment on the surface morphology of clinoptilolite

The SEM images of the water and acid treated clinoptilolite are shown in Figure 4.5a and b. From the SEM images (Figure 4.5), the shapes and size of the clinoptilolite agree with that described in Dixon and Weed (1989) that these clinoptilolite occurs in almost auhedral masses, with only rare crystal faces or edges.

Figure 4.5a and b show the topography of the water treated and acid treated clinoptilolite respectively. The results suggest that an increased amount of fine particles is observed in the water treated sample and even a greater increase in the ARD treated sample as compared to that in the non-treated sample. This may due to the disaggregation of fine particles between non-treated and treated samples. It is also noticed that fewer larger particles were found in water and ARD treated sample. Sizes of particles are more uniformly graded in the ARD treated sample as compared to that of the non-treated (Figure 4.1) and water treated sample (Figure 4.5a). The increased number of small particles found attached to the surface of each lath in the ARD treated sample may be a result of flocculation of fine particles in the low pH and high ionic strength environment of the ARD.

Treatment appears to affect the range of particle sizes within the samples and the appearances of the surfaces. Although the images do not provide conclusive evidence of degrees of aggregation (flocculation), they suggest that treatment did resulted in some disaggregation of larger particles (see Figures 4.1 and 4.5).

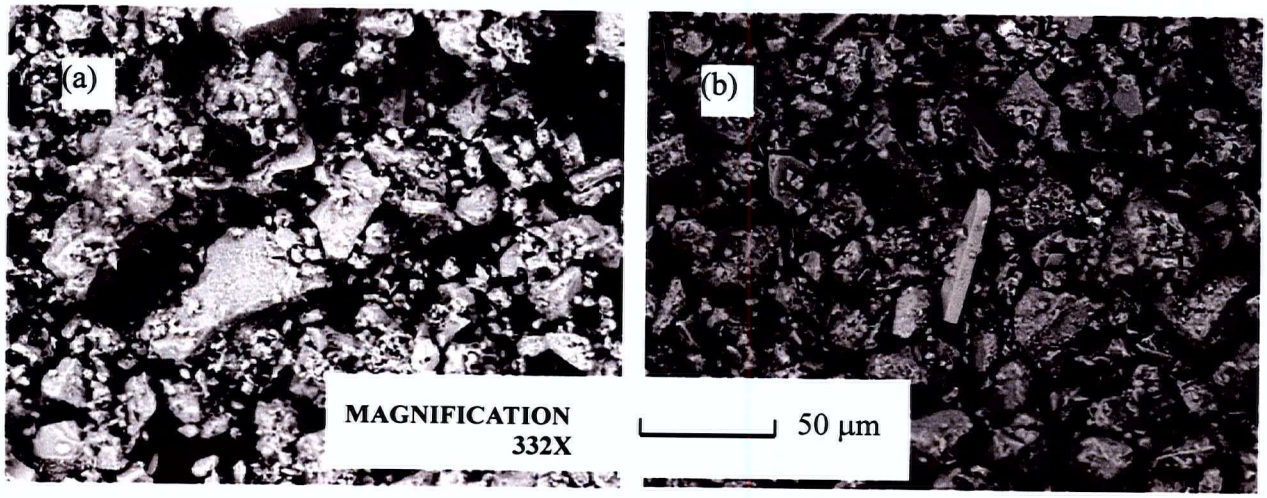

Figure 4.5 Scanning electron microscopic (SEM) diagrams of clinoptilolite with particle size ranges 2 to 50 μm: (a) after water treatment; (b) after ARD treatment

4.4 Neutralization ability of clinoptilolite

One of the major problems of ARD is its low pH, which enhances the mobility of metals in the drainage and hence increases the metal concentration. Since solubility of most metals increases with decreasing pH levels, to minimize the mobilization of metals from ARD entails raising the pH of the drainage to a level that metal cations will start to precipitate. The metal cations in turn are transformed into a form of precipitate and become less mobile in the environment.

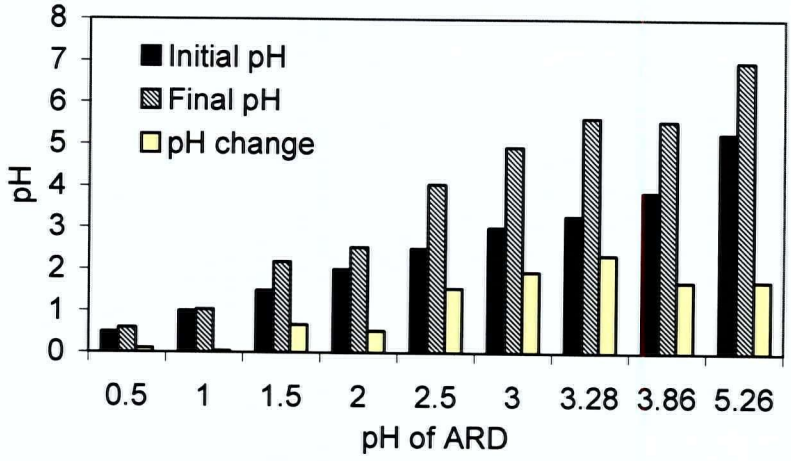

Figure 4.6 The changes of pH in the ARD after 24-hour exposure of clinoptilolite to ARD of various pH levels

The pH of the clinoptilolite sample studied in this experiment is 7.58 (1:2 soil:$CaCl_2$ measurement), and the pH of the treatment solutions ranged from 0.5 to 3.78. The resulting pH values of the treatment solutions after 24 hours of contact are given in Figure 4.6.

Results indicate that clinoptilolite has a pH neutralization ability to the ARD. The final pH of the natural ARD after reacting with clinoptilolite was 5.63 at equilibrium, which was an increase of 2.34 pH units from an initial pH of 3.28. Although the pH of the final leachate did not reach neutral pH levels, at this pH, metals could be present in concentrations that would allow the Fe^{3+}, Al^{3+}, Zn^{2+}, and Cu^{2+} to be precipitated in the form of metal hydroxides or oxides and become immobile in the solute solution (Garrels and Christ 1965). The increase in pH is the result of dissolution of secondary minerals in the clinoptilolite sample, such as hydroxides and aluminosilicates, as suggested in Section 4.2.2, which have neutralizing capacities (Blowes and Ptacek 1994; Nordstorm and Alpers 1997). For example, in this study, dissolution of aluminosilicates by the oxidizers (hydrogen ion, H^+ and ferric ion, Fe^{3+}) in ARD provides a primary source of dissolved K^+ and Al^{3+} in the ARD solution. To illustrate this reaction, the weathering reaction for K-feldspar may be expressed as follows:

$$\underset{\text{K-feldspar}}{2KAlSi_3O_8} + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ + 4H_4SiO_4$$

Since all silicate weathering reactions are acid-consuming, hence a pH buffering effect results (Appelo and Postma 1993).

Although chemical reactions such as precipitation and dissolution occurred within the clinoptilolite, the hydraulic conductivity was found not to be significantly affected, as discussed in Section 4.3.2. Such precipitation occurred in the form of: (1) metal-Fe- and Mn- oxide; and (2) oxidizable compounds, and will be discussed in Section 6.2.2. For example, metals associated with the metal-oxide or hydroxide-oxide phase were identified in the weak acid extraction procedure by using hydroxylamine hydrochloride. Metals associated with the

oxidizable elements and minerals, such as sulphide to sulphate fractions in the samples, were identified in the strong acid extraction procedure by using hydrogen peroxide and ammonium acetate. Dissolution of secondary minerals has occurred and was discussed in Section 4.2. This includes the dissolution of secondary minerals such as amorphous material and oxides.

The presence of precipitates did not affect the hydraulic conductivity significantly and it may be reasoned that the precipitates of metals are too fine to cause major clogging within the barrier material. Alternatively, they may have occurred as coatings on the mineral surfaces, as will be discussed in Section 6.2.2.

However, the dissolution of secondary minerals could be seen to increase the hydraulic conductivity of the barrier material by: (1) extraction of lattice aluminum ions from the octahedral sheets of the clay mineral; (2) ion exchange on the surface of the clay minerals due to replacement of naturally adsorbed cations of lower valence by the extracted aluminum ions whose valence is 3. This results in a reduction in the thickness of the diffuse ion layer; and (3) increase in effective pore space and a decrease in the tortuosity factor, resulting in an increase in the soil hydraulic conductivity (Mohamed and Antia 1998). Yet, from experimental results, these effects do not appear significant.

From the pH stability tests, the observations in the mineralogical changes and neutralization ability of the clinoptilolite, the clinoptilolite is observed to be reasonably chemically and physically stable under acidic environments.

CHAPTER 5 RETENTION OF METALS ON CLINOPTILOLITE

5.1 Adsorption of metals

Adsorption of metals on the clinoptilolite was tested in: (i) single-species solutions, (ii) multiple-species solutions with natural ARD as background matrix, and (iii) multiple-species solution with nitric acid and distilled water as background matrix. Adsorption isotherms were obtained and the adsorptivities of the metals under each set of conditions are discussed. The adsorption of metals as a function of pH is also discussed in this chapter.

5.1.1 Adsorption isotherms of metals on clinoptilolite

The retention of metals on the clinoptilolite was tested in single species solutions of Cu, Fe, Zn or Al at a pH 3.5 (adjusted by nitric acid and distilled water) matrix. The second part of the retention of metals was conducted using multiple species ($Cu^{2+}Fe^{3+}Zn^{2+}Al^{3+}$) solutions in a background matrix of the natural ARD (pH 3.28) and in a pH 2.0 nitric acid/distilled water matrix. The adsorption isotherms were fitted using the Langmuir equation (Sparks 1995) as described by:

$$q = \frac{kCb}{1 + kC}$$

where,
k = constant related to the binding strength, L/mg
b = maximum amount of adsorptive that can be adsorbed (monolayer coverage), mg/kg
q = amount of adsorption, adsorbate per unit mass of adsorbent in mg/kg. In some literature, the weight of the adsorbate per unit weight of adsorbed is plotted in lieu of q.
C = equilibrium concentration of the adsorptive, mg/L

The relationship between the adsorbed concentrations and the equilibrium concentrations at fixed temperature and applied pressure is portrayed in an adsorption isotherm. Adsorption

isotherms are convenient for representing the effect of adsorptive concentration on soil surfaces, especially if other variables such as pH and ionic strength are controlled, along with temperature and pressure.

The adsorption isotherms were fitted into the Langmuir equation because it equally well describes both adsorption and precipitation (Veith and Sposito 1977). The L-curve isotherm is the most commonly encountered in soils because it provides an estimate of the maximum amount of adsorptive that can be adsorbed on the soil based on monolayer coverage. Langmuir isotherm is used instead of the Freudlich isotherm because Langmuir isotherm provides a more realistic estimate of the actual surface coverage rather than Freudlich isotherm, which projects an infinite amount of absorptive that can be adsorbed on the soil. It must be noted that adsorption isotherm equations cannot be interpreted to indicate any particular adsorption mechanism and should be regarded as curve-fitting models without particular process significance. However, they can be used as predictive tools under limited conditions (Mohamed and Antia 1998).

The constant related to the binding strength, k, was obtained for each metal in each scenario. The adsorption isotherms obtained with details and sample calculations are presented in Appendix D. A summary of the distribution coefficient, k, of the metals in single and multiple species solutions are presented in Table 5.1.

Table 5.1 Constant related to binding strength, *k* [L/mg], from Langmuir equation obtained in batch equilibirum adsorption tests in single and multiple-species solutions

Metal	**Single species solution**	**Multiple species solution (CuFeZnAl)**	
	HNO_3/distilled water @ pH 3.5	**HNO_3/distilled water @ pH 2**	**ARD @ pH 3.28**
Cu	0.0138	0.00255	0.00761
Fe	0.0778	0.017	0.005
Zn	0.0072	0.00836	0.002896
Al	0.0563	0.000237	0.002899

Results from Table 5.1 show that the distribution coefficient, which is a constant related to the binding strength that describes both adsorption and precipitation of the metal, is greatest for Fe in nitric acid/distilled water as background matrix. The high distribution coefficient of Fe contributes to its low solubility at pH > 2 and hence high retention onto the clinoptilolite. Results also indicate that distribution coefficients of metals are lower in multiple-species systems, which is due to the competition among metals for binding sites on the surface of the clinoptilolite. In the case when clinoptilolite is exposed to multiple-species solutions, the selectivity of the metals are $Cu^{2+}>Fe^{3+}>Al^{3+}>Zn^{2+}$ in ARD and $Fe^{3+}>Zn^{2+}>Cu^{2+}>Al^{3+}$ in nitric acid/distilled water background. This sequence takes into account both adsorption and precipitation.

Experimental results of the adsorption of the metal ions Cu^{2+}, Fe^{3+}, Zn^{2+} and Al^{3+} on clinoptilolite in multiple-species solution with natural ARD, and nitric acid/distilled water as background matrix are shown in the adsorption isotherms in Figures 5.1 and 5.2 respectively. The leaching of the metal ions, which occurs naturally in the structure of the clinoptilolite, was also tested. An increase in Al^{3+} ions was found in the leachate when the pH of the solution drops below a pH of 2. However, Fe^{3+} precipitates in natural ARD environments as a result of the relatively high ionic concentration at the corresponding pH level according to the solubility product. The adsorption isotherm of Fe is linear, which agrees with the accumulation of precipitates in the leachate. Fe^{3+} has a very low solubility and will start precipitating at a pH above 2 (Lindsay 1979).

K^{+}, Al^{3+}, Si^{4+} and Na^{+}, the naturally occurring ions, were leached out from the clinoptilolite, with Na^{+} leached in the largest amount. The high Na^{+} concentration in the supernatant is likely the result of its replacement with metal cations of higher valencies.

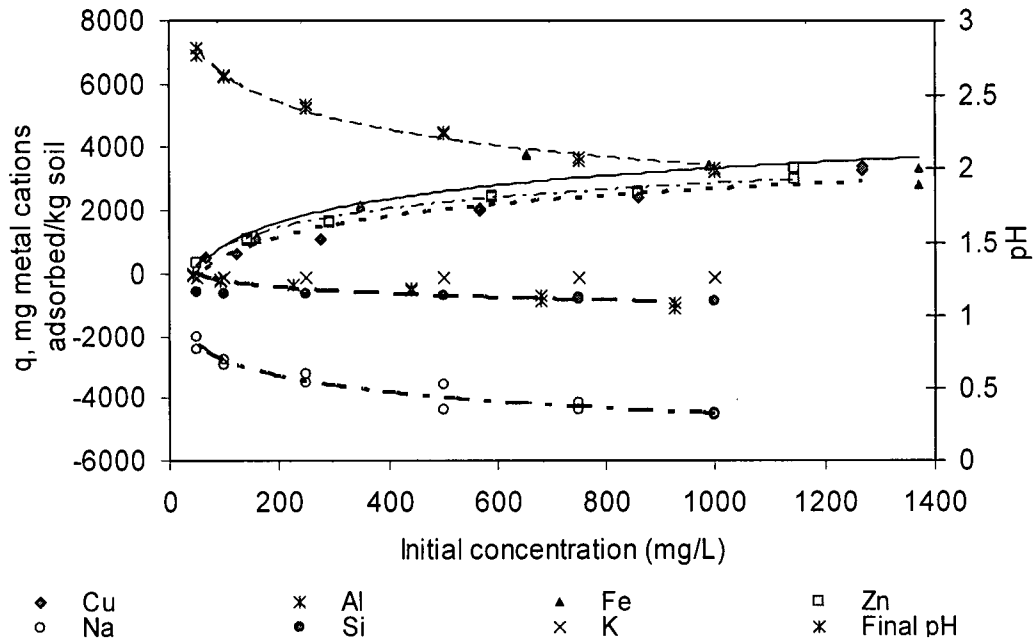

Figure 5.1 Adsorption of metal ions in multiple Cu, Al, Fe and Zn species on clinoptilolite with natural ARD (pH 3.28) as background solution

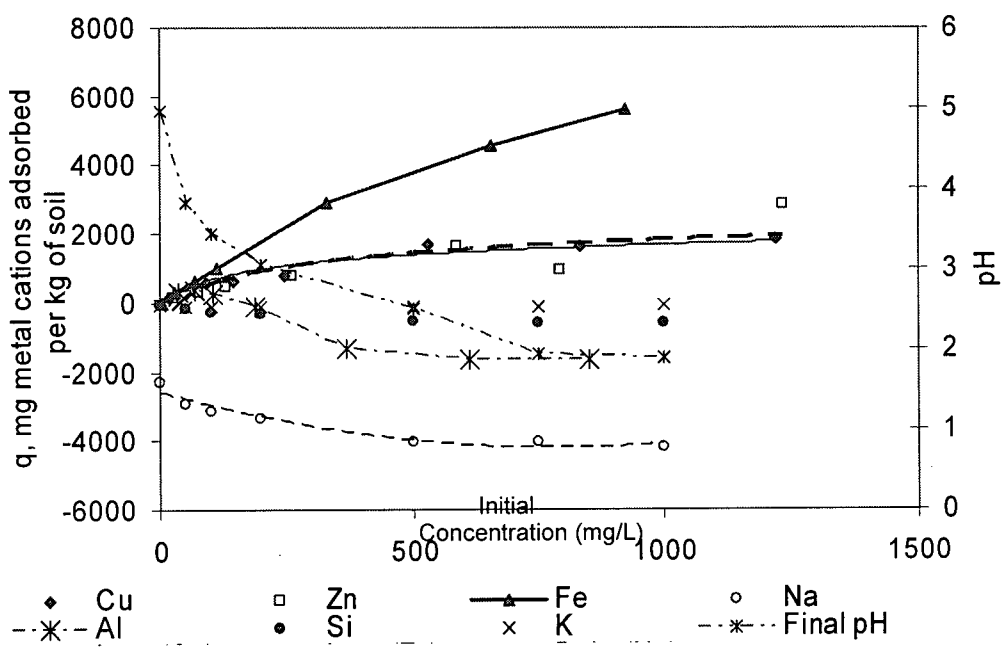

Figure 5.2 Multiple Cu, Al, Fe and Zn species adsorption on clinoptilolite with background solution of nitric acid/distilled water at pH 2

To illustrate that ion exchange is occurring in the clinoptilolite-ARD interface and that the mass of adsorbed cation equals the mass of desorbed cations, a sample mass balance calculation is extracted from Figure 5.1 as follows:

Mass of adsorbed ions = mass of desorbed ions

Mass of adsorbed Cu + Zn + Fe + Mn = Mass of desorbed Al + Na + Si + K

For example, at metal concentrations of 500 mg/L, the amount of metal retained and leached from the soil (as obtained from graph and data) were:

Species	**Mass expressed in terms of**		
	mg/kg	**mmol/kg**	**meq/kg**
Al	-1341.65	-49.7232	-149.17
Cu	1700.0	26.75	53.5
Zn	1653.05	25.279	50.558
Fe	2885.34	51.667	155.0
Na	-4038.68	-175.67	-175.67
Si	-522.35	-18.599	-74.396
K	-109.94	-2.812	-2.812
Mn	1443	26.27	52.54
Net amount on soil			+90.45

(Note, negative values indicated that ions were leached)

From the calculation,

Mass of adsorbed Cu + Zn + Fe + Mn = Mass of desorbed Al + Na + Si + K + 90.45 meq/kg

The net positive amount of ions present on the clinoptilolite sample indicated that reactions other than ion exchange (for example, precipitation and surface complexation, which will be discussed in Section 6.2.2) may have occurred.

5.1.2 Adsorption of metals affected by pH

The negative values of Al^{3+}, Fe^{3+} and K^{+} below pH 2.5 shown in Figure 5.3 indicate that these three metal ions were leached out from the clinoptilolite framework structure, whereas when pH>2.5, the clinoptilolite adsorbs cations from the ARD and the "synthetic ARD" solution.

Al^{3+} was leached from the structure of the clinoptilolite because it has a high solubility in the acidic environment. However, Si^{4+}leaching was not detected because it has a high solubility only in alkaline environments (Gottardi and Galli 1985). In addition, since the framework of clinoptilolite is dominated by the SiO_4^{4-} tetrahedral framework, with Si/Al ratio of 5.4, the loss of Al^{3+} ions would not cause significant changes in its physical and chemical stability of clinoptilolite in acidic environments (Gottardi and Galli 1985; Dyer 1988), which has been shown in Section 4.3. The leached Al^{3+} would be hydrolyzed to a variety of species such as $Al(OH)^{2+}$, $Al(OH)_2^{+}$ and $Al(OH)_3$ in which the metal is hexa-coordinated (Dyer 1988) by the following reactions:

- $Al^{3+} + H_2O \rightarrow Al(OH)_2^{+} + H^{+}$
- $Al(OH)_2^{+} + H_2O \rightarrow Al(OH)_2^{+} + H^{+}$
- $Al(OH)_2^{+} + H_2O \rightarrow Al(OH)_3 + H^{+}$

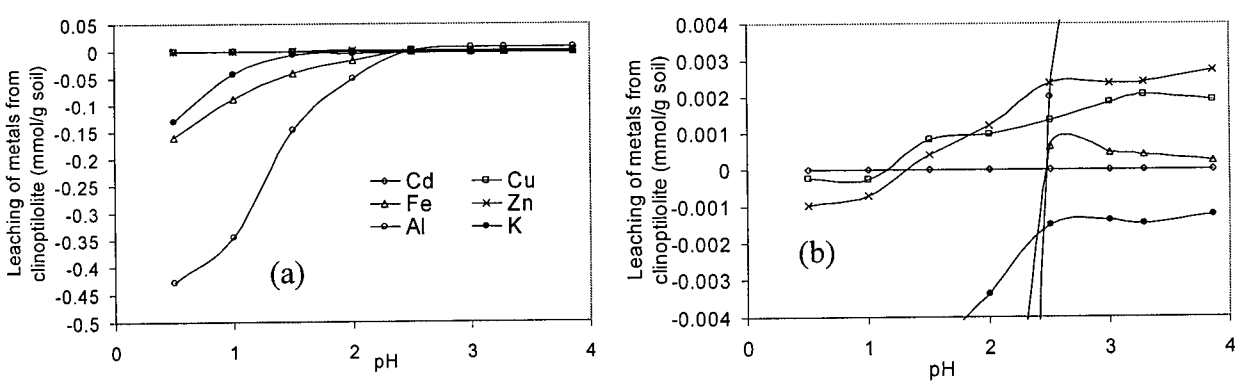

Figure 5.3 The leaching of metals from clinoptilolite in 24-hr batch equilibrium tests with natural ARD at various pH level: (a) overview of the adsorption curve, (b) zoomed-in view of Figure 5.3a at the metal leaching to adsorption transition

A large amount of Fe^{3+} ion was found to be leached from the clinoptilolite at pH < 2.5. Fe^{3+} ions go into solution from Fe-hydroxide precipitates at pH's < 2.9 (Sawyer, McCarty et al. 1994). The source of Fe could also be from the mineral, where there was 36,000 μg of Fe per gram of clinoptilolite, present from XRF analysis.

The effects of pH on the transition of metal leaching to metal adsorption from ARD by the clinoptilolite are given in Figure 5.3b. It indicates that there is an increase in adsorption of metals as the pH of solution is increased. The removal of metals due to the precipitation as hydroxides and/or with other present anions such as oxides, oxidizable compounds and metals attached to the surfaces of amorphous minerals; decreased the availability of the metals in the ARD in less acidic environments.

Desorption of Cu^{2+} and Zn^{2+} from the clinoptilolite ceased above pH ~ 1.2, where adsorption started to happen. Al^{3+} and Fe^{3+} transformed from desorption to adsorption at pH levels above 2.5, yet there was still slight desorption of K^{+} from the clinoptilolite. A summary of the removal of metals from the natural ARD by the clinoptilolite is presented in Table 5.2. Desorption of K^{+} would have occurred mainly as a result of the displacement ions of higher valences or smaller sizes, such as Cu, Al, Fe and Zn..

Table 5.2 Percentage removal of metals in the natural Britannia copper mine drainage (pH 3.28) by the clinoptilolite (24-hour batch test)

Metal	**Initial concentration**		**Final concentration**		**removal of metals (amount metal/ amount sorbate)**		**Percentage removal**
	mg/L	*mmole/L*	*mg/L*	*mmole/L*	*mg/g*	*mole/kg*	
Al	24.0	0.89	2.46	0.091	0.215	0.0080	89.7%
Cu	20.5	0.32	7.435	0.117	0.131	0.0021	63.8%
Fe	2.76	0.05	0.495	0.009	0.022	0.00039	82.1%
K	1.10	0.03	6.896	0.176	-0.058	-0.0015	-527%
Zn	40.0	0.61	24.2	0.370	0.158	0.0024	39.5%

The amount of metal ions removed by the clinoptilolite based on the 24-hr batch equilibrium adsorption test from the natural ARD of Britannia Mine (pH 3.28) is summarized in Table 5.2. The results show that there is 89.7% of Al^{3+}, 63.8% of Cu^{2+}, 82.1% of Fe^{3+}, and 39.5% of Zn^{2+} removal from the natural ARD. The retention of ions are ranked $Al^{3+} > Fe^{3+} > Cu^{2+} > Zn^{2+}$ based on percentage mass removal.

The amount of the metals being removed by the clinoptilolite is affected by many factors. These factors include the free energy of hydration of the cations, the valence of the cations, the molecular size and hydrated radius of the cations (Semmens and Seyfarth 1978; Yuan 1999), the size of the "molecular sieve" of the clinoptilolite, the framework topology (channel configuration and dimensions) and electrolyte composition and concentration in the aqueous phase (Barrer and Sand 1978; Ming and Mumpton 1989).

For example, ion-exchange selectivity or the preference of one ion over another is determined by the strength of electrostatic forces. Since electrostatic forces are involved in the retention of counter ions, it can be predicted from Coulomb's Law that the ion having the smallest "effective" radius will be preferred. It has been demonstrated that there is a definite relationship between ion size and ion selectivity. Since cations present in soils are hydrated, ions with the smaller hydrated size or the larger crystalline size are preferred. From the ionization energy, molecular size and its respective hydrated radii (which is related to its crystalline radii), the retention order $Al^{3+} > Fe^{3+} > Cu^{2+} > Zn^{2+}$ could be explained.

Table 5.3 Ionization energies and ionic radii of Al^{3+}, Fe^{3+}, Cu^{2+} and Zn^{2+} ions

	Al^{3+}	**Fe^{3+}**	**Cu^{2+}**	**Zn^{2+}**
Ionization energy (kJ/mol)	577.5	762.5	745.5	906.4
Molecular size (Å)*	0.50	0.55 to 0.645	0.57	0.60
Hydrated radii (Å)**	9	9	6	6

*Effective radii of elements (Lide 1997/98)
**Approximate effective ionic radii in aqueous solution at 25oC (Lide 1997/98)

In addition, as shown in Figures 5.1 and 5.2, the adsorption of metal ions is higher in the HNO_3 matrix solution than the ARD because there is competition among trace metals in the ARD matrix solute, which has a higher ionic strength.

The retention of Al^{3+} and Fe^{3+} may be due to their high 3+ valency. The results agree with the study conducted by Yuan (1999), where the selectivity of Cu^{2+}, followed by Zn^{2+} on clinoptilolite was obtained. Yuan (1999) suggested that according to the non-hydrated and hydrated ionic size of the cations, Cu^{2+} is the smaller cation between Cu^{2+} and Zn^{2+}, which implies that the affinity of the Cu^{2+} cation to be attached to the negatively charged site of clinoptilolite is higher than that of Zn^{2+}.

The preference for a particular cation to be attached on the mineral surface may be affected by the concentration in the aqueous phase (Ming and Mumpton 1989). From the initial concentration of Cu^{2+} (20.54 mg/L or 0.115 mmole/L), which was lower than that of Zn^{2+} (40.0 mg/L or 0.612 mmole/L), the preferred adsorption of Zn^{2+} over Cu^{2+} probably the result of a concentration effect rather than ionic size or ionic radius (Thompson and Troeh 1993).

5.2 Effect of retention of copper with contact time

Retention kinetics is an important factor for the sorption of metals from the clinoptilolite. In this section, the retention kinetics were conducted on Cu because Cu was the major contaminant of concern in the ARD and is present in highest concentration among other metals in the mine drainages. The understanding of the retention of Cu is essential. Results from the kinetic test at various conditions were compared based on:

- The effect of mixing in batch adsorption tests of 1000 mg/L Cu solution with: (i) continuous mixing; and (ii) without mixing.

- The effect of flow rates in mini column leaching cell tests with 1000 mg/L Cu leaching solution between linear flow rates of: (i) 1 m/day; and (ii) 2 m/day. These flow rates were determined preliminarily to cover the typical range of flow rates that might occur on-site.
- The effect of influent Cu concentration in mini column leaching cells at flow rate of 2 m/day between: (i) 1000 mg/L Cu; and (ii) 500 mg/L Cu.

5.2.1 Effects of mixing in batch adsorption tests on the retention of copper

The comparison of Cu retention onto clinoptilolite between mixing and non-mixing batch adsorption tests is shown in Figure 5.4.

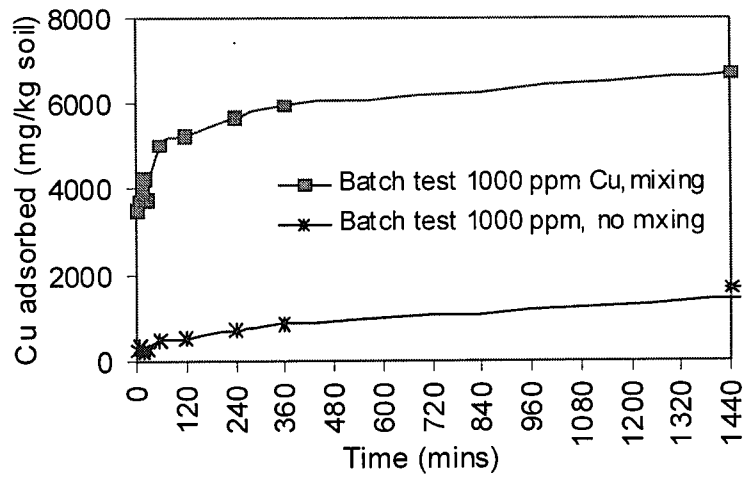

Figure 5.4 Comparison of the retention of Cu onto clinoptilolite between mixing and non-mixing batch tests

The retention of Cu on clinoptilolite is greater in the mixing batch adsorption test than in the non-mixing batch test. This is a result of the dynamic movements and interactions between clinoptilolite and metal ions during the continuous shaking, which gives higher surface exposures and contacts between the surface sites and free cations in the solution. This increases the amount of metal cations to be attached onto the soil surface and to be exchanged on the sites

which were occupied by other exchangeable cations. Whereas when there was no mixing applied, transport of free cations in the permeant to the surface sites depends primarily on diffusion (in which without mixing), retention of cations was observed to be lower. Long-term monitoring was conducted on the non-mixing batch test. Results show that adsorption of Cu onto clinoptilolite reached approximately 50% of that in the mixing batch adsorption test after 10 days of treatment. Since no mixing was performed, this information could be used to estimate the retention of copper when clinoptilolite is used as a reactive bed adsorbent in the field. Results obtained from the mixing/flow through tests may be applied to predict the effect and to estimate the maximum amount of Cu the clinoptilolite may retain in a permeable reactive barrier system.

5.2.2 Effects of flow rates in mini-column leaching cell tests on the retention of copper

In mini-column leaching cells, interactions between free cations in the solution and the sorbate depend mainly on the rate of ion transport from solution during the leaching process. Soil particles in column leaching cells would have significantly less exposure to the free cations in the leaching solution compared to that in the mixing batch test. To examine the effect of flow rates on the retention of copper onto clinoptilolite, a comparison of the results obtained from leaching cell tests with linear flow rate of 1 m/day and 2 m/day were conducted. The result of Cu retention onto clinoptilolite in column leaching cells at different flow rates is given in Figure 5.5. Results indicate that at the early stage of reaction (from 0 to 4 hour), retention of Cu onto the clinoptilolite was greater in the leaching cell with a higher flow rate.

Retention also depends on the surface charge and thickness of double layer of the particle. When flow rate increases, the double layer thickness of the particle would be suppressed due to increased amount of ions present in the permeating solution, and hence more cations could be

attached on the surface of the particle (Sparks 1995). This could also be explained by the observation that the higher the flow rates of leachate, the greater the flow of cations and interactions with the soil surface, which leads to higher ion retention.

However, in both flow rates scenarios, the amounts of Cu retained after 4 hours of reaction were comparable. This implies that the amount of Cu retained ceased to be dependent on flow rate after 4 hours of reaction, eventually due to saturation of surface sites with metal cations. The slope of the adsorption curves indicates that the rate of copper adsorption in the 2 m/day leaching cell was faster than that in 1 m/day, until after the second hour of reaction. After 2 hours, the rate of Cu adsorption in the leaching cell with the faster flow rate started to decrease, whereas the rate of adsorption in the 1 m/day leaching cell remained constant. The decreased rate in adsorption in the 2 m/day leaching cell could be a result of exhaustion of cation exchange sites on the soil surface following the rapid exchange in the early stage of reaction. In the 1 m/day leaching cell, since there was adequate contact time between the substrate and the free cations in the solution, the increased retention of cations may also have been carried out by other mechanisms.

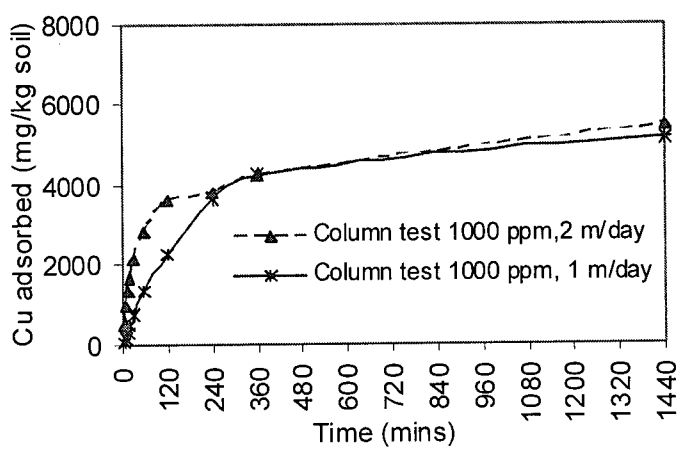

Figure 5.5 Comparison of the retention of Cu onto clinoptilolite at different flow rates in mini-column leaching tests

5.2.3 Effects of copper concentration in column leaching tests on the adsorption onto clinoptilolite

Experimental results of: i) 500 mg/L Cu leachate at linear flow rate of 2 m/day and ii) 1000 mg/L Cu at 2 m/day in the column leaching cell indicated that the retention of copper is more favorable in solutions with a higher solute concentration. A comparison of the adsorption isotherms for different solute concentrations in the column leaching tests are presented in Figure 5.6.

During the first 60 minutes of the test, the retention of copper is comparable in the leaching cells of both 500 mg/L and 1000 mg/L copper leaching solutions. This implies that concentration had no significant effect on the metal retention at these flow rates.

After the first hour of reaction, the retention of copper onto clinoptilolite can be differentiated from the initial concentration of the feeding leaching solution. The greater the concentration of the initial leaching solution, the higher the retention of copper was achieved at the end of the 24-hour reaction period.

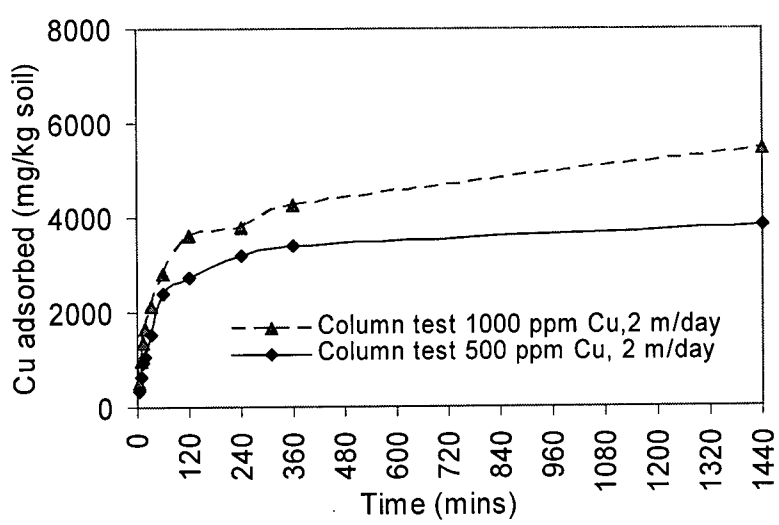

Figure 5.6 Comparison of the retention of Cu onto clinoptilolite in mini-column-leaching tests with different solute concentrations

5.2.4 Summary of comparison of the retention of copper onto clinoptilolite in different testing methods

The amounts of Cu retained on the clinoptilolite sample with respect to time obtained by different testing methods are summarized in Figure 5.7.

In time period from 180 minutes (3 hours) to 300 minutes (6 hours), although the flow rate of 2 m/day were used in both 500 mg/L and only 1 m/day of 1000 mg/L were used in the column leaching cells, the retention of copper from the cell of a slower flow rate but higher initial solute concentration is greater than that of a lower concentration but faster rate. This implies that the retention of copper was driven by concentration after a certain point, and the influence of flow rate is negligible. The amount of solute in the lower concentration solution but a faster flow rate may be exhausted after this time and the flow rate of the leachate ceased to be a factor of high retention.

Beyond 5 hours, the retentions of Cu in the two leaching cells, of linear flow rate of 2 m/day and 1 m/day, were almost the same. The results suggest at these flow rates, solute velocity is not a critical consideration in the retention of Cu ions onto the clinoptilolite.

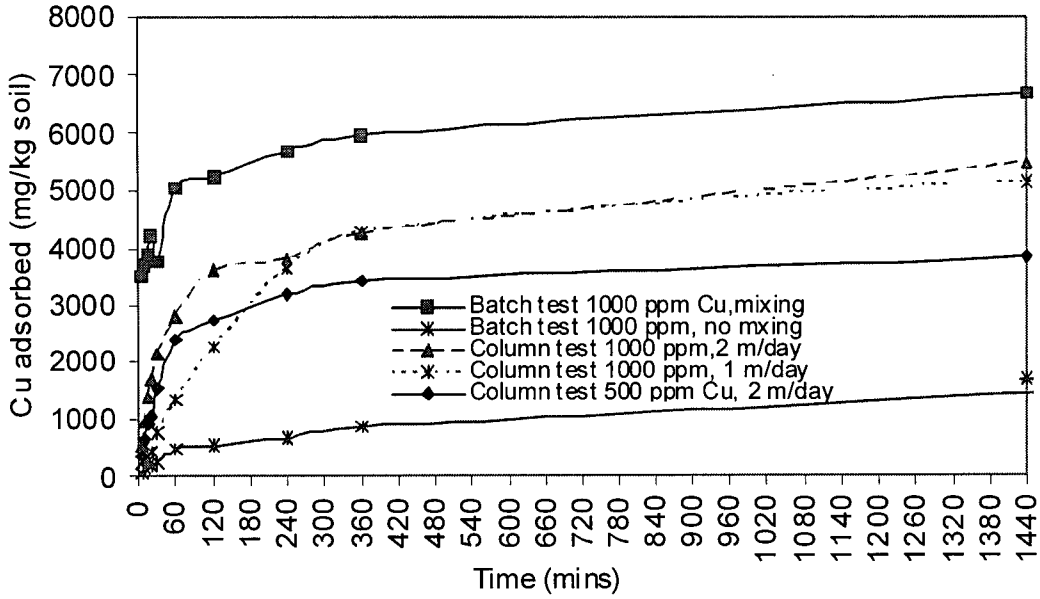

Figure 5.7 Adsorption of Cu with time on clinoptilolite in various testing conditions

A summary of the retention of Cu (expressed in terms of amount retained per Kg of clinoptilolite) at the end of the 24-hour reaction time is presented in Table 5.4.

Shown in Table 5.4 is the batch equilibrium test over-estimated the amount of Cu that could be retained on the clinoptilolite, relative to the column leaching cell test using the flow rate as in the field condition. At the end of the 24-hour reaction time, results show that the amounts of Cu that were retained onto the clinoptilolite are similar in the two leaching columns (1 m/day and 2 m/day).

Table 5.4 Comparison of retention of Cu onto clinoptilolite using different methods of treatment

Method	**Initial Design Concentration of Cu [mg/L]**	**Amount of Cu retained on clinoptilolite at the end of 24 hours [mg Cu/Kg soil]**
Batch equilibrium test – 24-hr continuous shaking	1000	6684
Leaching cell @ 2 m/day	1000	5440
Leaching cell @ 2 m/day	500	3839
Leaching cell @ 1 m/day	1000	5138
Batch reactor "static" test	1000	1696

Integrating the Cu adsorption results obtained from the mini column leaching tests into the same graph as the adsorption isotherms obtained in Section 5.1.1 (Figure 5.8) indicated that the amount of metals adsorbed on the clinoptilolite obtained from the mini column leaching tests was consistent with the results from the 24-hr batch adsorption tests.

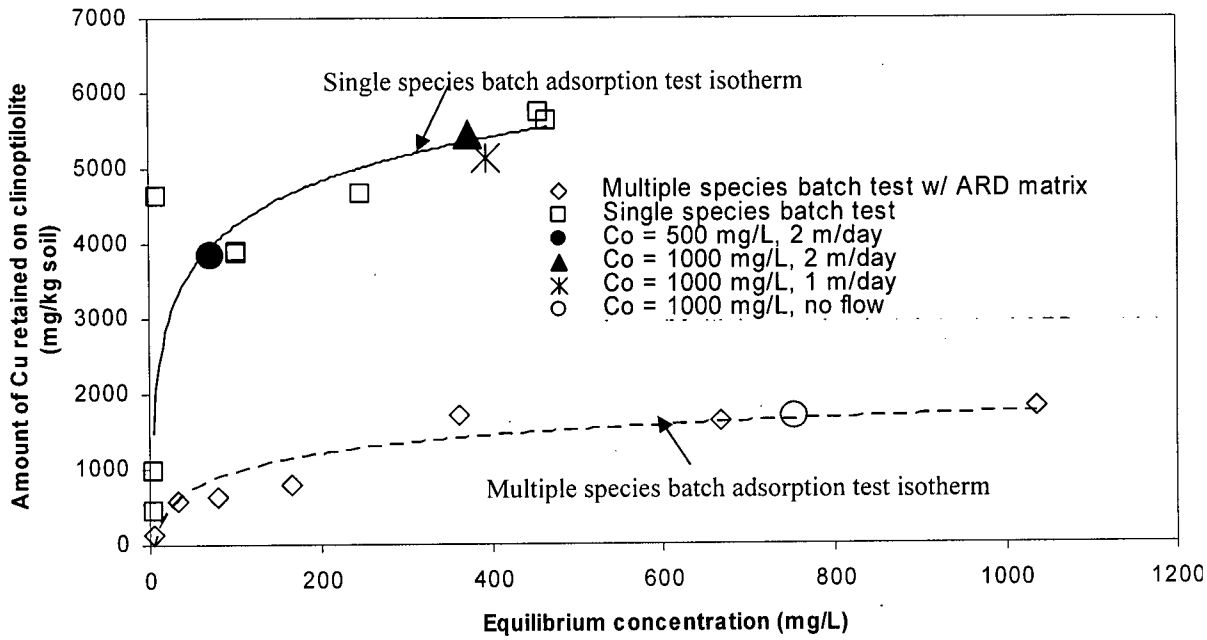

Figure 5.8 Comparison of the retention of Cu in mini-leaching cell to the batch equilibrium adsorption tests (C_o denotes initial concentration of copper)

The results indicated that regardless of the initial concentration and flow rate, the amount of metals that could be retained on the clinoptilolite falls on the adsorption isotherm. The results confirmed that equilibrated adsorption was dependent mainly on the availability or the loading of metal cations in the equilibrated solution. However, in the non-mixing mini column leaching cell, the adsorption of Cu in a single species solution falls onto the isotherm of the multiple species solution test.

CHAPTER 6 COLUMN LEACHING CELL TESTS

Column leaching tests were conducted in addition to the batch equilibrium adsorption tests to determine the retention capacity of the zeolite clinoptilolite while simulating the field condition that may be encountered by the substrate in an on-site environment.

The chemical stability study and batch-adsorption tests demonstrated that clinoptilolite maintained its structure in an acidic environment and had a high metal retention capacity. In this chapter, column leaching test results are presented. The intent of this work is to provide information that is applicable to the field situation.

Leaching cell tests were conducted by varying the parameters as described in Section 3.2.4. Water samples were taken from the outlet (50 cm from influent) and sampling ports (nominally 10, 20, 30, and 40 cm from the influent) along the length of the leaching cell. The collected water samples were tested for Cu, Fe, Mn, Zn, and Al. The pH, reduction-oxidation (redox) potential, and electrical conductivity (EC) were also measured to determine retention mechanism at different distances from the influent port (experimental setup is shown is Section 3.2.4).

Results were used for validating a geochemical model prediction to evaluate the performance of the permeable reactive barrier and to determine the thickness or the amount of substrate material needed.

6.1 Column leaching tests (I) – Bulk Clinoptilolite

The first task of the testing procedures is to feed the natural ARD, containing multiple metal species, through the column-leaching cell filled with bulk clinoptilolite with a flow rate of 1 m/day, which approximates the on-site conditions.

Summaries of the change in pH, redox potential, EC, concentration of Cu, Fe, Mn, Zn, and Al over the number of pore volumes of leachate at the various sampling ports are shown in Figure 6.1a to Figure 6.1i, respectively. Figure 6.1j to Figure 6.1n show the change of effective concentration, C/C_o, of different metals at various depths with number of pore volumes of leachate that passed through the leaching cell. (Note: the first parameter in the legend of the Figures represents the measured parameters from the leaching cell tests; the second parameter in the legend represents the distance, in cm, from the influent port along the column leaching cell at which the water sample was taken. For example, pH-10 denotes the pH in the water sample obtained from the 10 cm sampling port). A total of 41.5 pore volumes of leachate were passed through this leaching column.

Figure 6.1a shows the change of pH in the pore fluid at the various depths along the column. The influent of pH 3.11 has been increased by the clinoptilolite to an equilibrium pH of 4 and electrical conductivity of 2.0 mS/cm. The concentration of Cu in the effluent reached the breakthrough point (50% of the influent concentration) after 38 pore volumes, 13 pore volumes for Mn, 24 pore volumes for Zn and 39.5 pore volumes for Al (Figure 6.1j). Fe is precipitated as ARD enters the leaching cell as a result of the rise of pH in the pore fluid. Mn concentration in the effluent doubled from that in the influent. The "extra" Mn in the effluent might have been displaced from the surface of the clinoptilolite when in contact with the acidic solution. Subsequent to this leaching cell test, investigations of the leaching of surface metal cations from the clinoptilolite were conducted as described in Appendix E. The surface washing of clinoptilolite indicates that 166 mg Mn/kg soil (47% of the total Mn), 30 mg Zn/kg soil (15% of total Zn), 6.8 mg Cu/kg soil (<10% of total Cu), and 2311 mg Fe/kg soil (<7% of total Fe) was washed out of the clinoptilolite after 4 washes with 0.01M HCl solution. These ions, which were washed with the 0.01M HCl, are present on the surface of the clinoptilolite and are potentially leachable when in contact with acidic solutions.

Pretreatment of the soil is proposed in order to eliminate the leaching metals from the surface of the clinoptilolite when in contact with acidic drainages, and to maximize the metal removal efficacy from ARD by homogenizing the surface cations with Na ions. The goal of the pretreatment was to remove loose impurities, such as surface-attached metal cations on the clinoptilolite, by replacing them with Na^+ ions from NaCl solutions. The pretreatment turns the surface of the clinoptilolite from hetero-ionic to homo-ionic. Since only one type of ion is present on the surface of the clinoptilolite, the competition for adsorption sites between the cations from the leachate and the Na^+ from the surface of the substrate would be minimized, leading to higher cation retentions. The determination of the pretreatment method is explained in Appendix F.

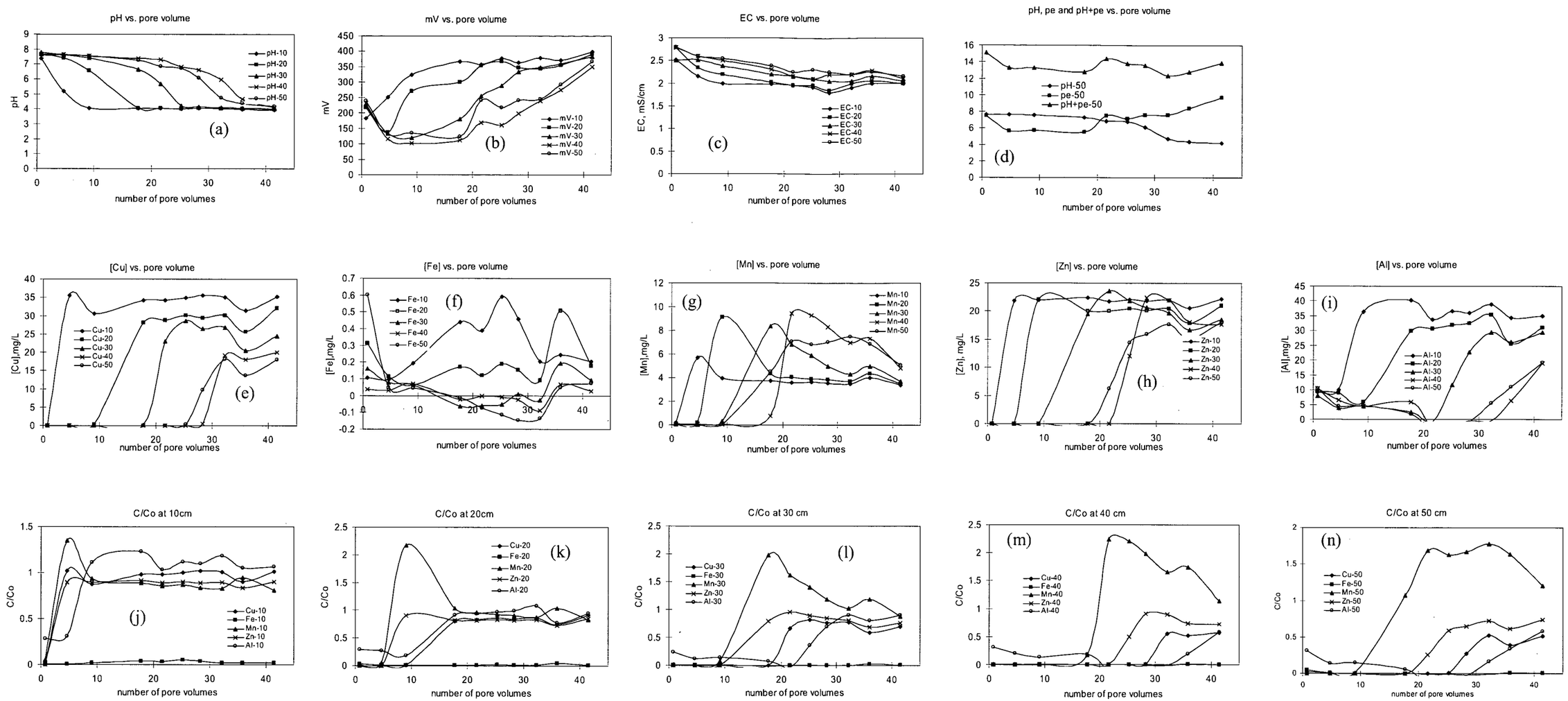

Figure 6.1 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell with bulk clinoptilolite, non-filtered natural ARD, and flow rate of 1 m/day. (column ID: NTNFC1)

6.2 Column Leaching Tests (II) – Pretreated Clinoptilolite

Mn leached from the bulk clinoptilolite when it was in contact with acidic drainages (Section 6.1). To minimize the leaching of Mn, pretreatment of the clinoptilolite was attempted. Pretreatment using 1M NaCl minimized the subsequent leaching of impurity cations, such as Mn, from the surface of the clinoptilolite. Subsequent to this finding, pretreated clinoptilolite was used for the following series of leaching cells tests to observe the improvement in the performance of clinoptilolite.

6.2.1 Leachate analyses

Chemical characteristics included the pH, redox potential expressed in millivolts (mV), electrical conductivity in mS/cm, and the sum of pH and pe, which would help predict the forms of metals present in the water sample. The change of concentrations of Cu, Fe, Mn, Zn and Al at the various depths along the columns are also presented. Followed by the change in the effective concentration (concentration at the sample/initial concentration present in the influent) of the metal species with time (breakthrough curves). The results of the changes in the chemical characteristics in the leachate obtained from the sampling ports along the leaching cells at different time (expressed in pore volumes) are shown in Figure 6.2 to 6.15.

The performances (in terms of breakthrough time of each metal species) of the clinoptilolite in the leaching cells based on results shown in Figure 6.2 to Figure 6.15 are compared in the following design parameters:

i) Clinoptilolite with pretreatment vs. bulk clinoptilolite (non-treated);

ii) Flowrates of 0.5 m/day (typical flowrate) vs. 1.5 m/day (high flow);

iii) Mine drainage of original concentration vs. maximum design concentration;

iv) Non-filtered (with presence of precipitates) vs. filtered mine drainage (no precipitates).

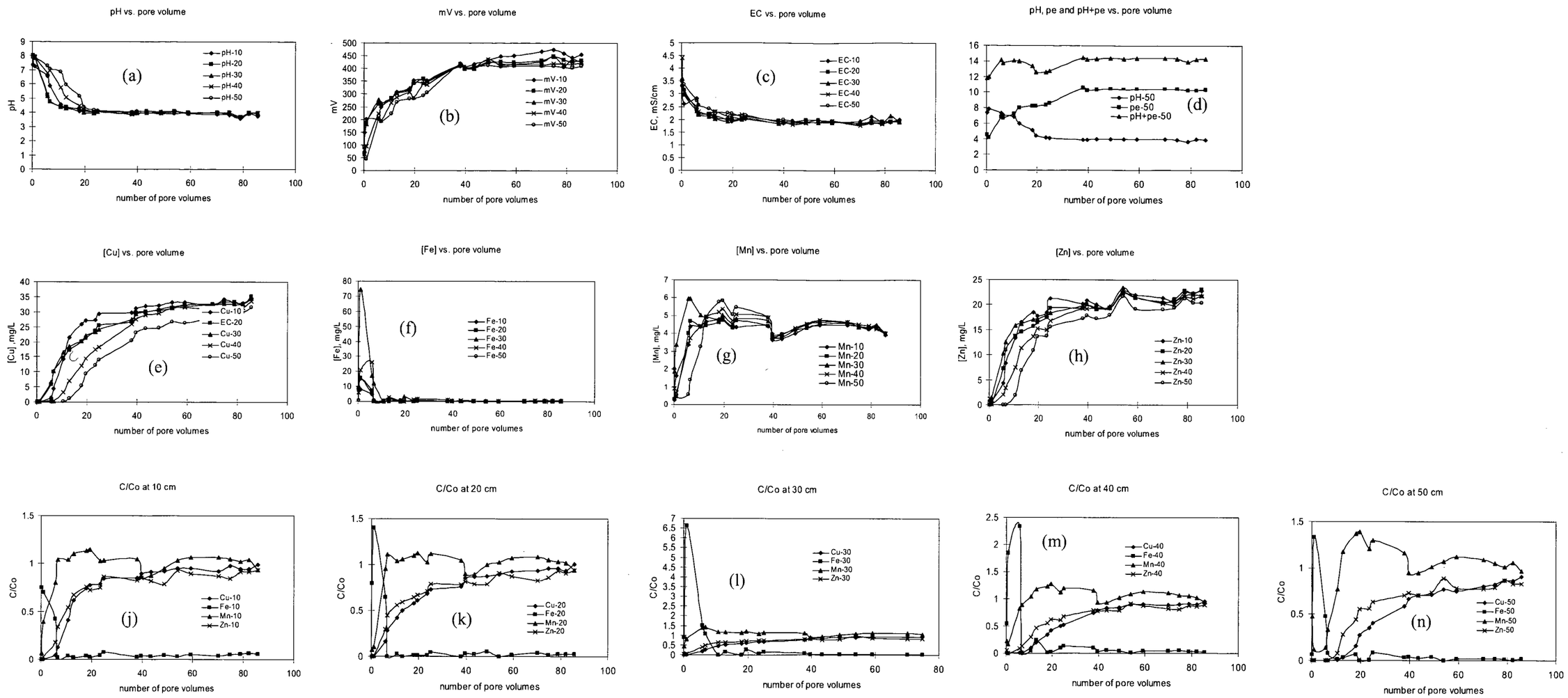

Figure 6.2 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; and (h) concentration of Zn, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered natural ARD, and flow rate of 1.5 m/day. (column ID: PTB1C1)

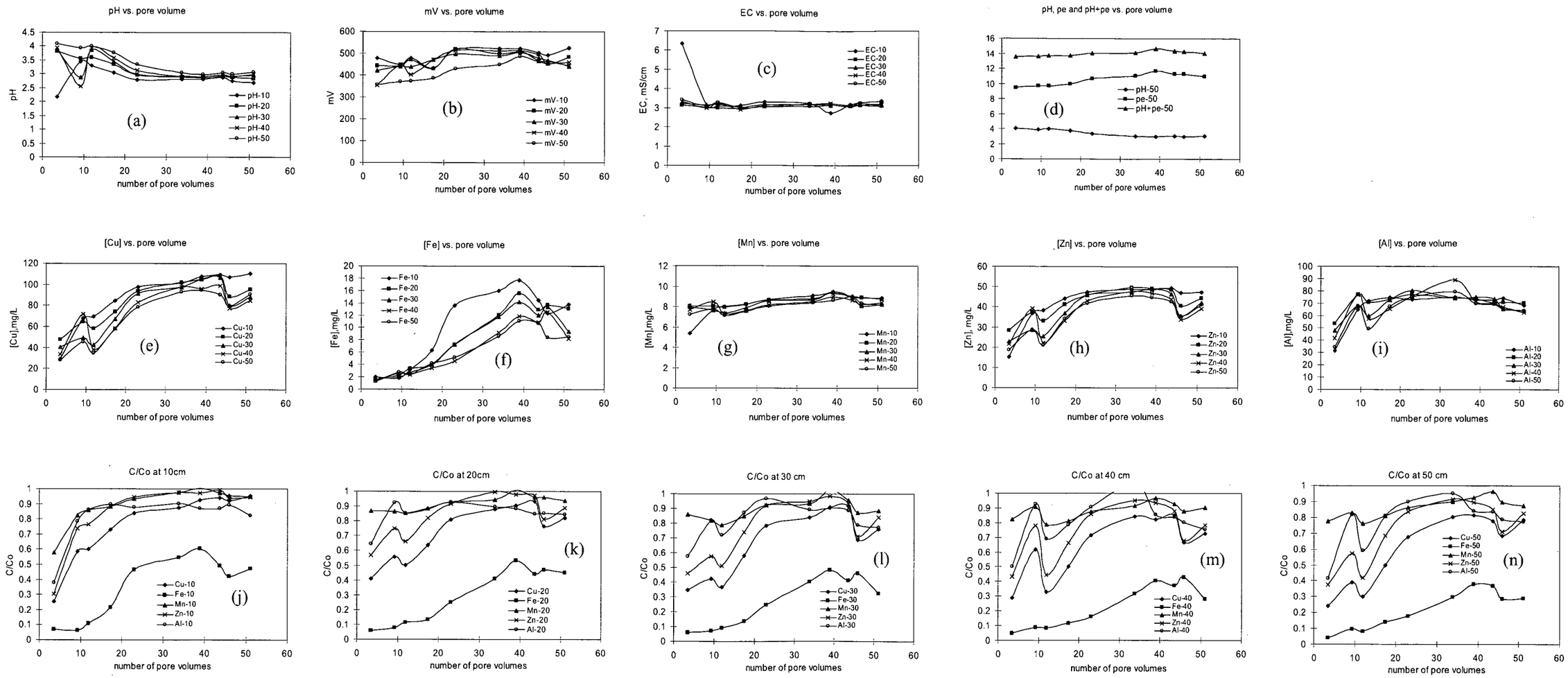

Figure 6.3 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD of maximum design concentration, and flow rate of 1.5 m/day. (column ID: PTB3)

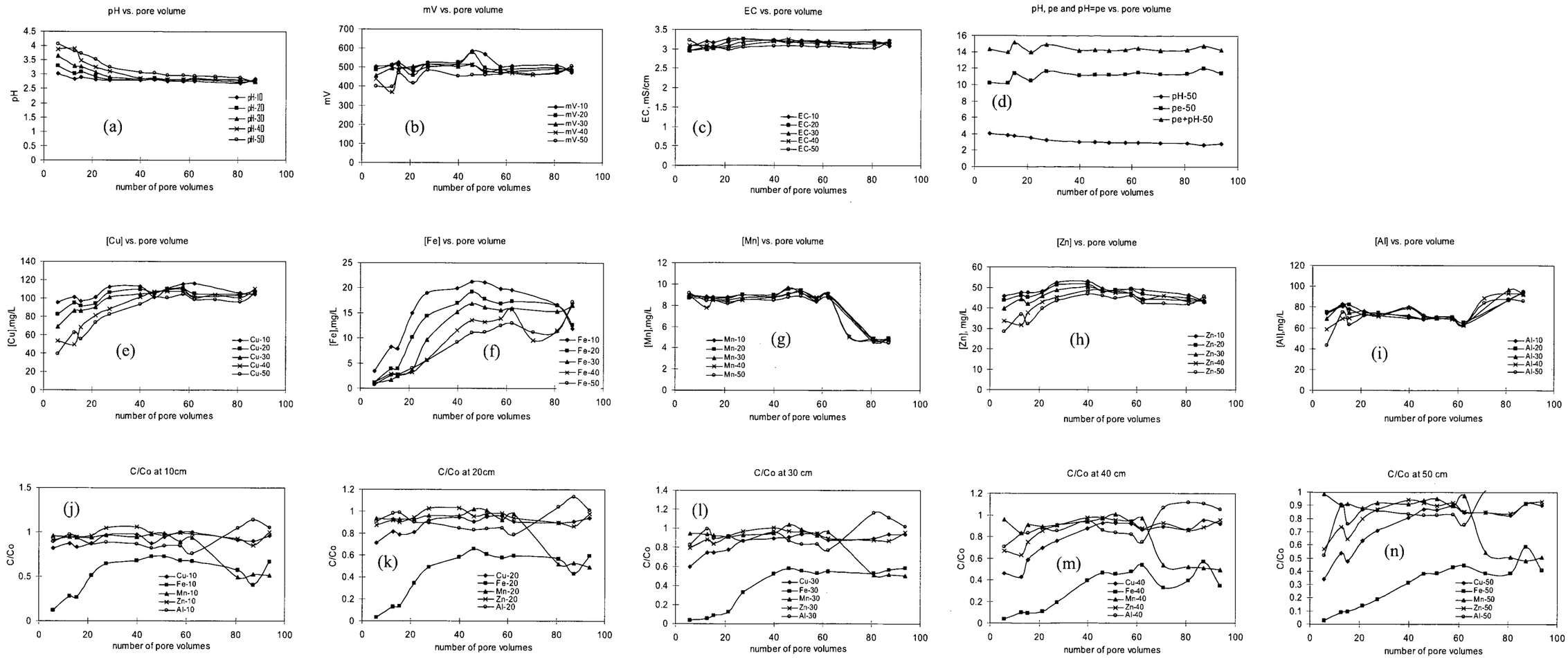

Figure 6.4 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD of maximum design concentration, and flow rate of 1.5 m/day. (column ID: PTB4)

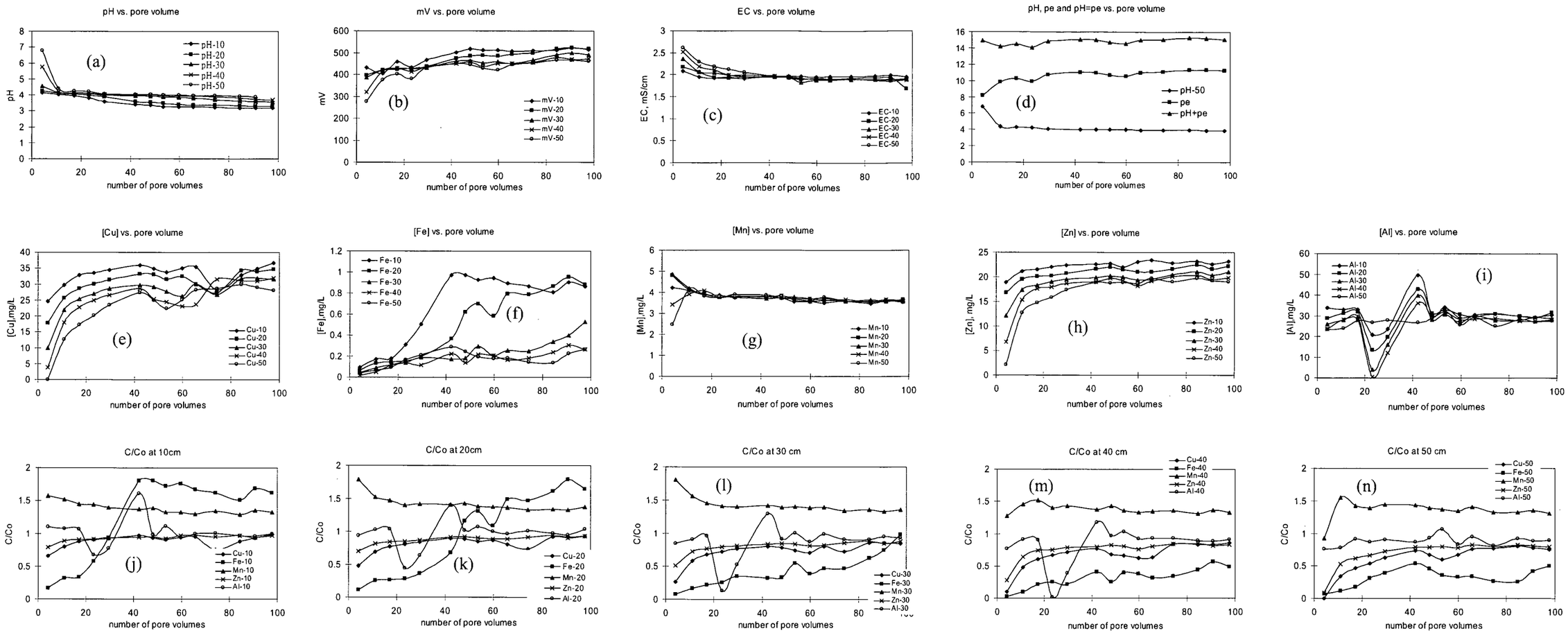

Figure 6.5 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 1.5 m/day. (column ID: PTB5)

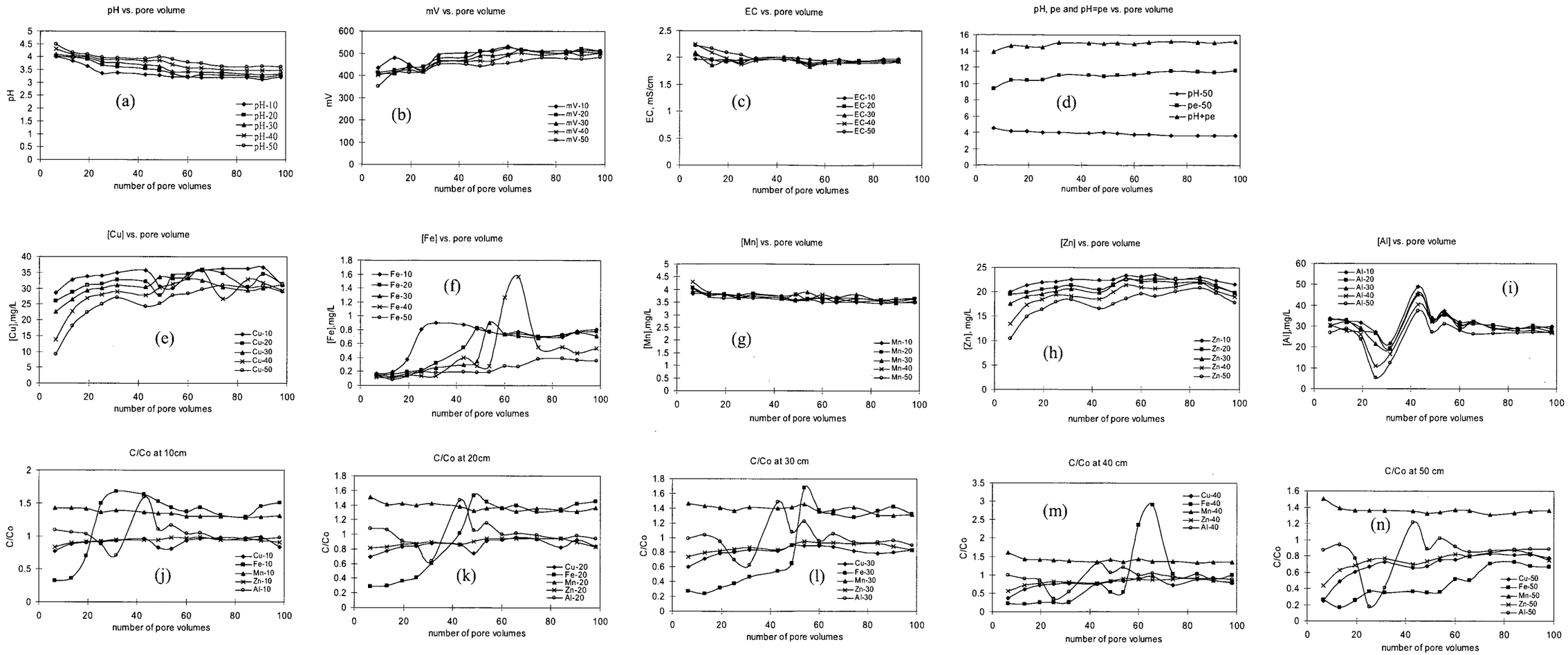

Figure 6.6 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 1.5 m/day. (column ID: PTB6)

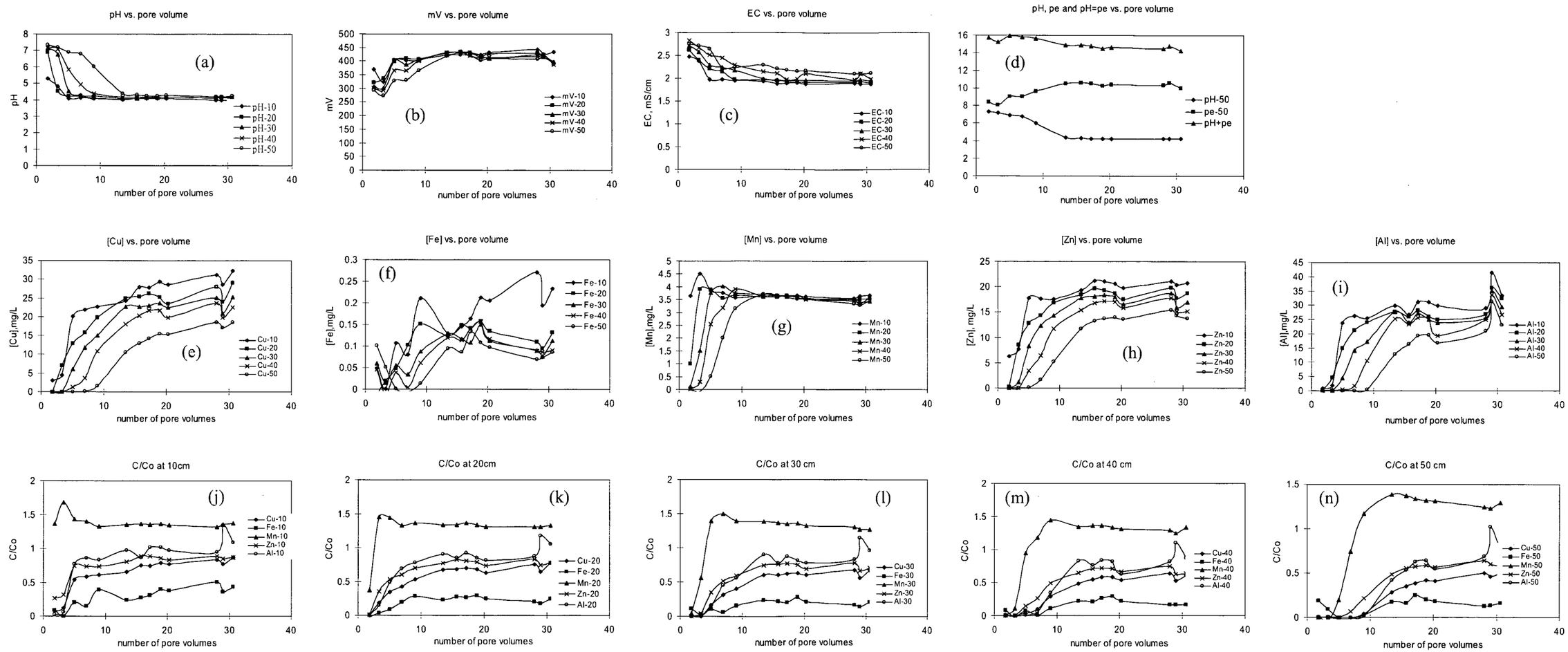

Figure 6.7 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 0.5 m/day. (column ID: PTB8)

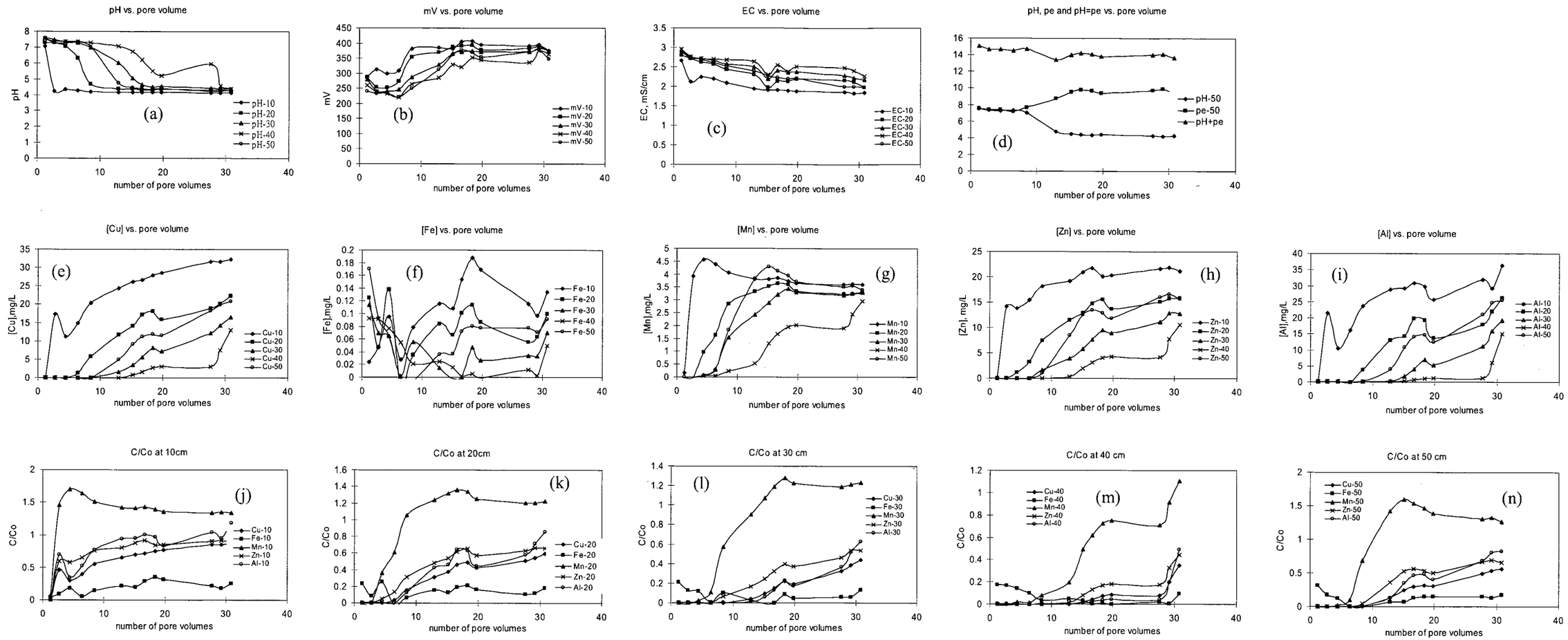

Figure 6.8 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 0.5 m/day. (column ID: PTB9)

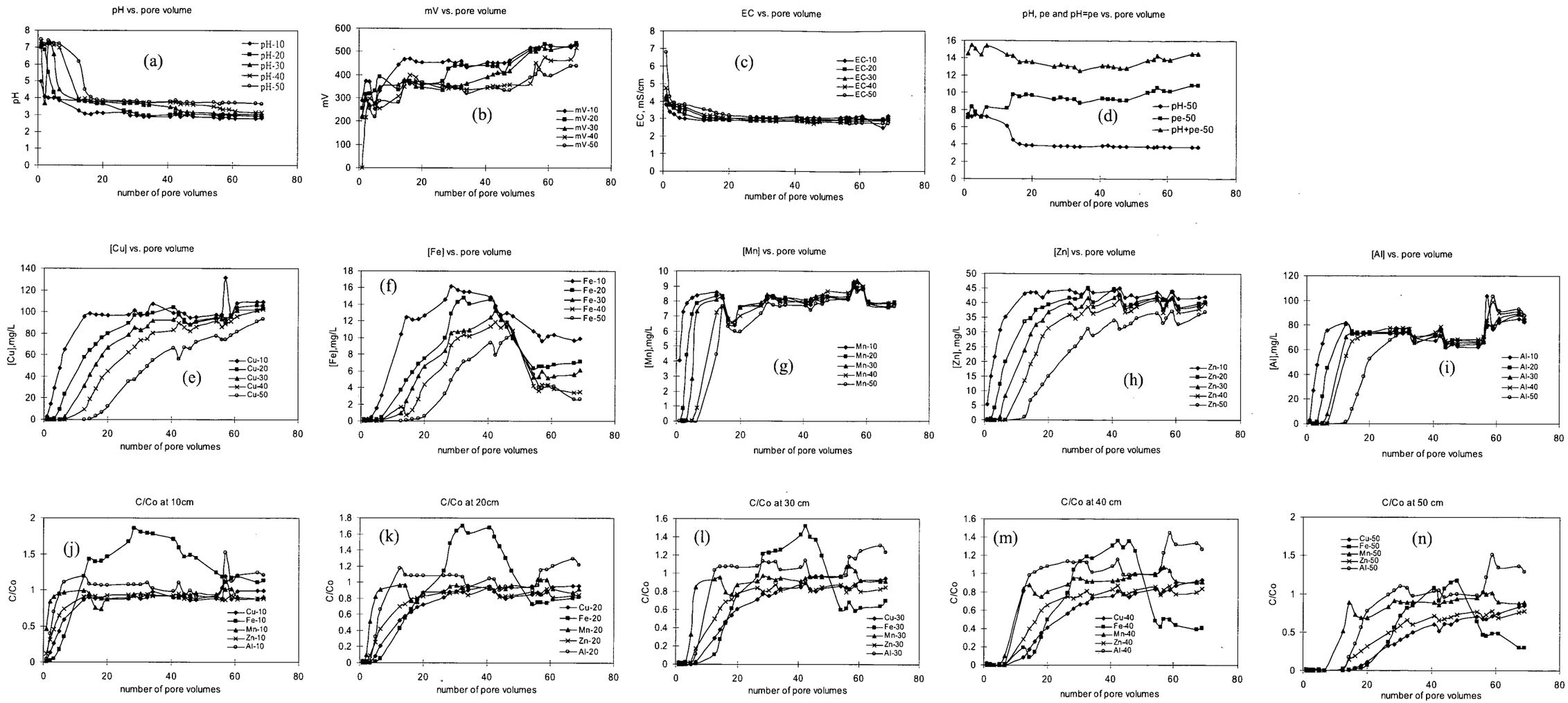

Figure 6.9 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (column ID: PTB11)

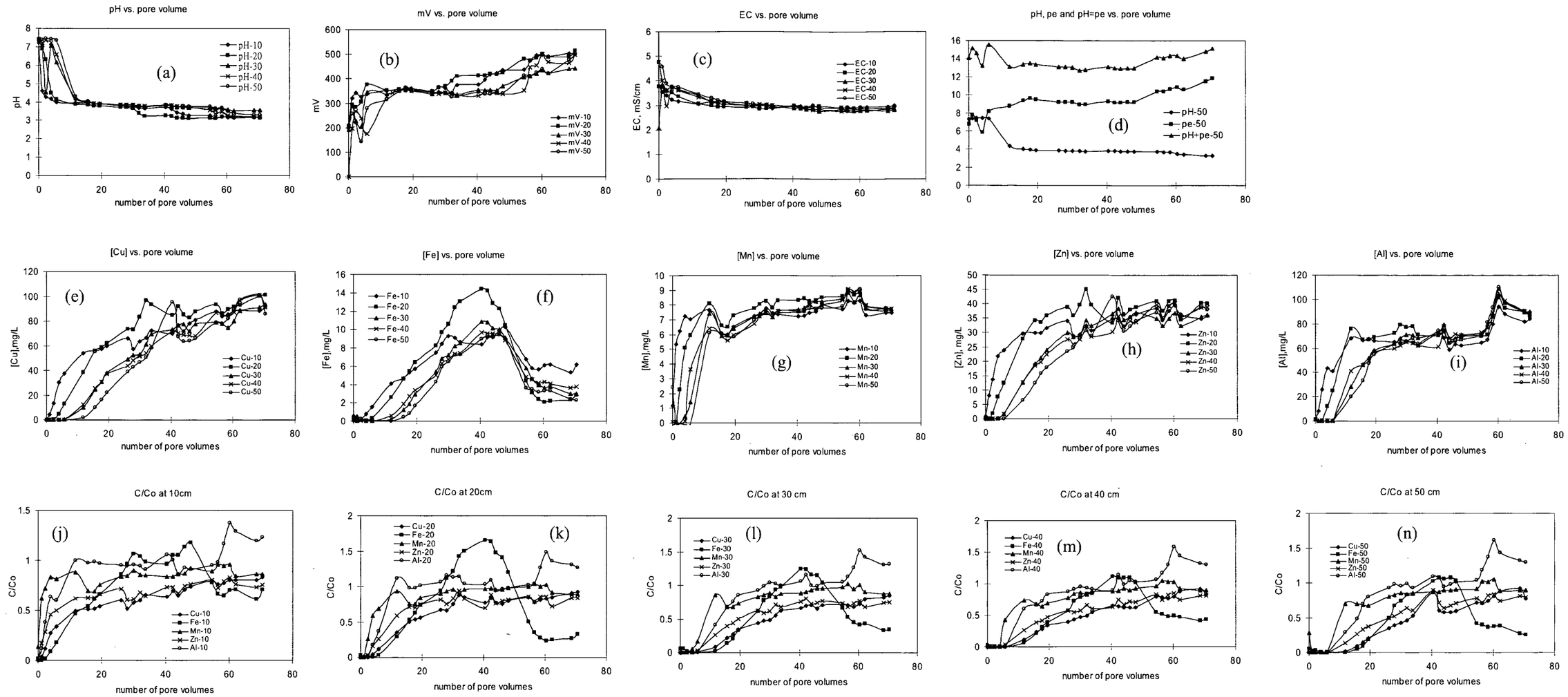

Figure 6.10 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (column ID: PTB12)

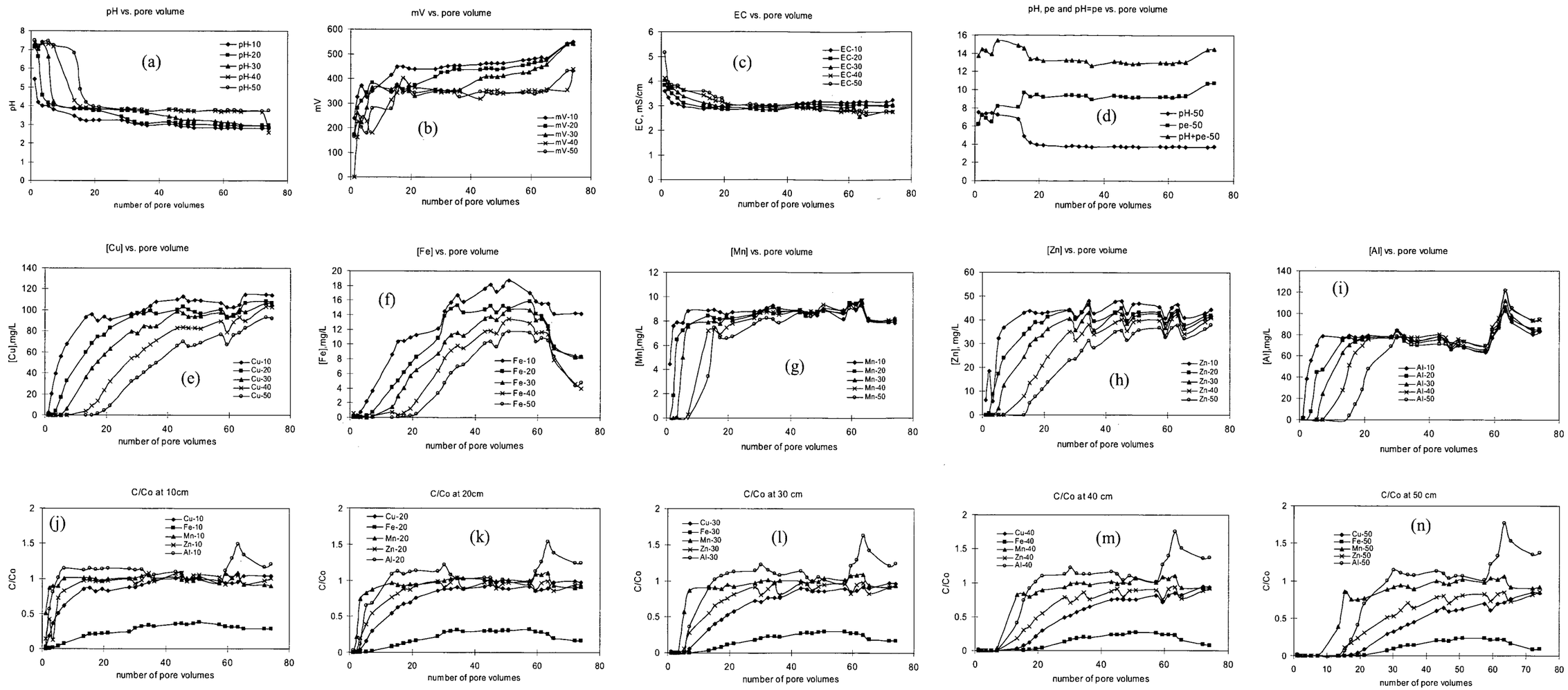

Figure 6.11 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (column ID: PTB13)

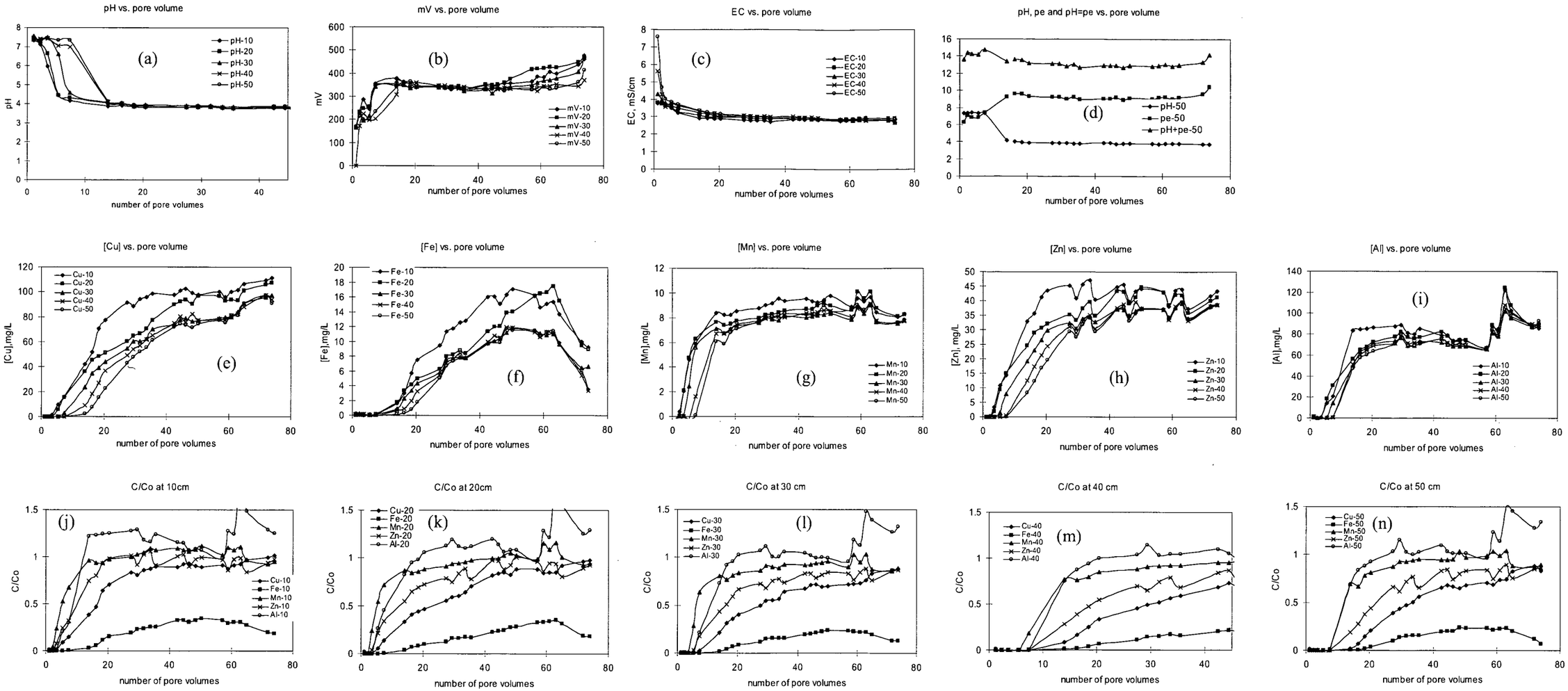

Figure 6.12 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered ARD with maximum design concentration, and flow rate of 0.5 m/day. (column ID: PTB14)

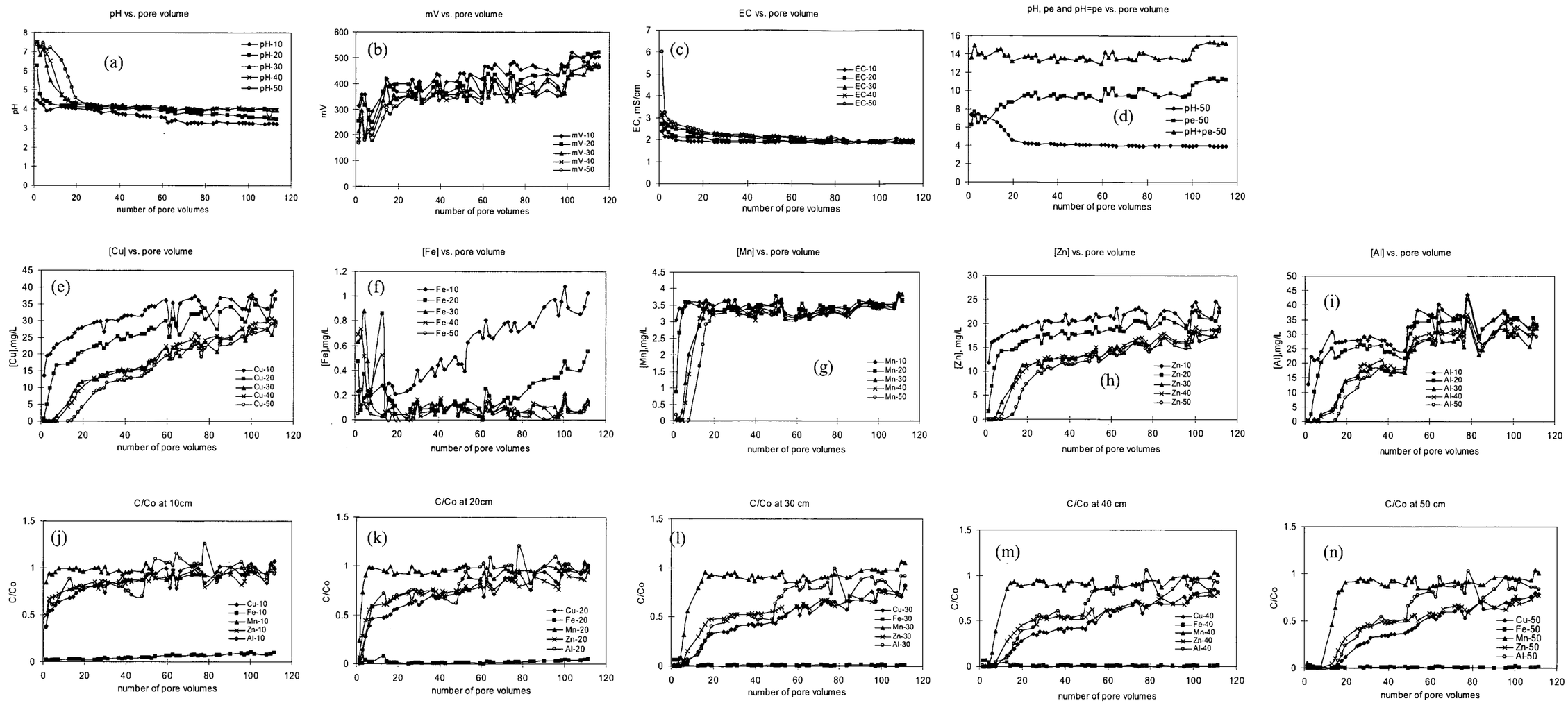

Figure 6.13 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 10cm; (k) 20 cm; (l) 30 cm; (m) 40 cm; and (n) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered natural ARD, and flow rate of 0.5 m/day. (column ID: PTB15)

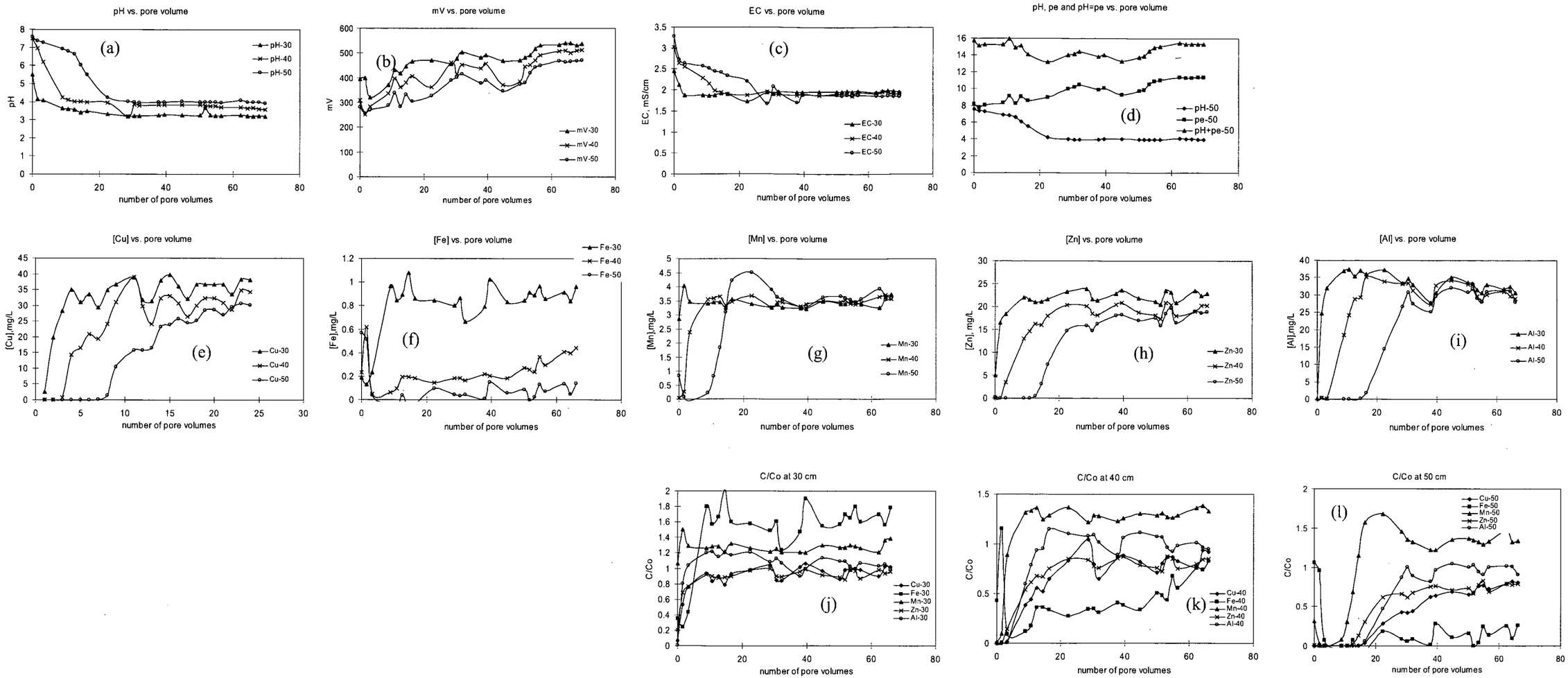

Figure 6.14 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 30 cm; (k) 40 cm; and (l) 50 cm for leaching cell 1M NaCl treated clinoptilolite, filtered natural ARD, and flow rate of 0.5 m/day in a packed bed system. (column ID: PTB17)

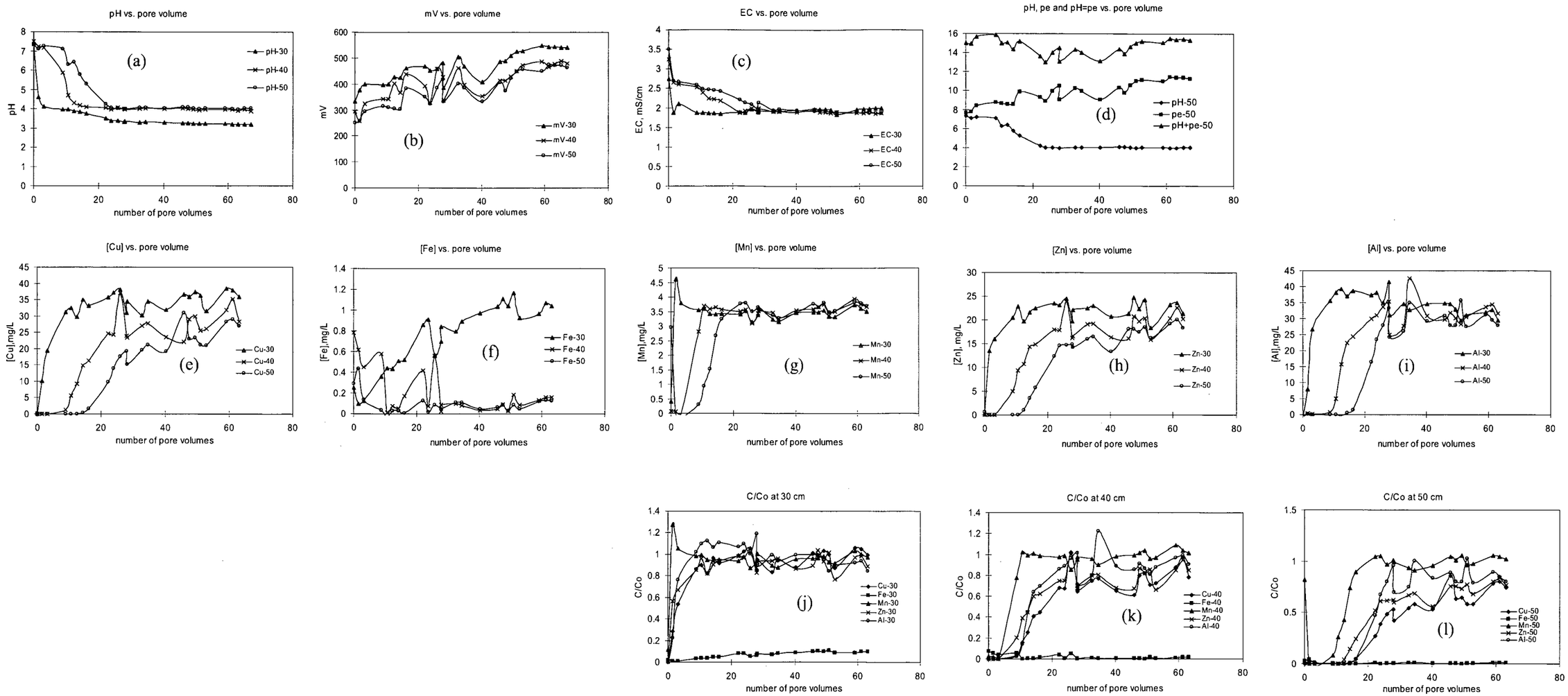

Figure 6.15 The change in chemical characteristics in water sample from sampling ports along the leaching cell with pore volumes for: (a) pH; (b) redox potential, mV; (c) specific electrical conductivity, mS/cm; (d) pH and pE at outlet; (e) concentration of Cu, mg/L; (f) concentration of Fe, mg/L; (g) concentration of Mn, mg/L; (h) concentration of Zn, mg/L; and (i) concentration of Al, mg/L. Breakthrough curves for metals at: (j) 30 cm; (k) 40 cm; and (l) 50 cm for leaching cell 1M NaCl treated clinoptilolite, non-filtered natural ARD, and flow rate of 0.5 m/day in a packed bed system. (column ID: PTB18)

A summary of the design parameters of the column leaching cell tests and the chemical characteristics of the leachates at equilibrium are shown in Table 6.1.

Table 6.1 Summary of the design parameters of the column leaching cell tests and the chemical characteristics of the leachates at equilibrium.

Figure no.	*6.1*	*6.2*	*6.3&6.4*	*6.5&6.6*	*6.7&6.8*	*6.9&6.10*	*6.11&6.12*	*6.13*	*6.14*	*6.15*
ARD	Natural	Natural	Max	Natural	Natural	Max	Max	Natural	Natural	Natural
Filtering	No	No	Yes	Yes	Yes	Yes	No	No	Yes	No
Pretreatment w/ 1M NaCl	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flowrate (m/day)	0.99	1.3	1.3	1.5	0.50	0.52	0.54	0.47	0.42	0.40
Total # pv	41.5	85.7	72.5	97.9	30.7	69.7	74.0	115	69.6	67.0
pH	4.0	4.0	2.7	3.5	4.05	3.0	3.15	3.2	3.0	3.0
Eh, mV	370	430	455	465	410	460	430	350	350	350
EC, mS/cm	2.0	2.0	3.0	1.9	1.9	2.8	2.7	1.9	1.9	1.9
[Cu], mg/L	38	32	14.5	17	28.8	34	36.5	59	34	29
[Fe] , mg/L	-	-	-	50	-	27	-	-	-	-
[Mn] , mg/L	13	7.5	0	1.0	6.75	11	13.3	13	12	13
[Zn] , mg/L	24	20	9.25	9.5	15.75	27.5	25.25	45	21	22
[Al] , mg/L	39.5	-	5.5	0	19.25	17	16	38	23	22.5

Clinoptilolite with pretreatment (treated clinoptilolite) vs. bulk clinoptilolite (non-treated)

As anticipated, pretreatment of clinoptilolite minimized the leaching of Mn from the surface of the clinoptilolite to the effluent.

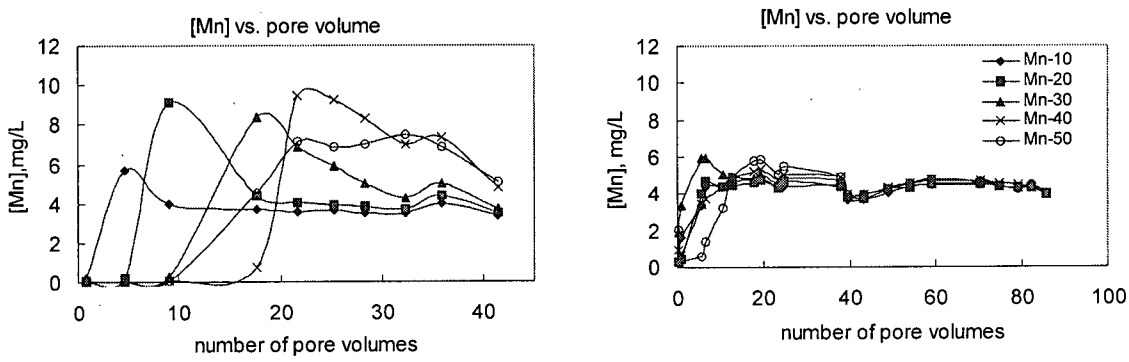

Figure 6.16 Concentration of Mn in the water sample in (a) bulk clinoptilolite – without pretreatment, (b) clinoptilolite after 1M NaCl pretreatment

The maximum concentration of Mn, Figure 6.16b, in the pretreated clinoptilolite column leaching test, is significantly lower than that of those without pretreatment (Figure 6.16a). The

peaks of Mn at each sampling port were eliminated in the pretreated soil column. However, the breakthrough time for the Mn was shorter for pretreated clinoptilolite than the bulk clinoptilolite and the breakthrough concentration was the same. Concentration of Mn reaches 50% of its influent concentration at 7.5 pore volume, whereas bulk clinoptilolite achieved a breakthrough at 13 pore volumes.

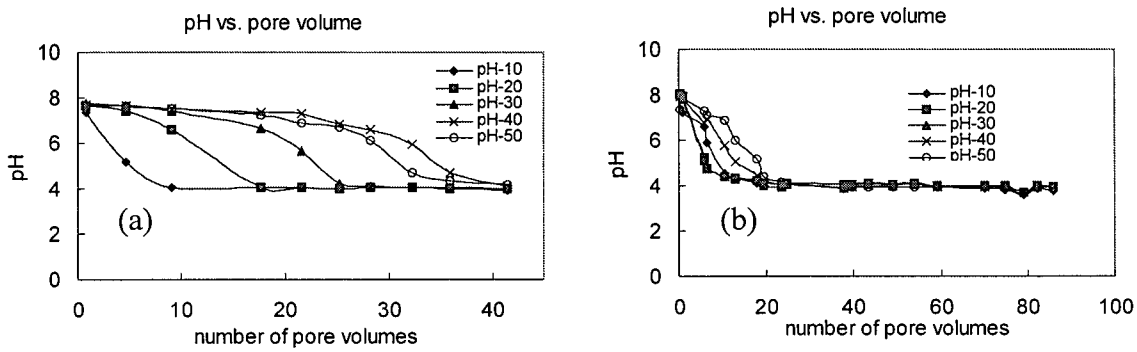

Figure 6.17 pH of the water sample in (a) bulk clinoptilolite – without pretreatment, (b) clinoptilolite after 1M NaCl pretreatment

Figure 6.17 indicates that the pH of the effluent in the treated clinoptilolite column at all depths reached a pH of 4 after 20 pore volumes, where as the pH of effluent in the non-treated column reached a pH of 4 after 40 pore volumes. This implies that the exchange of OH^- from the surface of the clinoptilolite has decreased after pretreatment. This may also imply that retention mechanisms of the pretreated clinoptilolite were primarily ion exchange and surface complexation, rather than precipitation with OH^- ions, due to the low availability of the OH^- groups.

During the pretreatment of the clinoptilolite, a significant amount of "impurities" on the bulk clinoptilolite were removed (Section 4.2.2 and Table 4.8). These impurities may include oxides or hydroxides, or other secondary minerals. The reduced adsorption sites associated

with the secondary minerals might have led to a reduction in Mn retention on the pretreated clinoptilolite. Although pretreatment of the clinoptilolite has slightly reduced the retention capacity of Mn onto the clinoptilolite, pretreatment is recommended. The reason is that reduction of Mn ion would minimize the deposition of Mn (>6 mg/L) from the surface of clinoptilolite when it is in contact with the groundwater plume, which may cause adverse effects to the receiving waters and aquatic life.

Flow rates of 0.5 m/day (typical flow rate) vs. 1.5 m/day (high flow)

Flow rate is an important factor on the retention of metals on the clinoptilolite. There is a general trend that the faster the flow rate of the leachate, the smaller the breakthrough volume before metal ions were detected.

Table 6.2 Comparison of breakthrough volume at different flow rates

ARD		**Natural ARD**		**ARD with maximum design concentration**	
filtering		Yes		Yes	
Flowrate (m/day)		**High**	**typical**	**High**	**typical**
		1.49	**0.50**	**1.31**	**0.52**
# pv conducted		97.93	30.725	72.45	69.7
Equilibrium pH		3.5	4.05	2.7	3
Equilibrium mV		465	410	455	460
Equilibrium EC		1.9	1.9	3	2.8
# of pore volumes at breakthrough	**[Cu]**	17	28.75	14.5	34
	[Fe]	50	-	-	27
	[Mn]	1	6.75	0	11
	[Zn]	9.5	15.75	9.25	27.5
	[Al]	0	19.25	5.5	17

Table 6.2 shows the comparison of the breakthrough volume in leaching cells with similar flow rates, but different chemical concentrations. The set of experiments for leaching cells was conducted with filtered natural ARD, the results indicated that Cu reached breakthrough after 17 pore volumes at a flow rate of 1.5 m/day, whereas at a flow rate of 0.5 m/day ARD, the breakthrough volume of Cu was 29 pore volumes. The same observation was found for Mn, Zn

and Al. The concentration of Fe was very low (< 0.1 mg/L) in the leachate, which is due to the precipitation of Fe at pH ≥ 4. When ARD was introduced to the column leaching cell and the leachate was neutralized by the secondary minerals and the OH^- on the surface of the clinoptilolite, Fe precipitation would be expected. This agrees with the results stated in Section 5.1.2. The form in which Fe was present could be found from the relationship between pH and Eh for mineral equilibria in water containing iron oxides and sulfides. Based on the pH/pe diagram for mineral equilibrium, and the conditions of this experimental studies, Fe was present as hematite (Fe_2O_3) (Garrels and Christ 1965; Lindsay 1979).

In the case of the 0.5 m/day flow rate, elevated Fe concentration was found after 50 pore volumes. Elevated amounts of Fe found in the effluent might be the result of the saturation of Fe in the pore fluid, hence increased amounts of Fe in the effluent. The form of Fe attached onto clinoptilolite will be discussed in the following Section 6.2.2.

The same trend appeared in the leaching columns with filtered ARD at maximum design concentration. Cu breakthrough at 14.5 pore volumes at 1.3 m/day of flow and at 34 pore volumes at 0.52 m/day of flow. Similar trends have been found with the other major metal cations in the ARD.

The shorter breakthrough time of Cu agrees with the results obtained in the retention kinetics of the clinoptilolite as described in Section 5.2. Results also indicated that columns with slower flow rates had a higher equilibrium pH at the outlet of the column leaching cell. The results signified that at slower flow rate, metal cations are able to attach to species other than the OH^- ions in the solution for retention. The form with which the metals associated will be discussed in the subsequent Section 6.2.2 on soil analyses. At slower flow rates, adequate contact time between the free ions in the solution and the surface of the soil particle results in an increase in the retention ability (within the time frame of the test).

Mine drainage of original concentration as obtained at the mine site vs. maximum design concentration

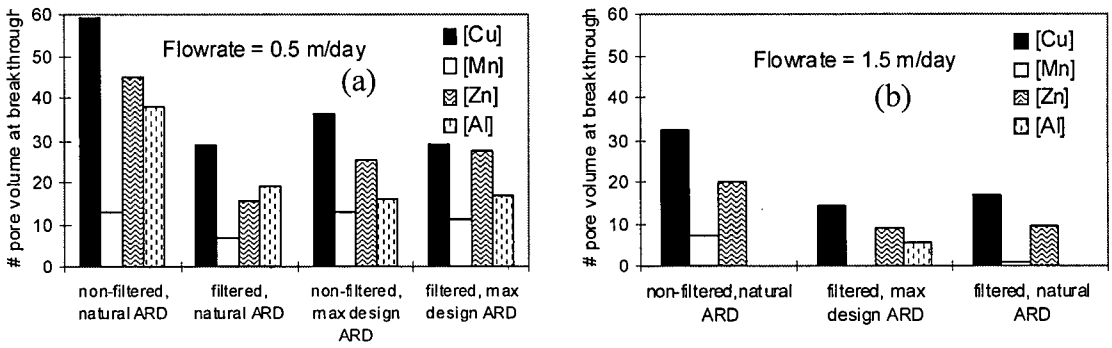

Figure 6.18 Comparison of breakthrough volume with various ARD concentrations in columns of flow rates: (a) 0.5 m/day; (b) 1.5 m/day

Figure 6.18 indicates that it takes a longer time for metal ions to reach breakthrough concentration when associated with natural ARD than with the ARD of maximum design metals concentrations. This may be explained by the fact that there was a larger amount of free metal cations in the maximum design concentration leachate than in the natural ARD. Under the same flow rate, the adsorption sites might be taken up by the metal in the higher concentration leachate sooner. Thus, the breakthrough of metal concentrations would be faster with the maximum design concentration ARD than with the natural ARD. Since only a finite number of adsorption sites were available on the clinoptilolite surface for metals ions, once the adsorption sites were occupied, there will be competition between the ions to take up the available adsorption sites and replacements of ions by those that have a greater affinity to the surface (Sparks, 1995).

Non-filtered mine drainage (with presence of precipitates) vs. filtered mine drainage (no precipitates)

A comparison of the breakthrough volume between the filtered and non-filtered natural ARD at flow rate of 0.5 m/day is presented in Table 6.3. With non-filtered leachate, the time for

the effluent concentration of the metal ions to reach 50% of the influent concentration was longer. Table 6.3 indicates that clinoptilolite columns with non-filtered ARD have a longer breakthrough time than that with filtered ARD at both 0.5 m/day and 1.5 m/day flow rates.

Since non-filtered leachate contains precipitates composed of 64% iron oxide and 32% loss of ignition materials (Appendix B-2), metals from the leachate could attach to the surface or be complexed with these metal oxides in the precipitates. As such, a larger number of pore volumes and longer time would be required to reach chemical breakthrough in the column filled with non-treated clinoptilolite.

Table 6.3 Comparison of breakthrough volume between the filtered and non-filtered ARD at 0.5 m/day

Filtering		yes	no
Flowrate (m/day)		0.5	0.471
# pv conducted		30.725	115.03
Equilibrium pH		4.05	3.2
Equilibrium Eh (mV)		410	350
Equilibrium EC (mS/cm)		1.9	1.9
# of pore volume at breakthrough	**[Cu]**	28.75	59
	[Fe]	-	-
	[Mn]	6.75	13
	[Zn]	15.75	45
	[Al]	19.25	38

6.2.2 Analysis of clinoptilolite – post-leaching

As the chemical composition of the effluent reaches that of the influent, it indicates that the leaching cell system (the clinoptilolite) is in equilibrium with the leaching solution (ARD). In order to find out the partitioning of the metals on the clinoptilolite, selective sequential extractions and total digestion of the soil were conducted. Partitioning of the metals in the soil was determined by selective sequential extraction, in the forms of exchangeable ions, ionically bound with amorphous materials, Fe- and Mn- oxides, oxidizable compounds and residual

fractions respectively (Tessier, Gampbell et al. 1979). Results were compared to those obtained from total digestions for percentage metal recovery and quality assurance/quality control purposes (Appendix J1).

The amounts of metals extracted from the clinoptilolite represent the amounts attached to the soil during the contamination in the column leaching cell tests; however, this may also include some of those metals that were present on the clinoptilolite itself. Therefore, the amount of metals leached as a background concentration from the bulk and the pretreated clinoptilolite were determined and the results are shown in Figure 6.19.

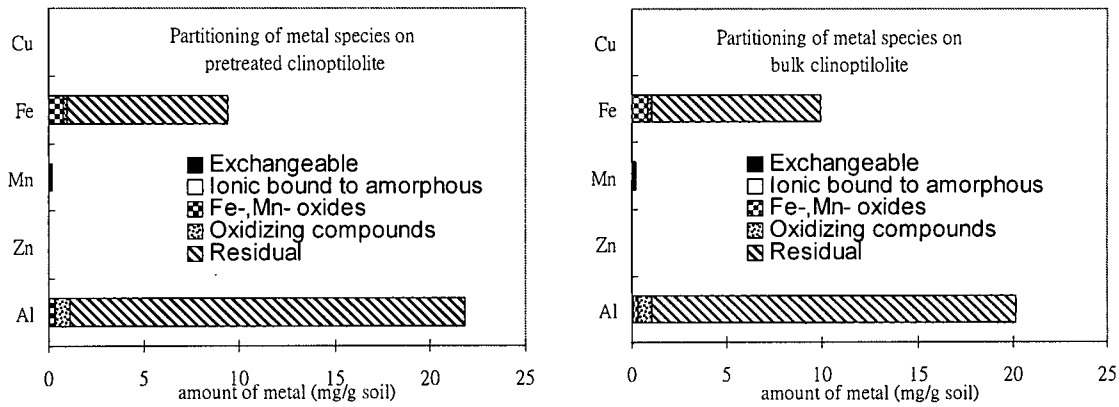

Figure 6.19 Partitioning of metals on (a) 1M NaCl pretreated clinoptilolite; (b) bulk clinoptilolite at ARD equilibrated condition

Approximately 10 mg of Fe was extracted from each gram of sample in sequential extractions and total digestion from the clinoptilolite, while most of the Fe was present in the residual form. About 20 mg of Al per gram of sample was also extracted from the clinoptilolite, whereas only minimal amounts of Cu, Mn and Zn leached from the clinoptilolite prior to the adsorption tests. These values of metal extracted will be used for background subtraction from metal extractions of the tested clinoptilolite. The results from the selective

sequential extraction and total digestions of the clinoptilolite shown in Figure 6.19 further confirm that the pretreatment of the clinoptilolite did not attack the residual crystalline structure of the clinoptilolite, nor dislodge any Fe or Al ions.

Comparison between metal retention of bulk clinoptilolite and pretreated clinoptilolite (1M NaCl) shows that a larger amount of metals was retained on the pretreated clinoptilolite. It was observed that a higher percentage of metals was present as exchangeable ions in the pretreated soil than in that without pretreatment. This may be explained by the pretreated clinoptilolite having been homogenized with Na^+ ions, the most readily exchangeable ions, instead of having on the surface many different types of ions with various affinities to the surface. The hetero-ionic surface would create more competition for the free ions in the leaching solution and would reduce the specific retention of a particular ionic species.

However, the percentage of which metals were attached to Fe- and Mn- oxides constitutes a larger portion in the non-treated (~50%) than in the pretreated (~40%) of the sum of the metals extracted from the selective sequential extraction. During pretreatment, many of the impurity surface cations were replaced by the Na^+ ions, including a large amount of Mn ions, which were found leached out from the bulk clinoptilolite. Hence, there was less Mn available for Mn-oxide bindings. The percentage of the partitioning of metals on both types of soils attached to oxidizable compounds and present in residual fractions was similar.

The partitioning and the amount of the each metal with each form present in clinoptilolite during column leaching tests are shown in Figure 6.20 to Figure 6.24. The partitioning of Cu and Zn are summarized in Table 6.4 and Table 6.5 respectively. Comparisons of the partitioning of each metal are given in terms of the design parameters between: (i) flow rates of 0.5 m/day (typical flow rate) vs. 1.5 m/day (high flow); (ii) mine drainage of original concentration as obtained at the mine site vs. maximum design concentration; and (iii)

non-filtered mine drainage (with presence of precipitates) vs. filtered mine drainage (no precipitates). Details of the results and the percentage of each fraction of metal are presented in Appendix H.

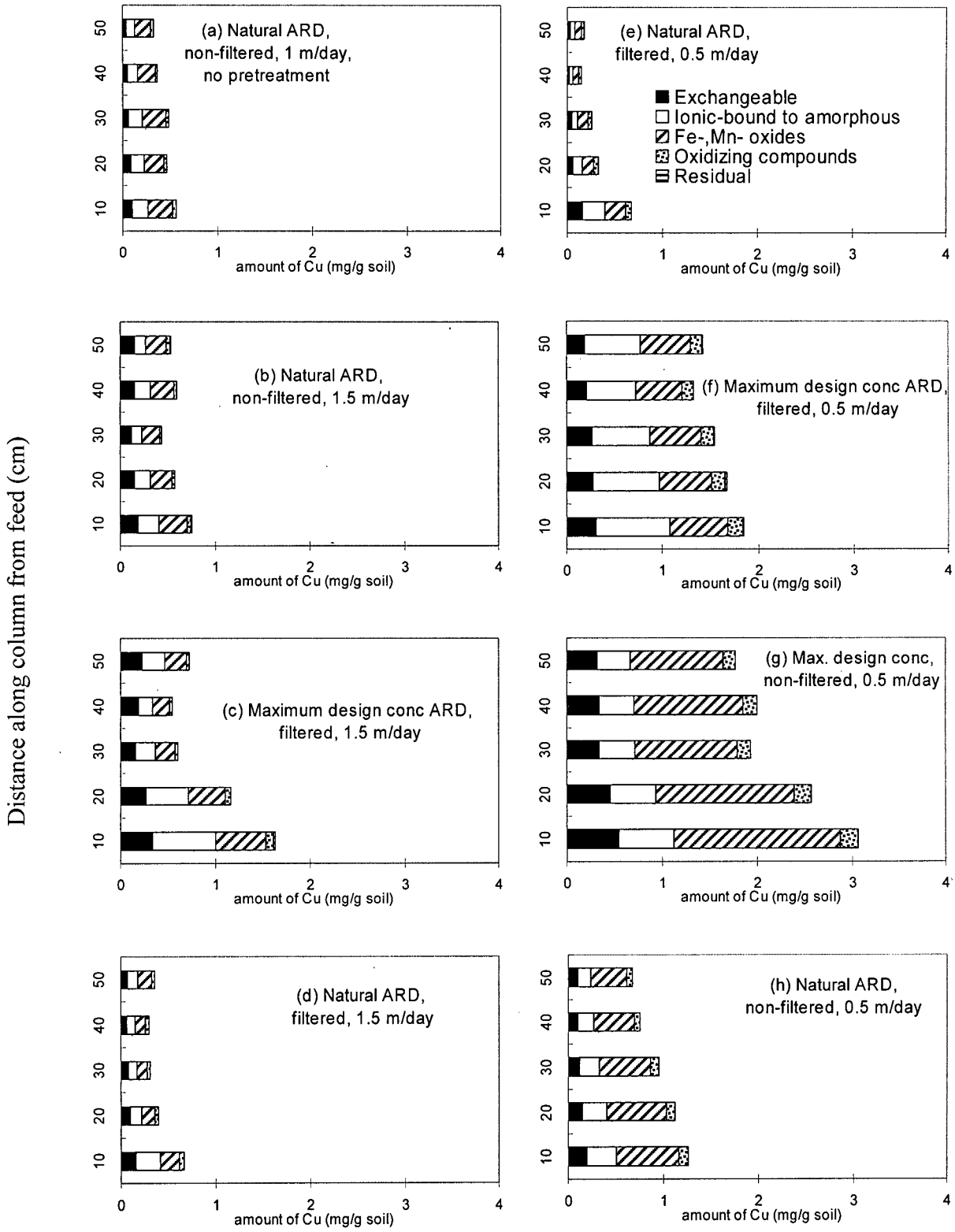

Figure 6.20 Partitioning of Cu in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day

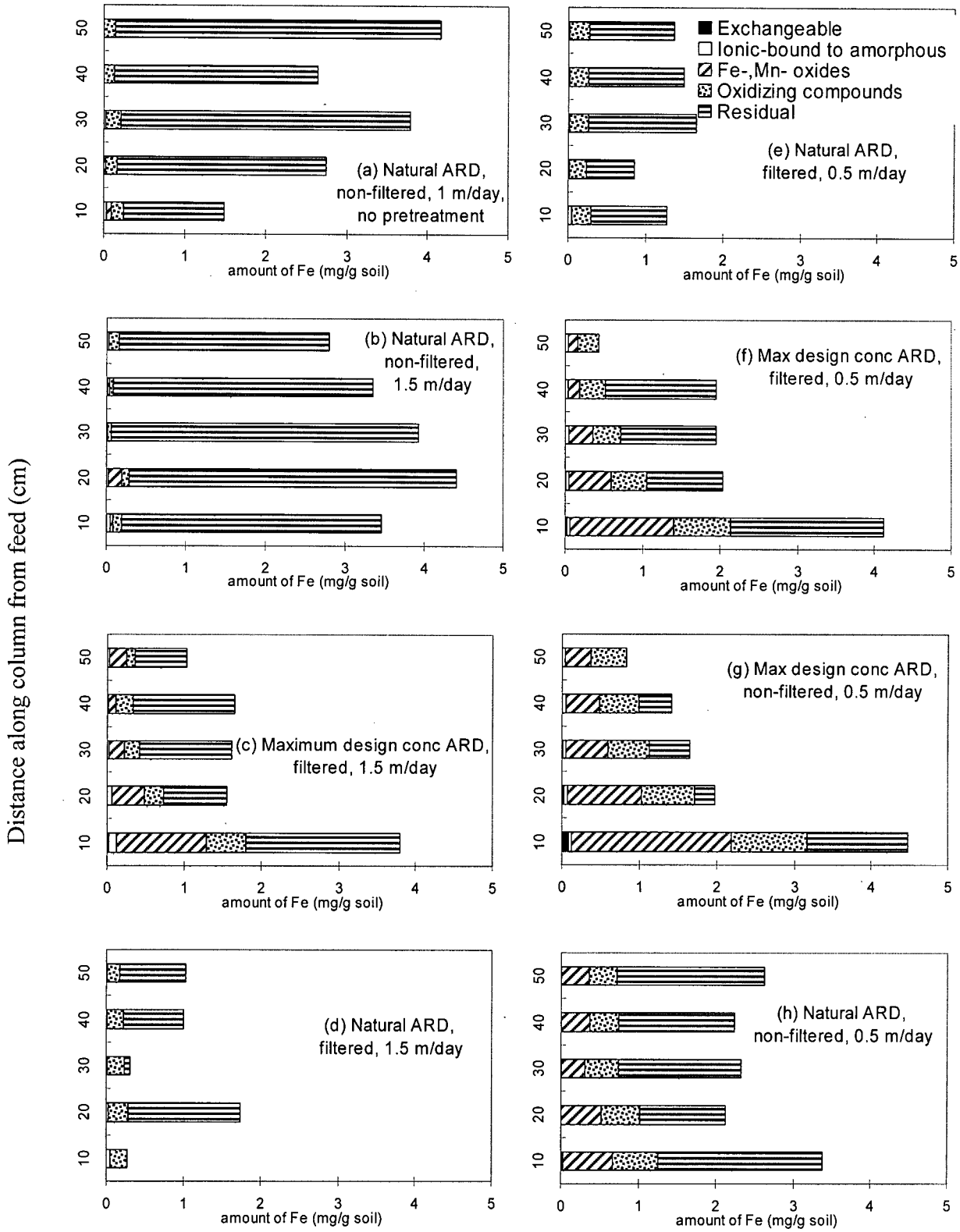

Figure 6.21 Partitioning of Fe in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day

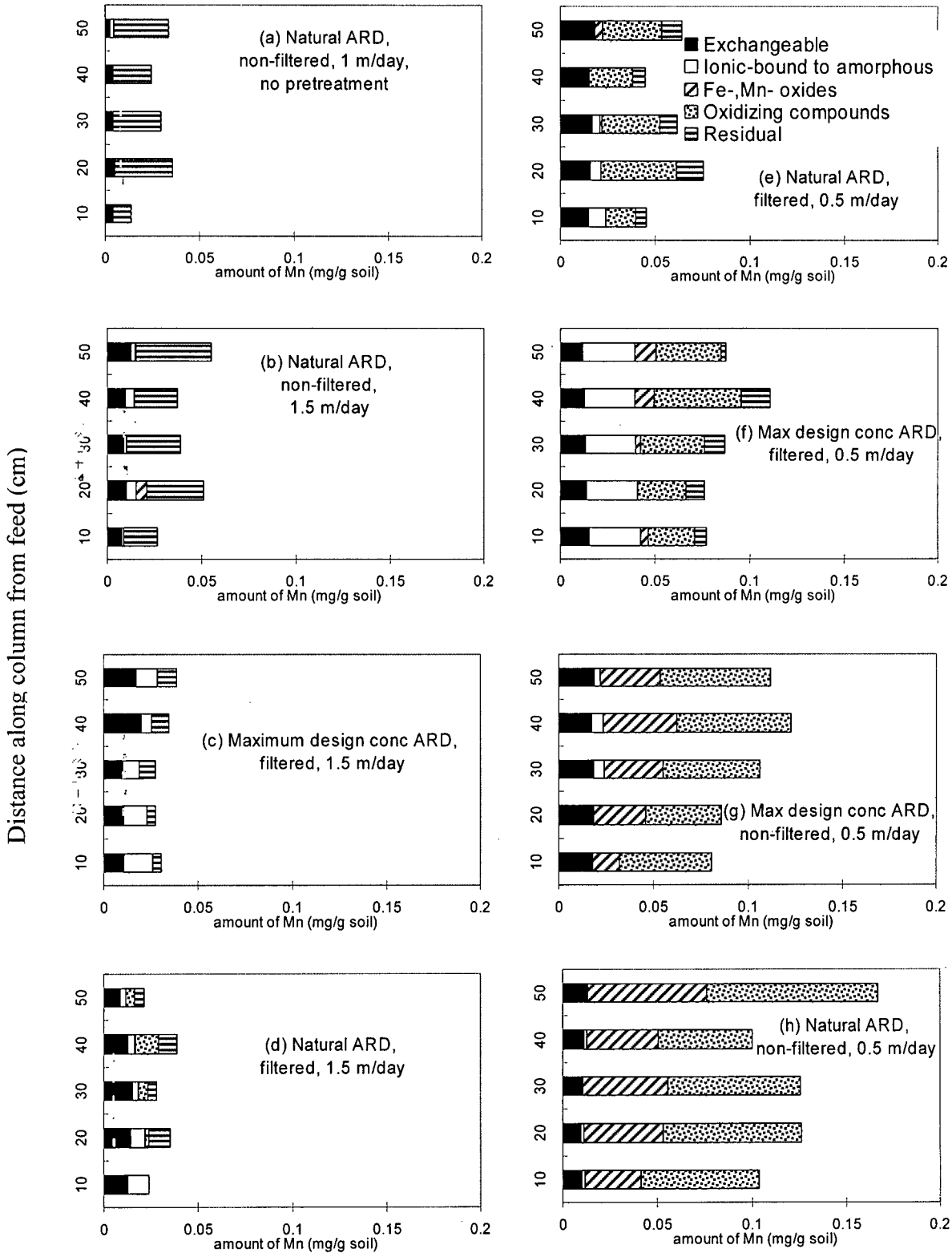

Figure 6.22 Partitioning of Mn in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day

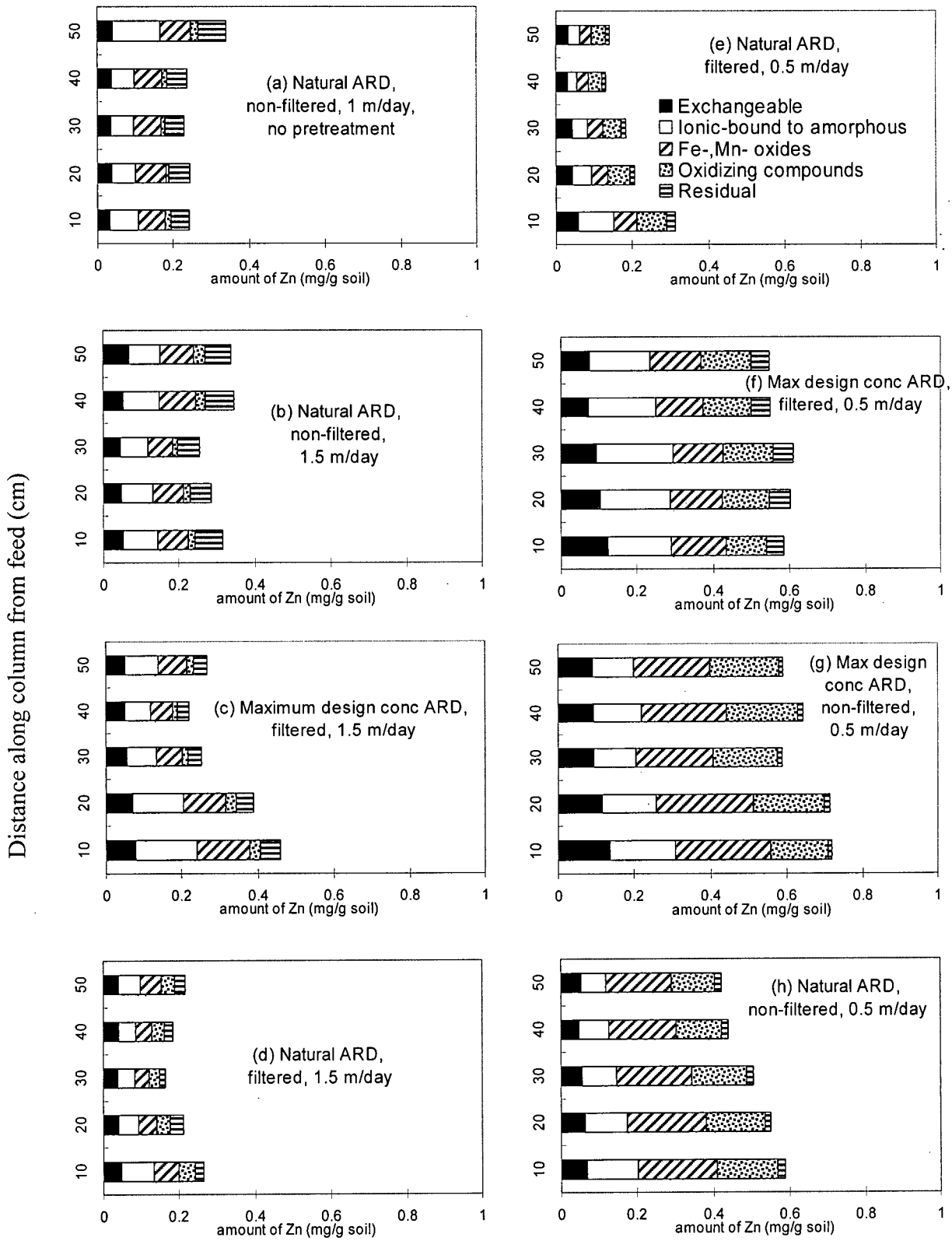

Figure 6.23 Partitioning of Zn in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day

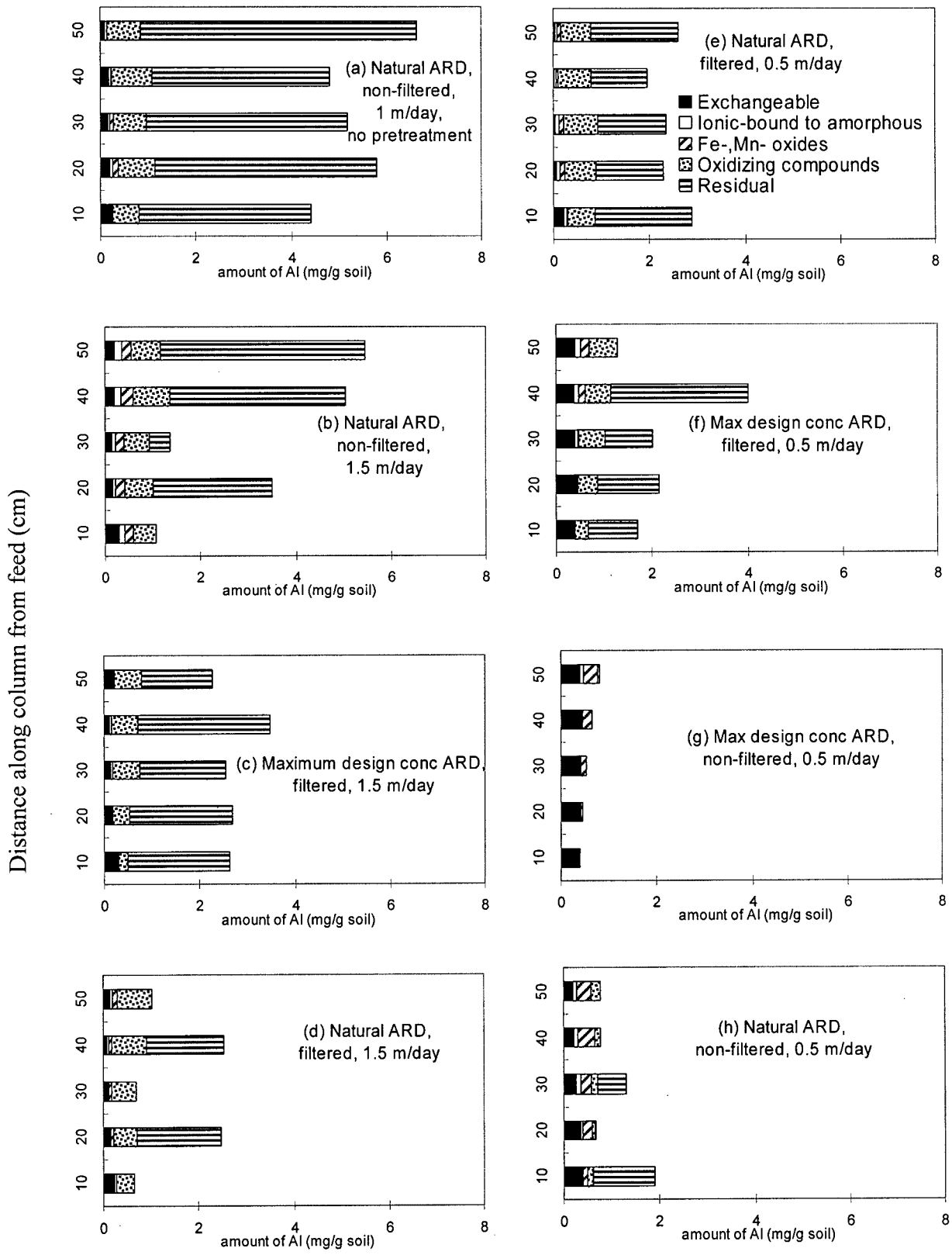

Figure 6.24 Partitioning of Al in the clinoptilolite at equilibrium from column leaching cell tests with conditions: (a) non-filtered natural ARD, 1 m/day, bulk clinoptilolite; treated clinoptilolite with (b) non-filtered natural ARD, 1.5 m/day, (c) filtered maximum design ARD at 1.5 m/day, (d) filtered natural ARD at 1.5 m/day, (e) filtered natural ARD at 0.5 m/day, (f) filtered maximum design ARD at 0.5 m/day, (g) non-filtered maximum design ARD at 0.5 m/day, (h) non-filtered natural ARD at 0.5 m/day

Retention of copper

The largest amount of Cu was retained on clinoptilolite located closest to the feed, with gradual decrease farther along the column (Figure 6.20). The percentages of the partitioned Cu in each fraction (exchangeable, ionically bound to amorphous materials, Fe- and Mn- oxides, oxidizable compounds, and residual) were distributed in a similar manner with columns conducted under similar conditions at all depths. A summary of the partitioning of Cu expressed in percentage of the total amount obtained from selective sequential extraction is presented in Table 6.4.

Table 6.4 Summary of the partitioning of Cu expressed in % of the total from SSE in each fraction

Pretreatment w/ 1M NaCl	no	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ARD	natural	natural	max	natural	natural	max	max	natural	natural	natural
filtering	no	no	yes	yes	yes	yes	no	no	yes	no
Flowrate (m/day)	0.99	1.26	1.312	1.4945	0.5	0.5235	0.54	0.471	0.42	0.399
# pv	41.47	85.65	72.45	97.93	30.73	69.7	73.96	115.03	69.57	67.01
Percentage of the partition of Cu in each fraction (value averaged along column), %										
Exchangeable	15.26	26.22	27.74	24.36	20.77	15.73	17.65	14.54	16.73	15.62
Ionically bound amorphous materials	30.04	27.15	35.05	33.25	32.31	40.43	19.11	22.85	23.26	21.81
Fe- & Mn- oxides	49.3	40.75	33.44	38.7	43.69	34.66	56.83	56.73	53.75	55.52
Oxidizable compounds	6.26	5.87	5.09	10.3	17.71	8.62	6.98	8.5	8.87	9.21
Residual	0	0.4	0	0	0	0.55	0	0	0	0

The columns for ARD with maximum design concentration showed that the percentage of exchangeable ions in the clinoptilolite was greater in columns leached with higher flow rate. This is because in higher flow rate conditions, shorter time was available for cations adsorption, hence more of the cations attached on the surface of the soil are present as exchangeable ions, which are the least strongly attached compared to other fractions. At 1.5 m/day, approximately 28% of the Cu was attached as exchangeable ions compared to 16% of Cu at 0.5 m/day flow rate. The results could be used to explain the kinetics of the adsorption of Cu on the clinoptilolite.

From the previous chapter, it was found that adsorption was most affected by the flow rate. Appended with the results obtained in this section, the variation in the retention of Cu on the clinoptilolite is mainly a function of the exchangeable fraction.

The results also indicated that for soils leached with non-filtered ARD, most of the Cu adsorption takes place with the Fe- & Mn- oxides fraction. This is because a large amount of Fe- precipitates was present in non-filtered ARD (Appendix B-2), hence, more Fe-oxides were available for complexation with the Cu. The results could also be used to identify the portion of the Cu which is attached to Fe- relative to Mn- oxides. Since residues from ARD filtration contains 64% of Fe_2O_3 and < 0.01% (detection limit) of MnO, the difference in the form in which Fe was retained in the non-filtered ARD were likely in the form of complexed Fe- oxides.

Another reason for the enhanced adsorption on clinoptilolite leached with non-filtered ARD can be suggested by the presence of higher amounts of SO_4^{2-} in the leachate relative to the filtered ARD. The formation of ternary complexes (e.g. $\equiv FeOHCuSO_4$) between oxide surfaces, SO_4, and the metal ion has been shown to be a likely mechanism by which co-adsorbed SO_4 may enhance metal adsorption (Webster, Swedlund et al. 1998). Surface precipitation of metal-SO_4 salt could also be encountered and will be discussed in the later sections.

The amount of Cu attached to oxidizable compounds and minerals which were present in the clinoptilolite sample ranges from 5 to 8.6%. The extraction procedure reflects oxidizable fractions such as sulphates and phosphates that were associated with the trace minerals found in the clinoptilolite sample (Forstner 1993). There was no Cu present in the residual portion, which may be a result of the insufficient time for Cu to precipitate into crystalline form. In addition, the pH of the solution (equilibrium pH ~ 3.0) was too low for precipitation to occur. From the results, Cu ions were mobile under the pH of the leachate (Sparks, 1995).

In columns where natural ARD was used as the leaching solution, the same trends were observed. Cu was distributed in the same manner at all the depths within the column. Flow rate was a factor affecting the amount of exchangeable ions being attached. Filtering of the ARD reduced the percentage of Cu attached to the Fe- and Mn- oxide fraction.

The results of all the clinoptilolite column leaching tests indicated that there were gradual decreases in the amount of metals attached to the soils located farther from the source. This indicated that the ability of the clinoptilolite to retain metals has not yet reached saturation for Cu. Although the concentration of the copper in the leachate had reached equilibrium, there were still reactions occurring between the Cu and the clinoptilolite. The reactions were slow and the removal of metals was negligible compared to the influent concentration.

As shown in Figure 6.25, the Cu adsorption results obtained from the column leaching cells were integrated into the same graph as the adsorption isotherms obtained in Section 5.1.1 and 5.2. Results indicated that the amount of metals adsorbed on the clinoptilolite was significantly lower in column leaching tests due to shorter interaction time between the clinoptilolite and the solution. It is also noted that results obtained from column leaching cells were clustered in the low range of the amount adsorbed. However, as expected, there was a general trend that higher amount of Cu were retained at increased equilibrium concentrations. This may due to the high availability of Cu ions in the solution for increased contact/activity with the clinoptilolite.

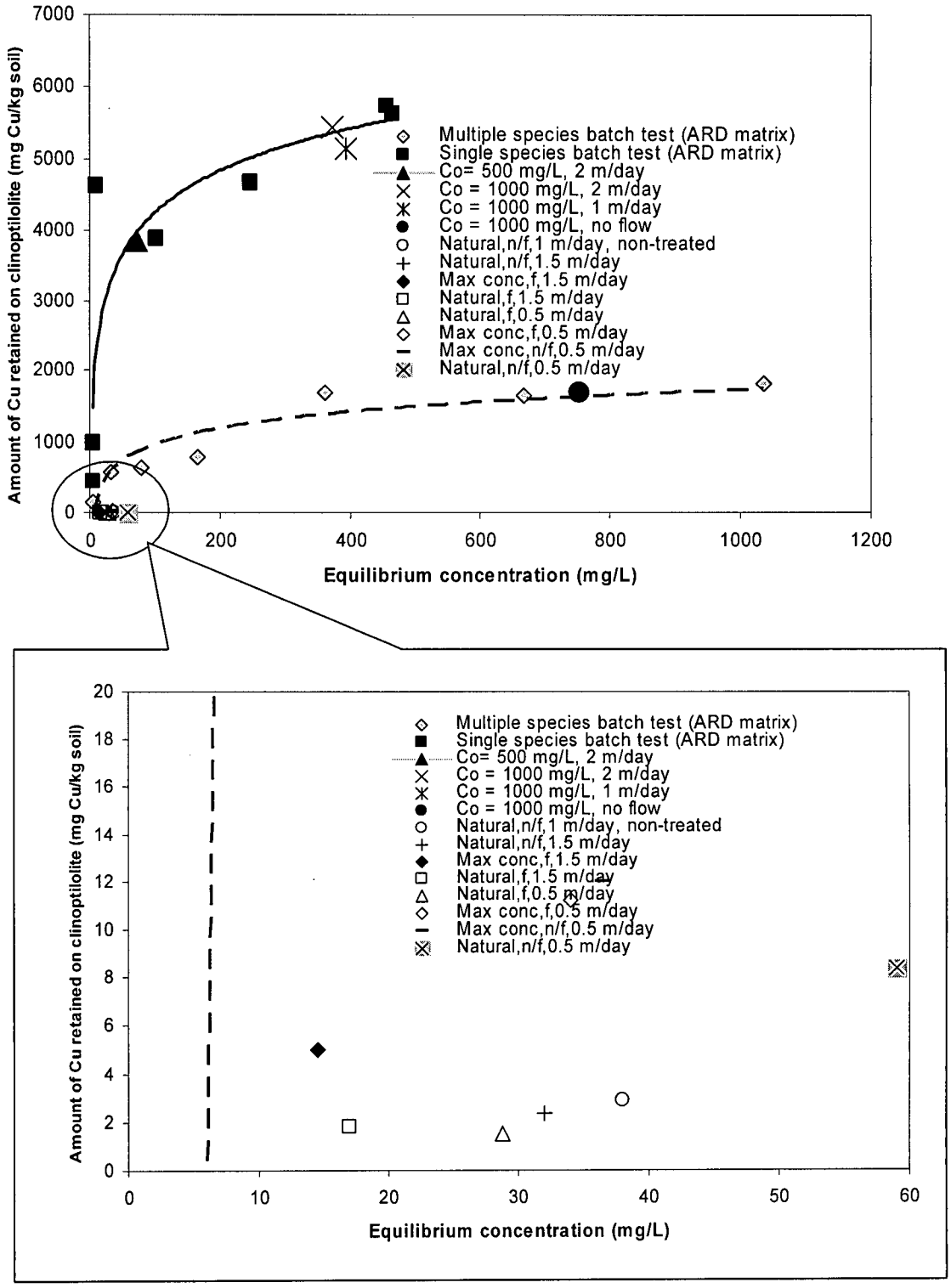

Figure 6.25 Comparison of retention of Cu in column leaching cells in adsorption isotherms

Retention of Iron

The retention of iron on the clinoptilolite is summarized in Figure 6.21. The majority of the iron is present in the residual form, followed by oxidizable fraction, and Fe- & Mn- oxides (reducible). The exchangeable fraction of Fe was less than 1% of that found with the Fe extractions and approximately 3% of Fe was ionically bound to amorphous or poorly crystallized minerals. The reason that a minimal amount of Fe was present in the soil was that Fe remains in solution only at a very low pH (pH<2). At the pH level of the pore water, which is above pH 4, most of the Fe should have been precipitated.

The distribution of the form which Fe was bound indicated that the majority of the Fe has been precipitated as secondary minerals, in crystalline form that could be extracted from the residual fraction. Fe was also found in the oxidizable fraction, which included sulphate and phosphate associated with the trace minerals found in the clinoptilolite sample (Section 4.2.2). The sulphate fraction may contribute to the SO_4^{2-} in the ARD. Fe- & Mn- oxides fraction was attached mainly to the secondary minerals found in the clinoptilolite sample (Section 4.2.2).

Retention of Manganese

The Mn retention on the clinoptilolite ranged from 0.02 to 0.15 mg/g sample. There was no variation in the retention of Mn with the distance to the source. As indicated in Figure 6.22, the mass of Mn in the exchangeable fraction increases with decreasing flow rates. Most of the Mn was bound to the oxidizable compounds and in the Fe- & Mn- oxides fractions.

Retention of Zinc

The retention of Zn was affected by the influent concentration, flow rate and the filtering of the leachate. A summary of the retention of Zn and the partitioning of Zn in the various

fractions are shown in Figure 6.23. A summary of the partitioning of Zn expressed as a percentage of the total amount obtained from SSE in each fraction is presented in Table 6.5.

The results indicated that soils located closer to the influent contained a larger amount of Zn, which gradually decreased away from the source. Results also indicated that clinoptilolite in columns leached with the maximum design concentration ARD contained a larger amount of Zn than that leached with natural ARD. This indicated that capacity of clinoptilolite to retain Zn ions could be increased if sufficient supply of Zn ions is present. Percentage fractionations of metals were distributed evenly with depth.

Table 6.5 Summary of the partitioning of Zn expressed in % of the total amount obtained from SSE in each fraction

Pretreatment w/ 1M NaCl	no	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
ARD	natural	natural	max	natural	natural	max	Max	natural	natural	natural
Filtering	no	no	yes	yes	yes	yes	No	no	yes	no
Flowrate (m/day)	0.99	1.26	1.32	1.50	0.5	0.524	0.54	0.471	0.42	0.4
# pv	41.47	85.65	72.45	97.93	30.73	69.7	73.96	115.0	69.57	67.01
Percentage of the partition of Zn in each fraction (value averaged along column), %										
Exchangeable	14.4	17.5	19.7	20.0	22.0	16.2	16.2	1.6	13.5	12.2
Ionically bound to amorphous materials	29.3	27.8	33.0	27.2	23.0	30.5	20.1	18.9	18.1	18.9
Fe- & Mn- oxides	29.6	26.8	28.1	24.2	21.2	23.0	34.6	38.4	37.9	35.7
Oxidizable compounds	5.2	6.5	6.1	17.1	26.7	21.4	27.2	27.8	27.8	29.3
Residual	21.6	21.4	13.1	11.5	7.2	8.8	1.9	3.3	2.8	3.8

The behavior of Zn was similar to that of Cu in terms the extent of which the partitioning of metals was affected. Yet the affinity of Zn onto the clinoptilolite was weaker because the amount of Zn being retained at equilibrium, as compared to the input amount, was less than that of Cu.

From Table 6.5, comparing the percentage fractionation of Zn on soils leached with maximum design concentration ARD indicated that the amount of Zn in the exchangeable

fraction was higher with higher flow rate than that in slower flow rate. This may be explained by the higher flow rate conditions, free cations in the leachate have a shorter time to interact with the soil particles to form strong bonds, hence, they only attached to the surface as exchangeable species. Nevertheless, the amount of Zn attached to the Fe- & Mn- oxides was higher in columns leached with non-filtered ARD than that leached with filtered ARD. This can be explained by the presence of iron precipitates in the non-filtered ARD, which lead to a higher retention of Zn in the Fe- & Mn- oxide fraction.

Retention of Aluminum

Shown in Figure 6.24 is the amount and the partitioning of Al on the clinoptilolite from column leaching cell tests. Results showed that the majority of the Al obtained by the extraction test was in the residual fraction. This is reasonable given that Al is present in the structure of the clinoptilolite from isomorphic substitution. Crystalline Al may also be formed by mineral-solution reaction and attached to the surface of the clinoptilolite. Al was found in the largest amount as compared to any other metals because of its high affinity to the charged surface, as a result of its high valency and small ionic radius, which enables it to be more competitive over other metal ions.

Since some of the residual Al might have come from the framework of the clinoptilolite, excluding the residual portion, it was found that the amount of Al retained on the clinoptilolite was higher at locations closer to the influent source. This was mainly due to higher availability of ions at locations closer to the source. At distances farther from the source, concentrations of the metal were lower because some of the ions might have been taken up while passing through the clinoptilolite column. The percentages of Al attached to Fe- & Mn- oxide were higher in non-filtered ARD.

6.3 Column leaching tests (III) – Changes in Clinoptilolite with Time

The previous section described the behavior of clinoptilolite in retaining metal ions based on effluent breakout criteria. The amount of metals present on the clinoptilolite reflects the condition when equilibrium of metal concentration of water sample at the effluent port was reached, after a certain number of pore volumes had passed through the column. The change of the retention of metals on the clinoptilolite with time (or volume of leachate flowed through) has not been investigated.

In this section, a set of 8 column leaching cells operating under identical conditions were conducted simultaneously. Water samples were taken throughout the course of the study. Clinoptilolite samples were extracted from different depths in the column after each pore volume interval (~ 15 pore volumes, ~ 7 days). The changes of the retention of metals in the clinoptilolite with the volume of leachate were observed, investigated and used to estimate equilibrium conditions.

The leaching cells were operated with 1M NaCl pretreated clinoptilolite at a flow rate of 0.5 m/day and leached with natural, non-filtered ARD from the Britannia Mine.

6.3.1 Leachate analyses

The changes in the chemical characteristics in the leachate sample obtained from the sampling ports along the leaching cells with time (expressed in pore volumes) are shown in Figure 6.26 to Figure 6.33. Chemical characteristics measured included pH, redox potential expressed in milli-volts (mV), electrical conductivity in milli-Siemens/cm (mS/cm), and the sum of pH and pe. The change of concentrations of Cu, Fe, Mn, Zn and Al at the various depths along the columns are also presented. A detailed summary of the concentration profile and breakthrough curves of the metals at different time intervals are given in Appendix I.

Results from the leaching cells showed that breakthrough for Cu was at 47 pore volumes (pv), whereas breakthrough volume for Mn was at 12.5 pv, Zn at 26 pv and Al at 35 pv. The equilibrium pH of the natural, non-filtered ARD column with 1M NaCl pretreated clinoptilolite was pH 4, pe was 8, electrical conductivity was 2.2 mS/cm, and equilibrium sum of pH and pe was 16.

The concentrations of Fe in the effluent were all detected to be below 0.1 mg/L. The form in which Fe was present could be inferred from the mineral equilibria at the pH and Eh conditions in this experiment. The equilibria system should contain Cu-Fe-S-O-H. This indicated that under the conditions (pH and Eh) that existed in the column leaching cells, Fe should be present as hematite (Fe_2O_3) (Garrels and Christ 1965; Lindsay 1979). The form in which Cu could precipitate was as Cu_2O and CuO when it is present as free ions in the leachate sample. Mn was present in the form of Mn^{2+} to Mn^{4+} at the early stages of the leaching (before 20 pore volumes), and was present as Mn^{2+} after 20 pore volumes.

Results show that chemical characteristics in the effluent reached steady state after approximately 40 pore volumes. Results indicated that the closer the sampling port is to the influent, the faster the chemical compositions in the water sample reached equilibrium. This is as expected because there is a gradient of concentration in the leaching column once the influent is introduced and the influent reacts with the substrate. The substrate closer to the source gets the highest concentration of the contaminant. Once the soil is saturated, or in thermodynamic equilibrium with the contaminant, then the contaminants would be transported to the subsequent section (higher position in this case of upward flow) in the clinoptilolite column.

The other explanation is that the pore volume is calculated based on dividing the amount of leachate at each effluent port (50 cm from the influent) by the volume of pores in the clinoptilolite leaching cell. Hence, by the time soils at the 40-50 cm section were leached with

the 10th pore volume, the soils in the 0-10 cm section would have been leached with 10.8 pore volumes. Therefore the samples located closer to the influent would reach equilibrium at a shorter time than those located farther away from the influent.

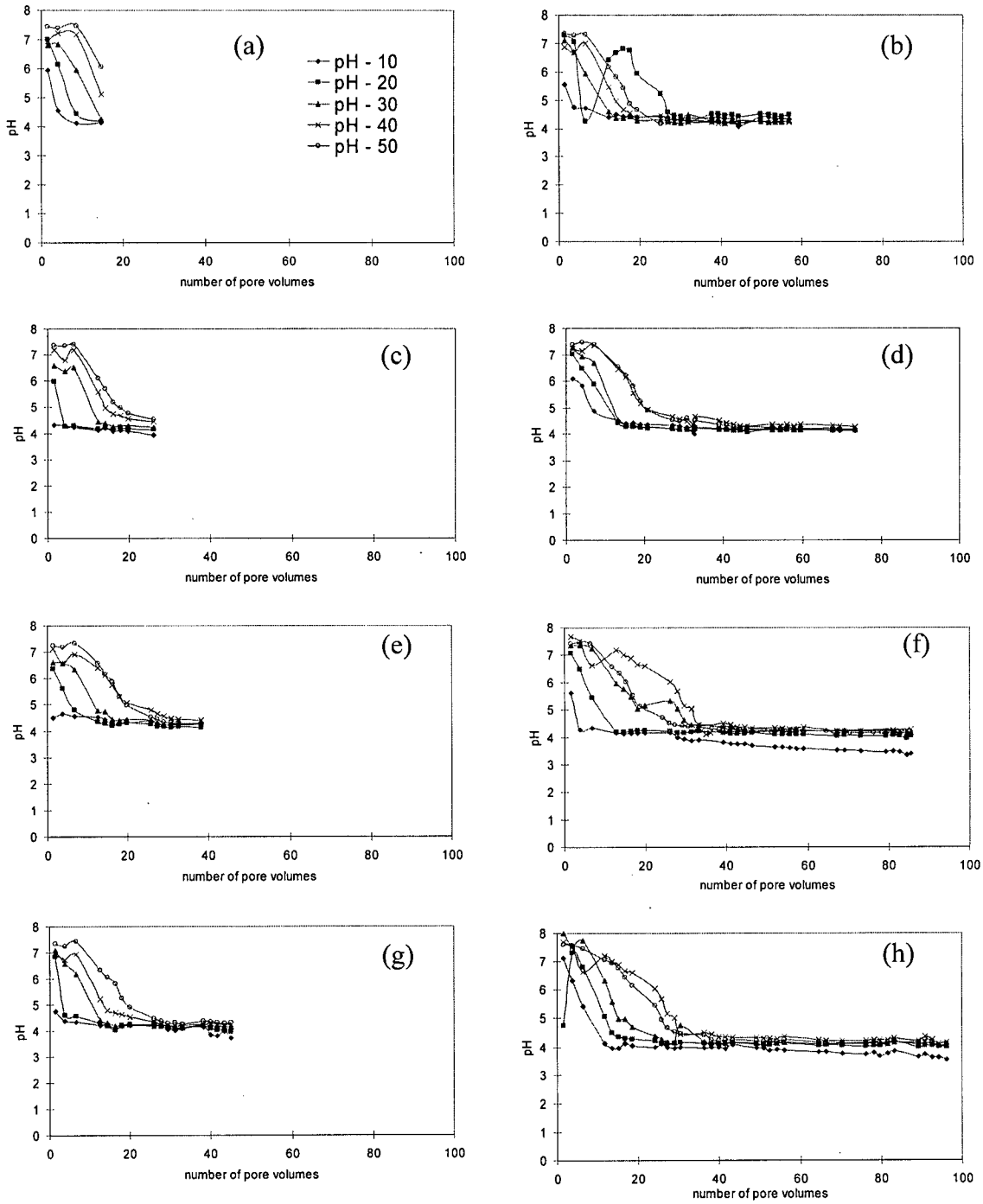

Figure 6.26 pH of water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. **pH-10 indicates pH levels at 10 cm from feed, etc.

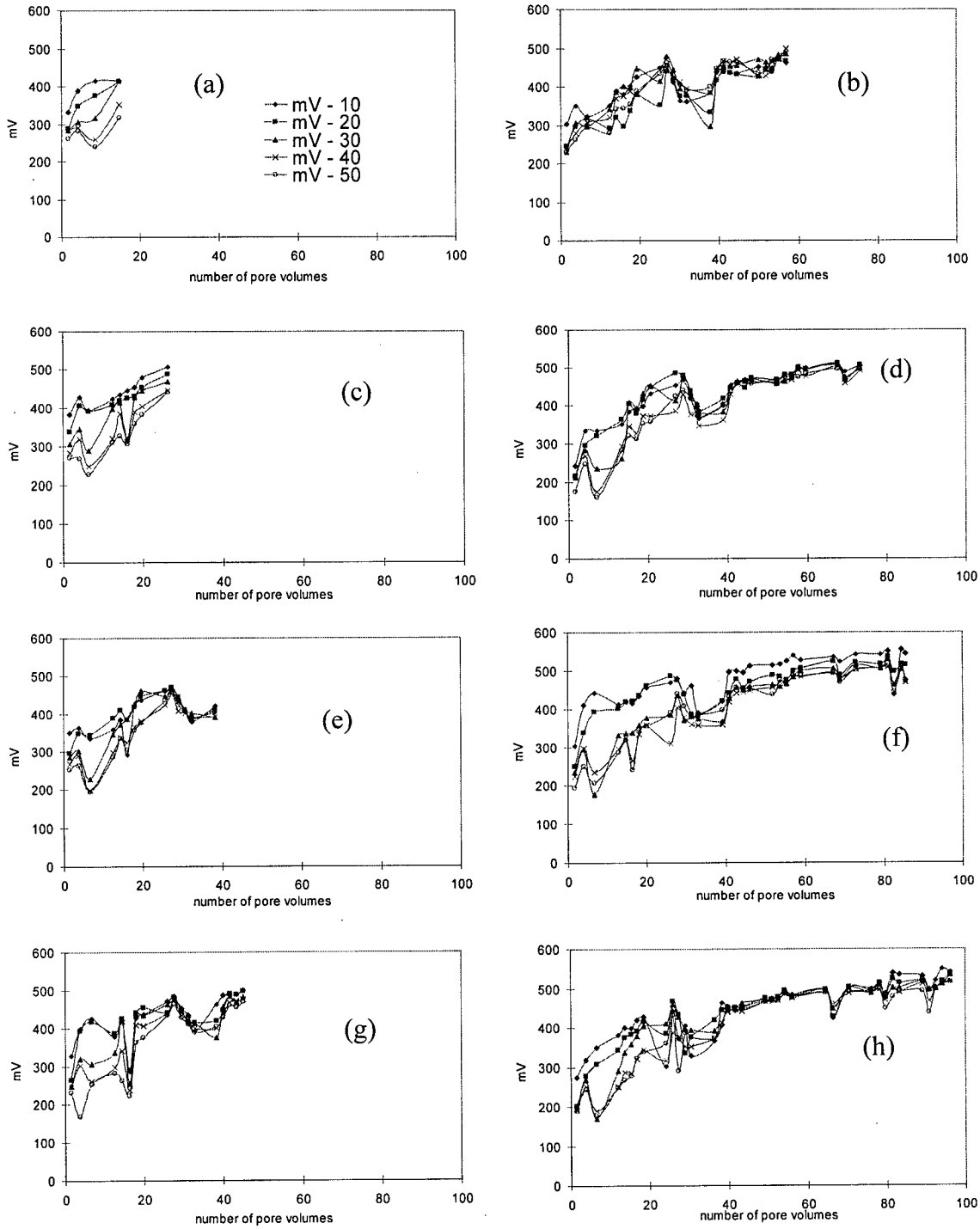

Figure 6.27 Redox potential (expressed in millivolts, mV) of water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. **mV-10 indicates mV at 10 cm from feed, etc.

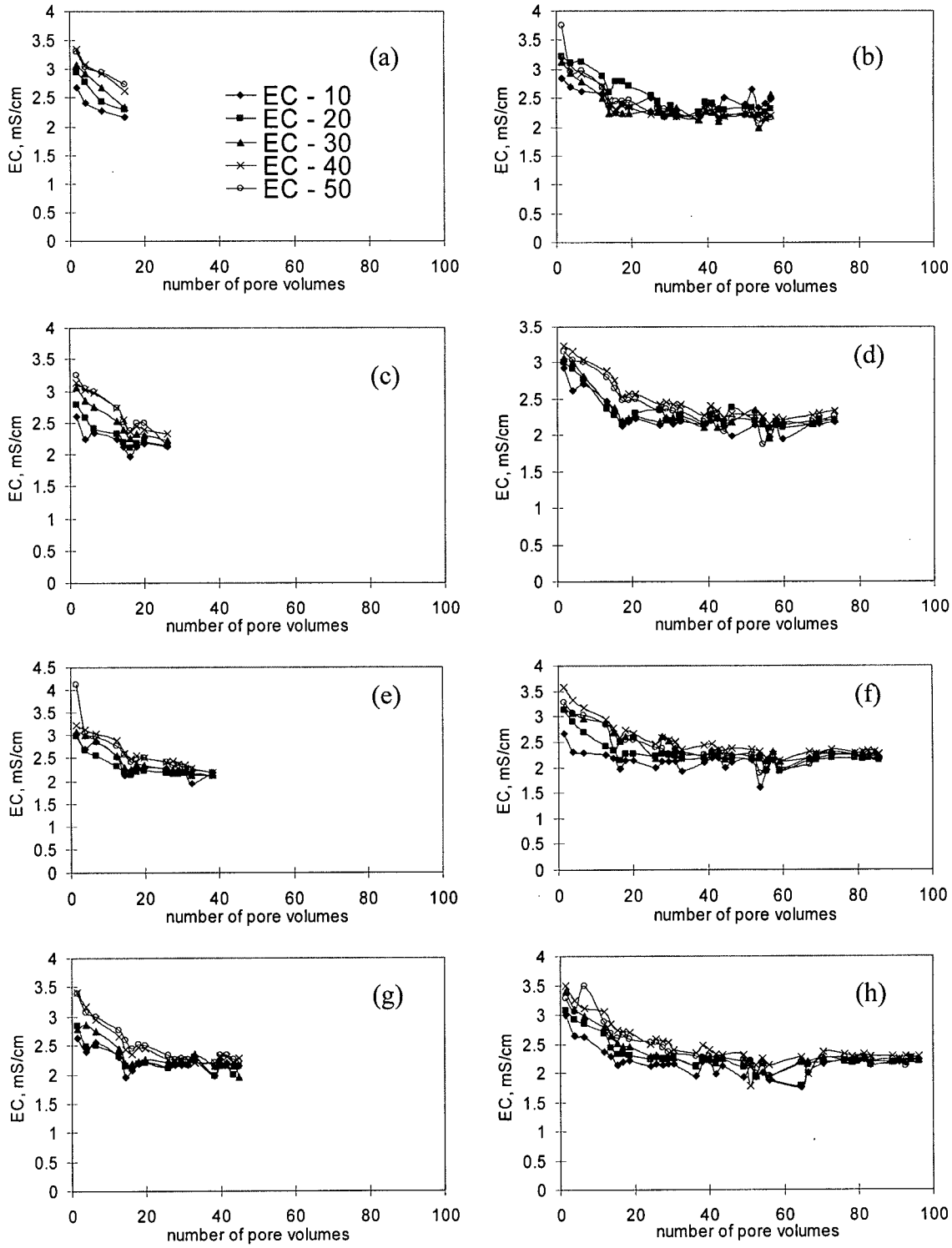

Figure 6.28 Specific Electrical conductivity of water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. **EC-10 indicates the specific conductivity at 10 cm from feed, etc.

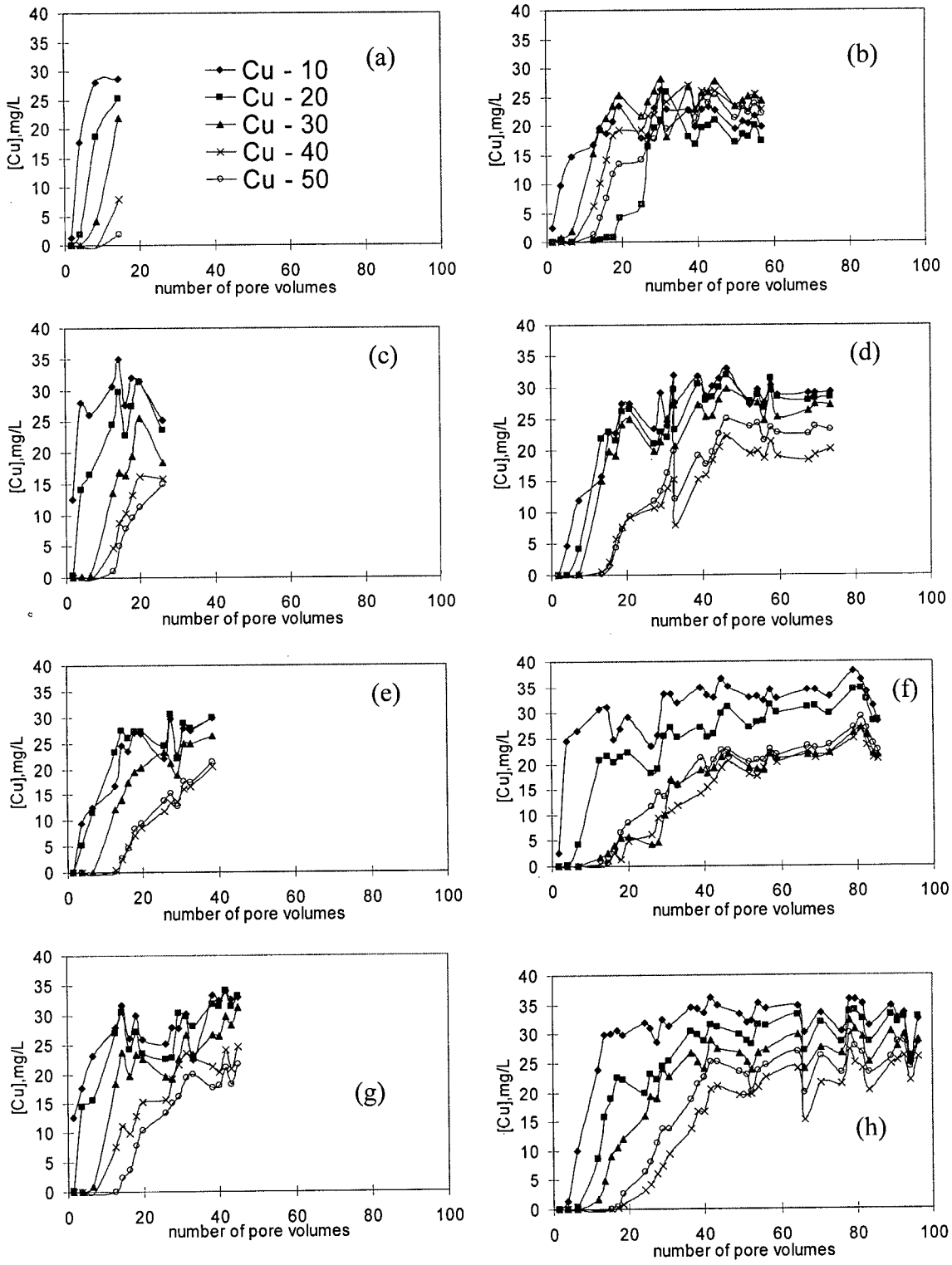

Figure 6.29 Concentration of Cu in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. **Cu-10 indicates Cu concentration at 10 cm from feed, etc.

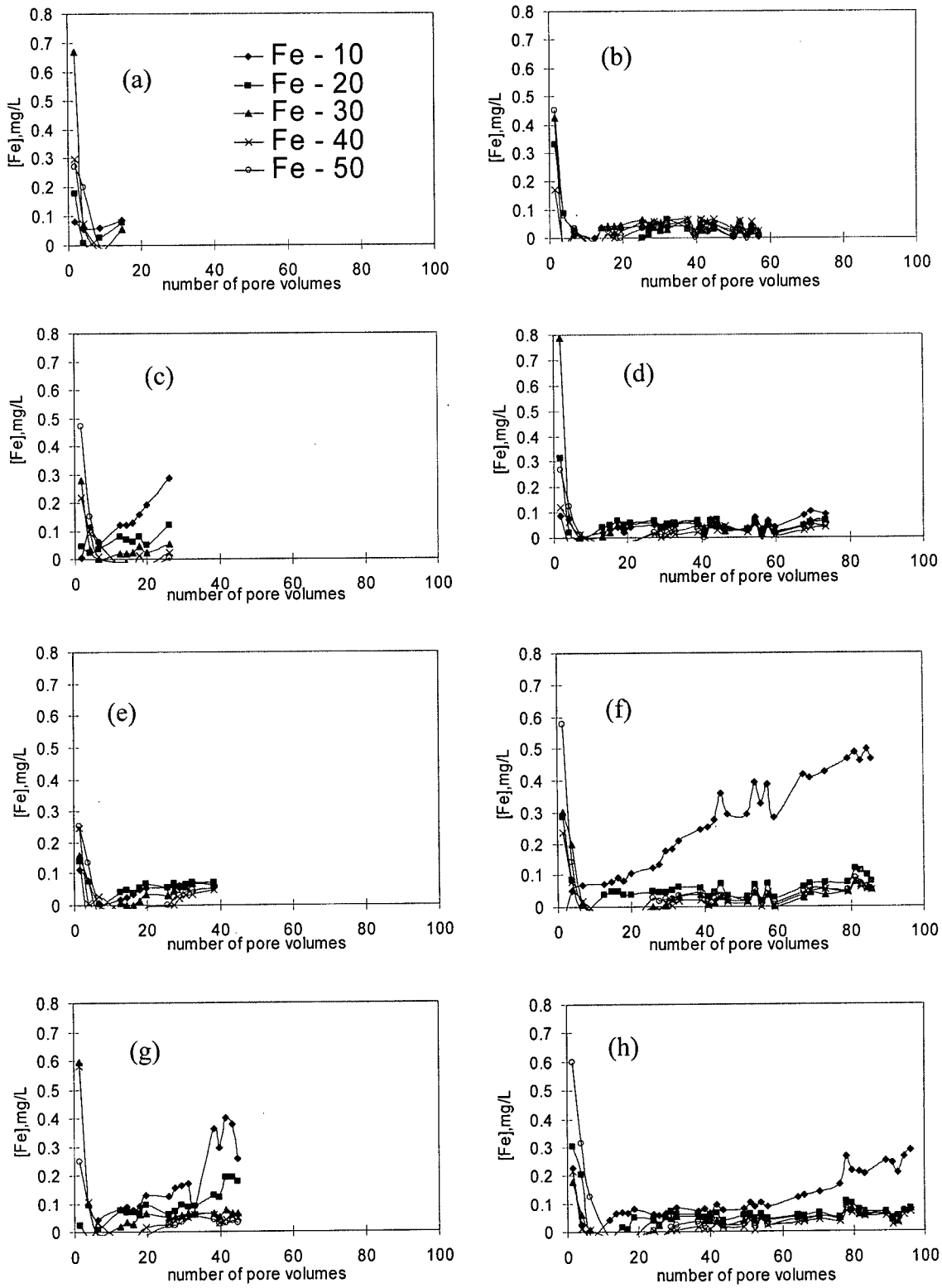

Figure 6.30 Concentration of Fe in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv **Fe-10 indicates Fe concentration at 10 cm from feed, etc.

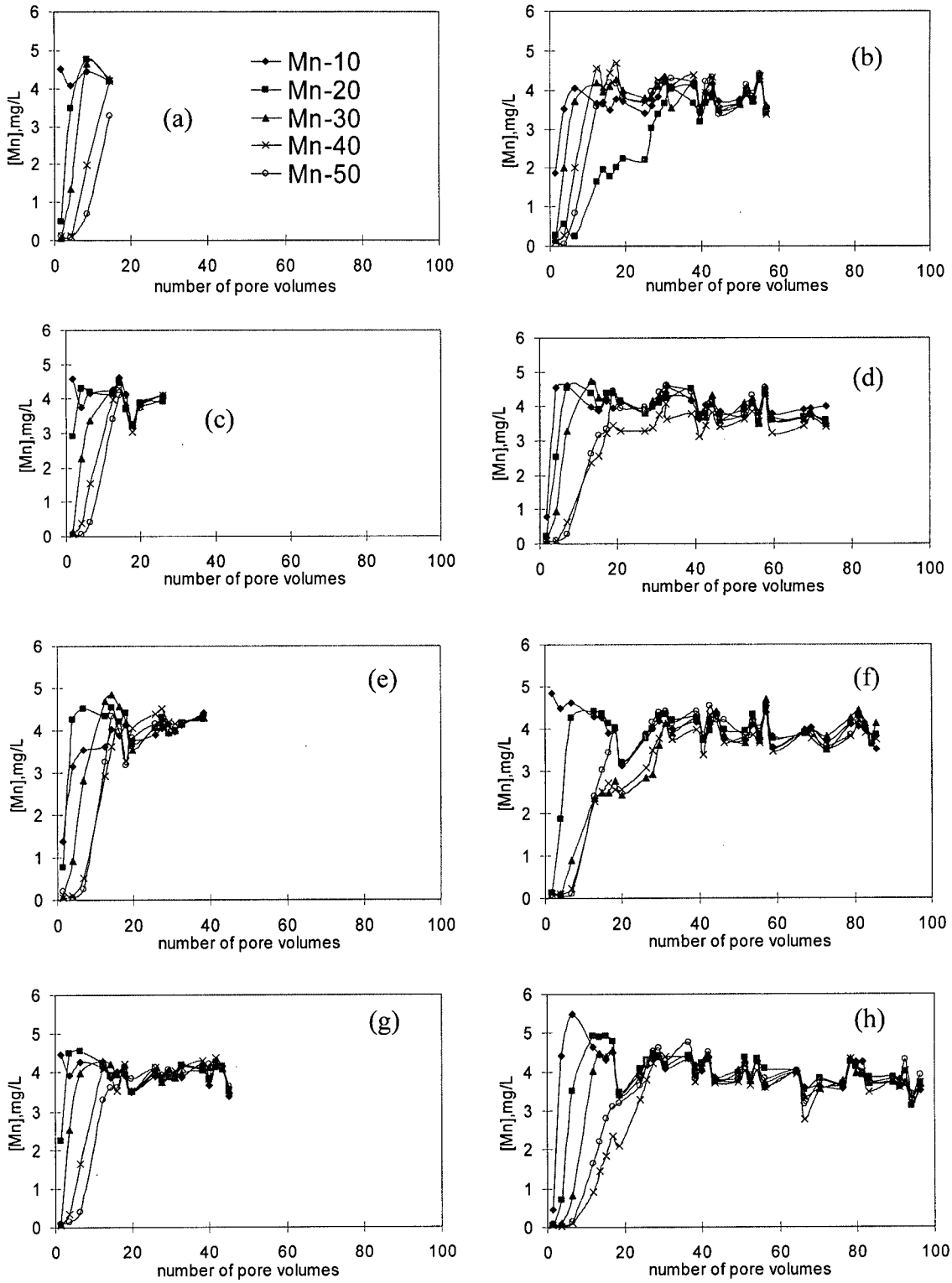

Figure 6.31 Concentration of Mn in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv **Mn-10 indicates Mn concentration at 10 cm from feed, etc.

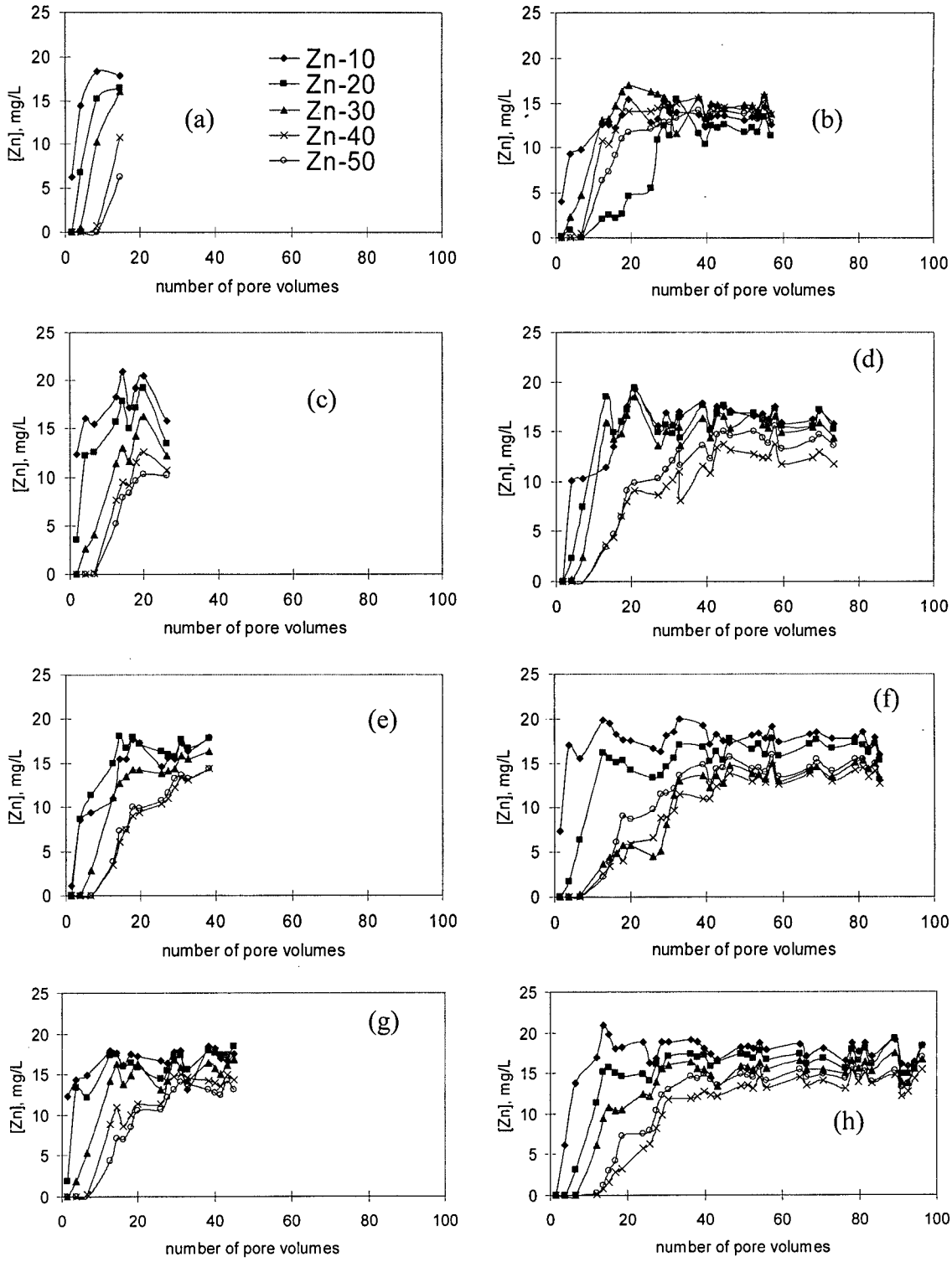

Figure 6.32 Concentration of Zn in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. **Zn-10 indicates Zn concentration at 10 cm from feed, etc.

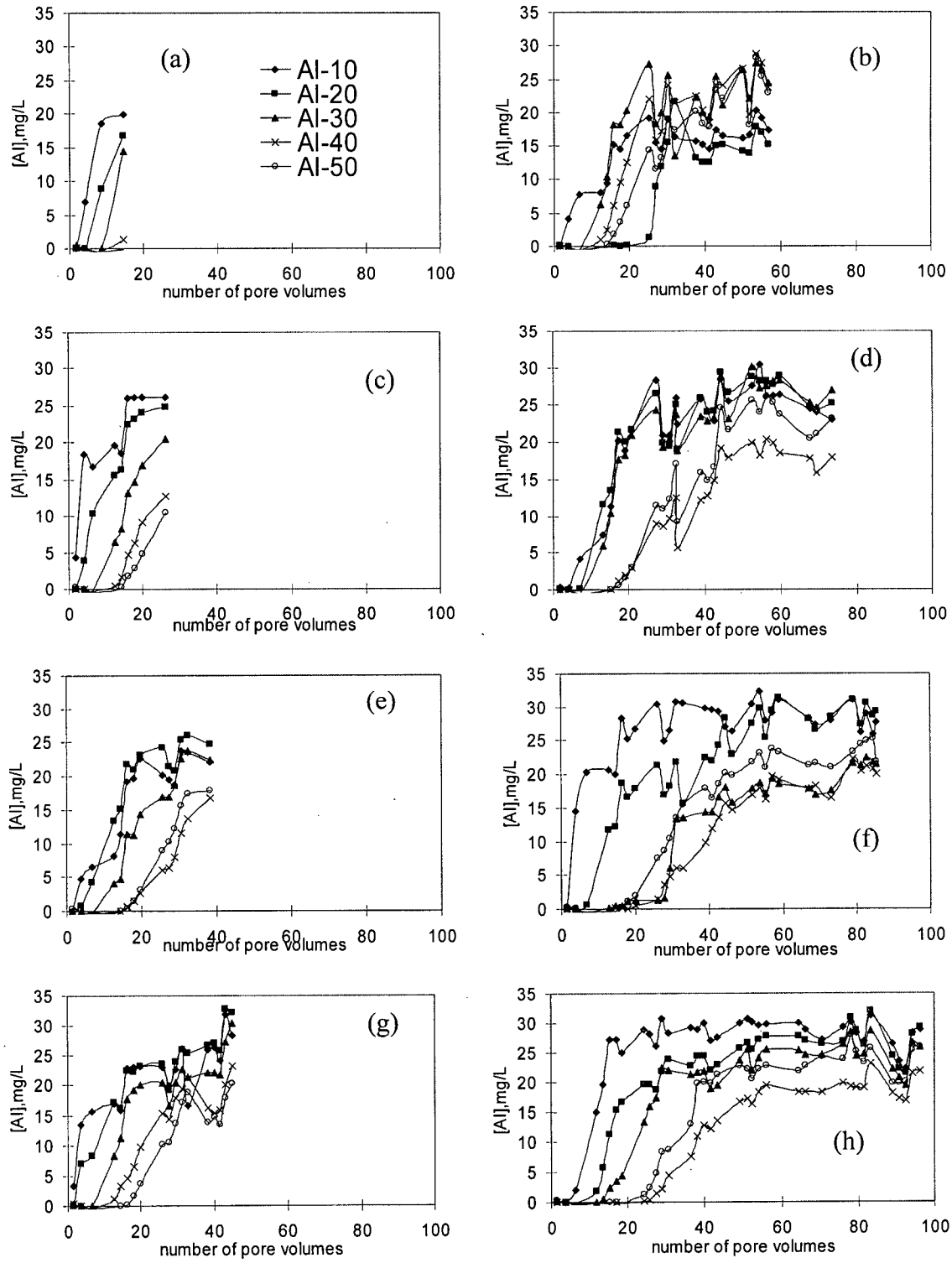

Figure 6.33 Concentration of Al in water samples from sampling ports along the column leaching cells up to pore volumes (pv) of: (a) 15 pv, (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv. **Al-10 indicates Al concentration at 10 cm from feed, etc.

6.3.2 Analyses of the clinoptilolite

Analyses on the clinoptilolite tested with natural non-filtered ARD at a flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite were conducted. In the critical path analysis experiment, 8 identical clinoptilolite columns were used. Soil was extracted after several amounts (pore volume) of mine drainage had passed through (15, 26, 38, 45, 57, 73, 85, and 96 pore volumes). The amount of metals present in the soils with time (expressed in number of pore volume flowed through) was measured. The significance of this experiment was to find out the retention and partitioning of metals onto each section of the clinoptilolite, as increasing amounts of leachate passed through. From the results, correlation between the depth and concentration of the metals could be followed, along with any partitioning of metals. The correlations could be used as a tool in determining the amount in each fraction that metal was bound to, or present, based on the total amount of pore volumes of leachate that flowed through the column, as well as the amount of metal present.

Figure 6.34 to Figure 6.38 show the partitioning of Cu, Fe, Mn, Zn and Al on the clinoptilolite at along the column leaching cells after 15, 26, 38, 45, 57, 73, 85, and 96 pore volumes respectively.

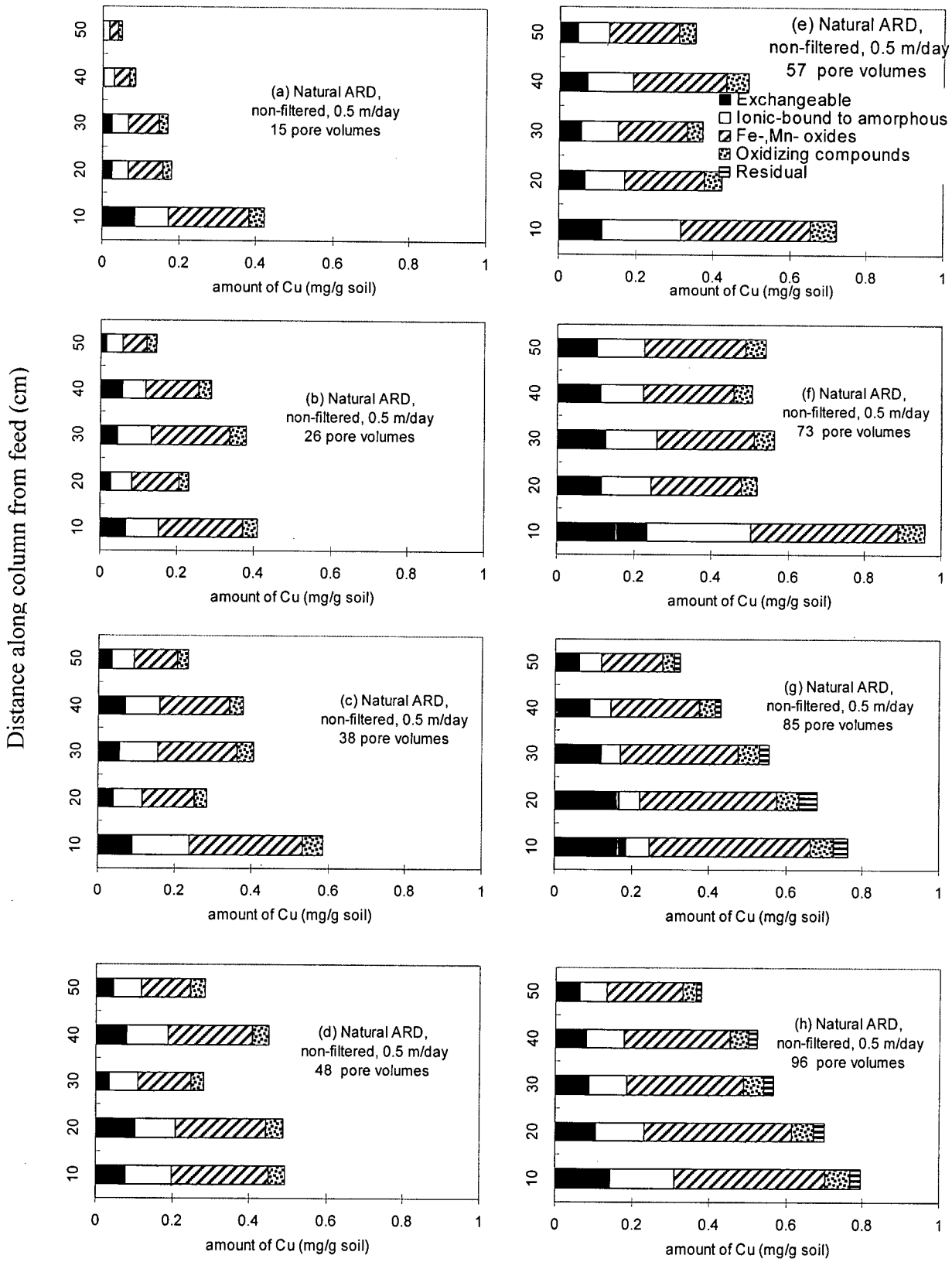

Figure 6.34 Partitioning of Cu on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv.

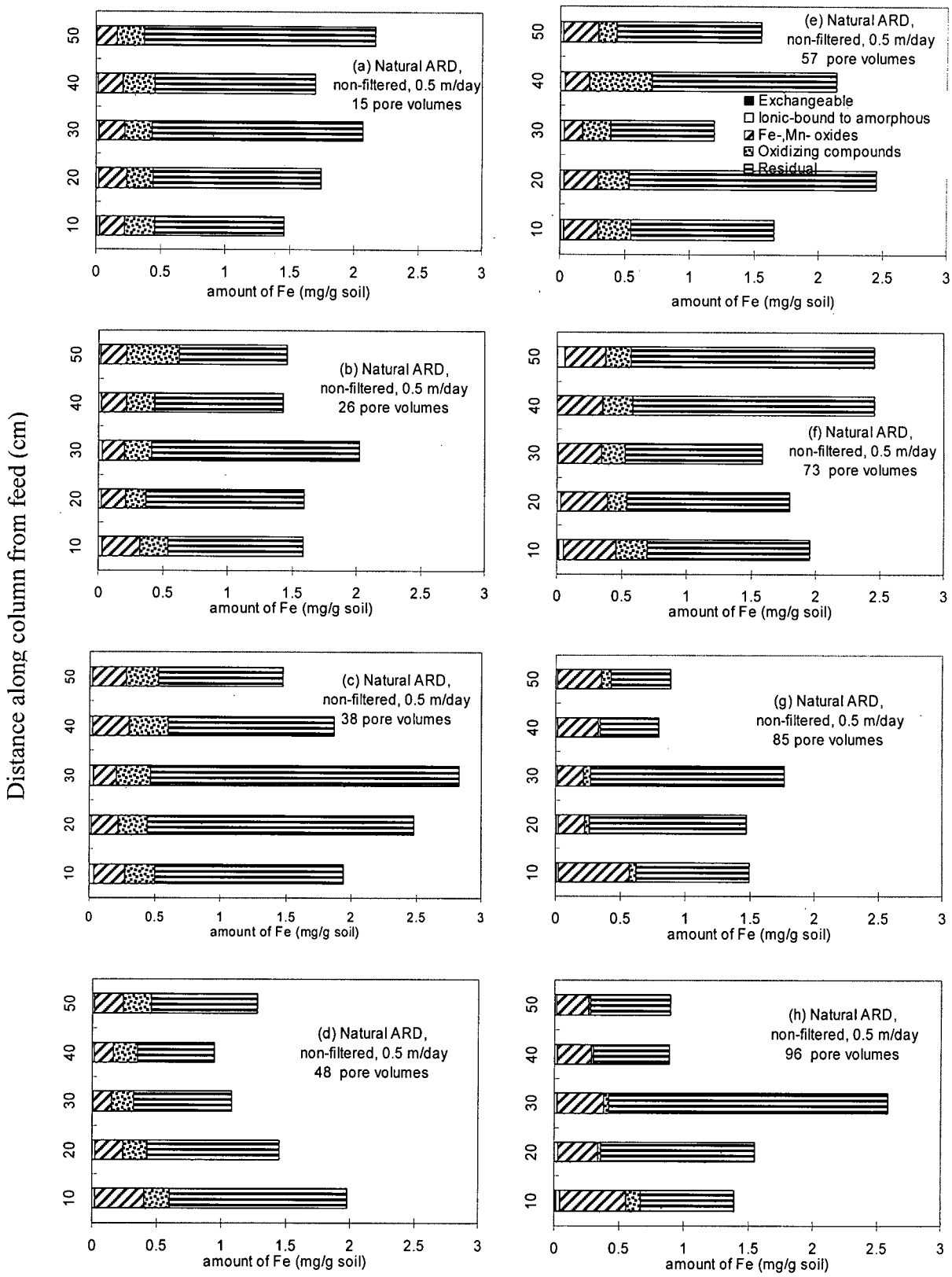

Figure 6.35 Partitioning of Fe on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv.

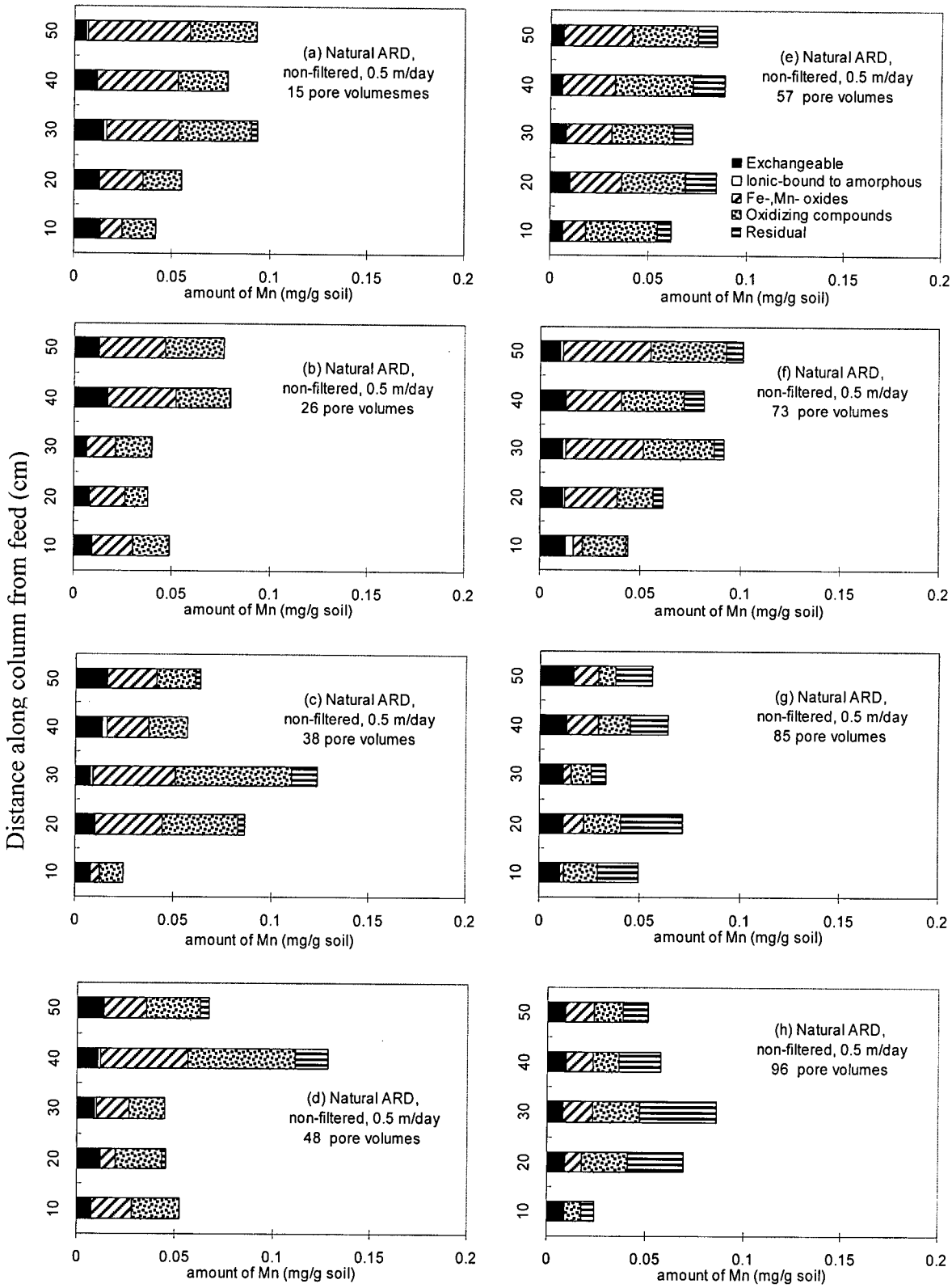

Figure 6.36 Partitioning of Mn on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv.

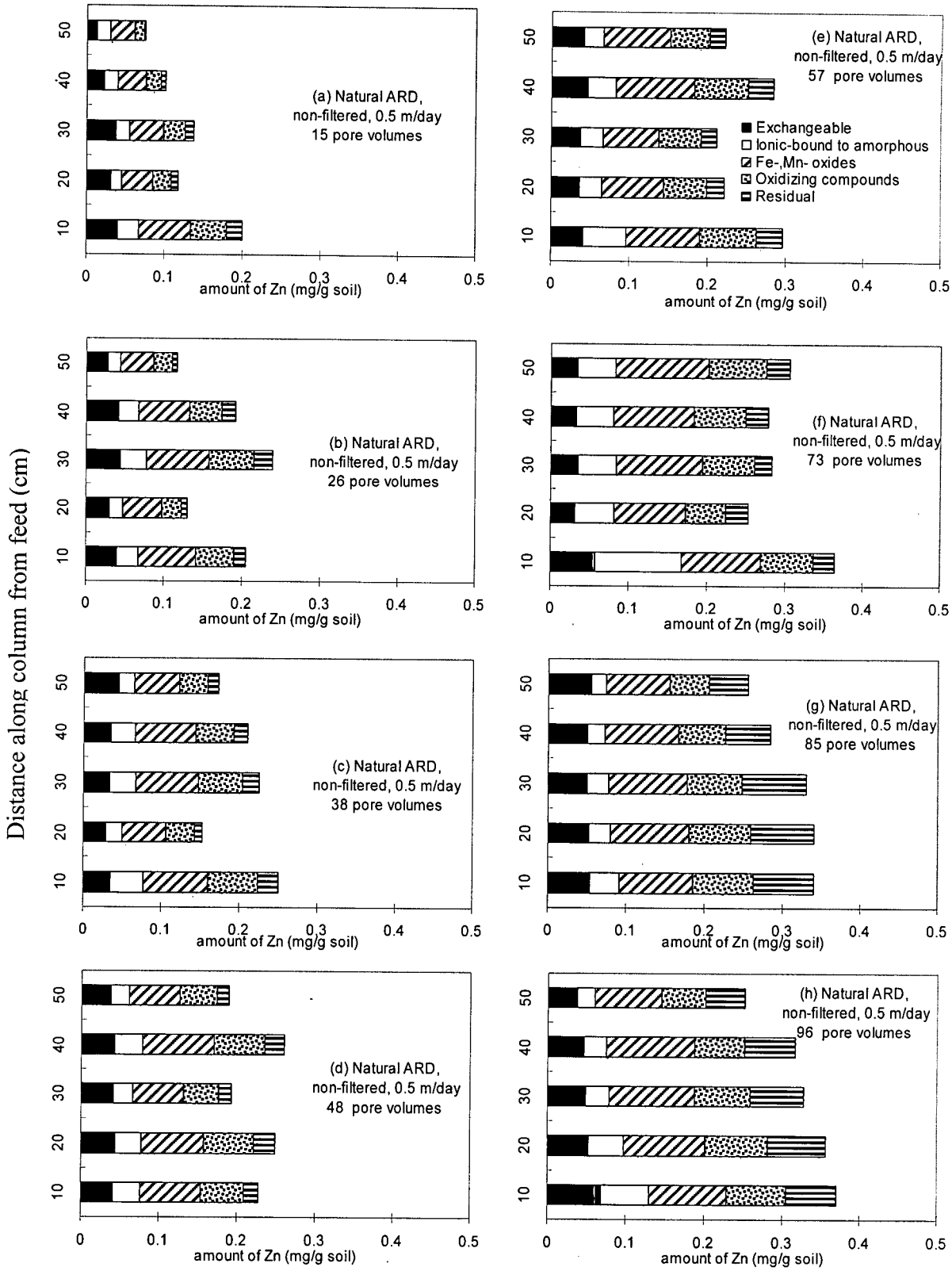

Figure 6.37 Partitioning of Zn on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv.

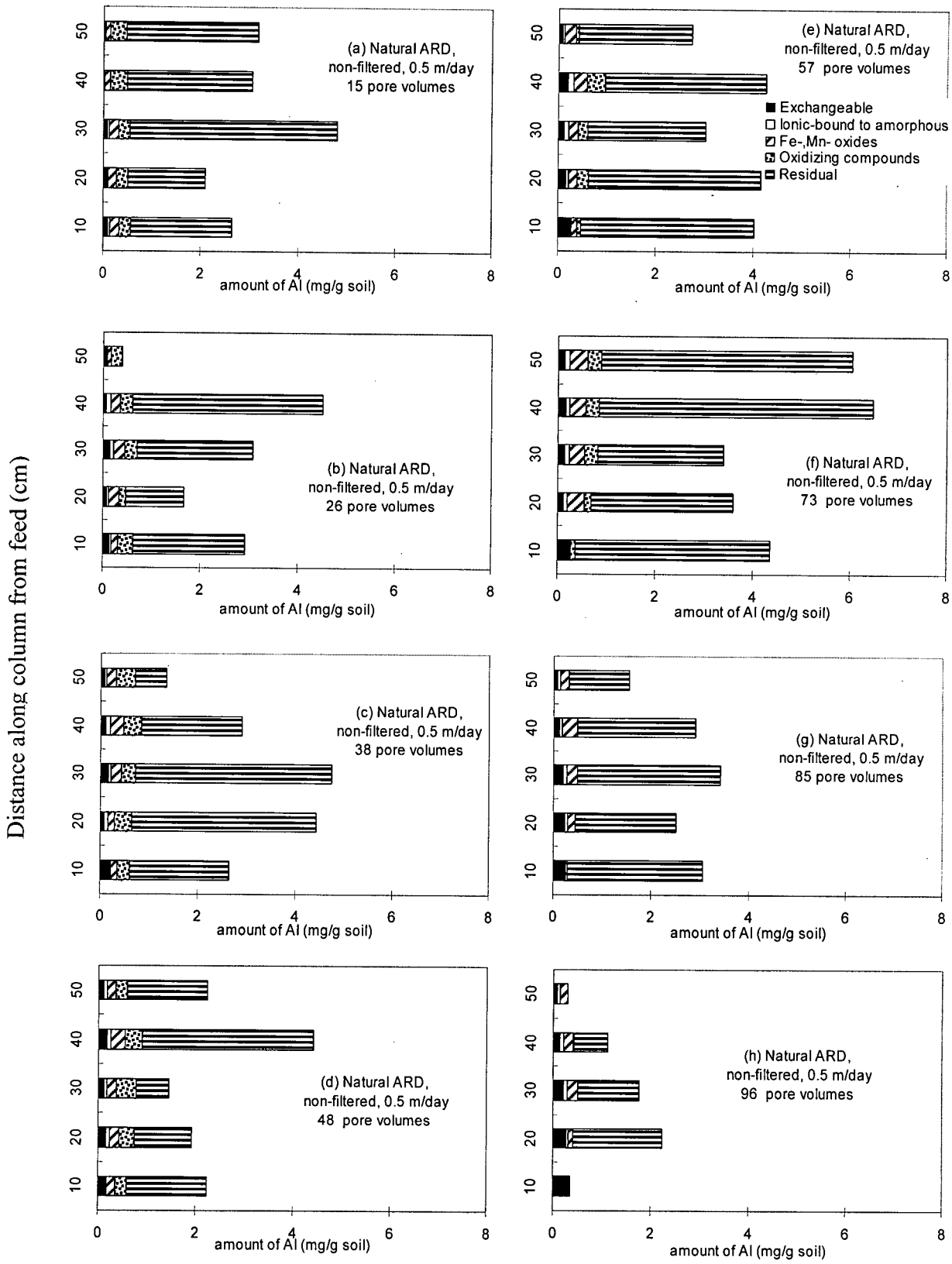

Figure 6.38 Partitioning of Al on the clinoptilolite at different depths along the column leaching cells with natural non-filtered ARD and flowrate of 0.5 m/day with 1M NaCl pretreated clinoptilolite after: (a) 15 pore volumes (pv), (b) 26 pv, (c) 38 pv, (d) 45 pv, (e) 57 pv, (f) 73 pv, (g) 85 pv, and (h) 96 pv.

Results showed that Cu and Zn accumulate on the clinoptilolite as the number of pore volumes flow increase through the columns. Higher amounts of Cu and Zn were found on the clinoptilolite located closer to the source.

Correlations were found between the amount of Cu and its fractionation on the clinoptilolite at the pore volume of which the column leaching cell was conducted and are shown in Figure 6.39 and Figure 6.40.

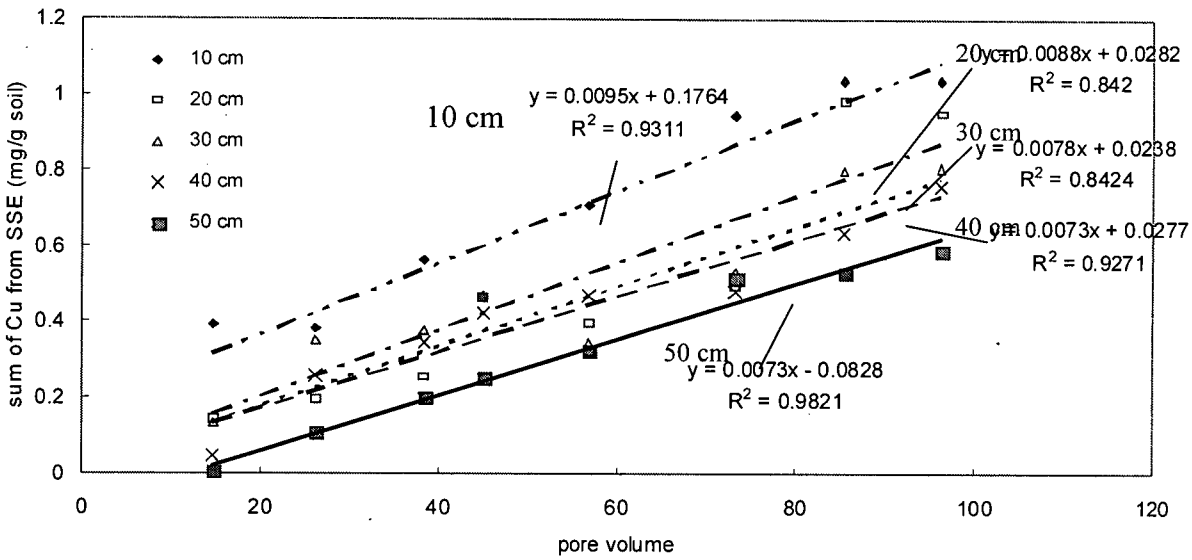

Figure 6.39 Correlation between the total amount of Cu retained on clinoptilolite with pore volumes

Table 6.6 Empirical relationships between the sum of the amount of Cu on clinoptilolite with the amount of leachate reacted

Soil section along the leaching cell	Empirical relationships
10 cm	$[Cu]_{10cm}$=0.0095 pv + 0.1764
20 cm	$[Cu]_{20cm}$=0.0088 pv + 0.0282
30 cm	$[Cu]_{30cm}$=0.0078 pv + 0.0238
40 cm	$[Cu]_{40cm}$=0.0073 pv + 0.0277
50 cm (effluent port @ end of column)	$[Cu]_{50cm}$=0.0073 pv - 0.0828

**Note: $[Cu]_{x\ cm}$ denotes the amount of Cu in units of mg/g soil at *x* cm section along the column leaching cell; pv = number of pore volume of leachate reacted with the soil

The correlations may be used to estimate the amount of metal in each fraction that is attached to the clinoptilolite when it is used as a reactive barrier substrate. If the amount of leachate is known, the amount of metal partitioning may be found.

Figure 6.39 shows the amount of Cu that could be retained on the clinoptilolite at each soil depth along the column. Soils closest to the feed (0-10 cm depth) retained the largest amount of Cu, whereas the amount of Cu on soils farthest away from the feed (40-50 cm depth) was the least. The derived equations could be used to estimate the amount of Cu after the designated number of pore volumes has passed through. When the amount of Cu that is present on the soil is found, the partitioning of metals could be estimated from Figure 6.40.

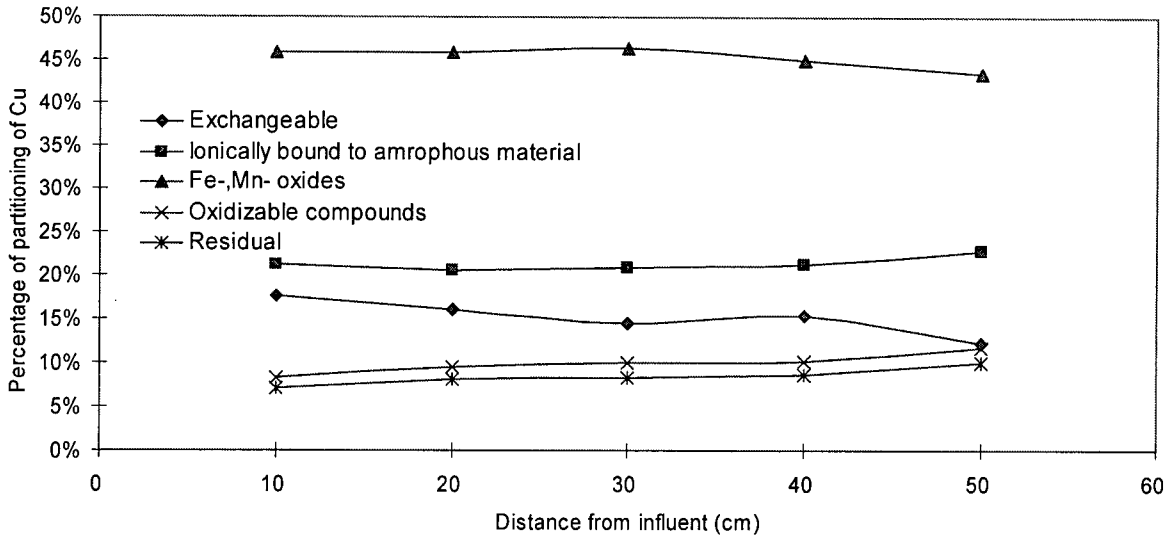

Figure 6.40 Percentages of partitioning of Cu in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizable compounds and residual fraction along the length of the column leaching cell

Variation of the distribution of the partition of each sequential extraction fraction was anticipated and is shown in Figure 6.40. Once the amount of metal was found and the location of the sample within the column was designated, the percentages of each fraction of metals and in which fraction they are attached, may be determined. Results from Figure 6.40 indicated that most of the Cu retained was attached to the Fe- and Mn- oxide fractions. It also indicated that less Cu was attached to the soil in the column farther away from the source. This agrees with the retention kinetics that Cu ions were attached to the exchangeable sites as a priority to other sites, hence there are more exchangeable Cu in the soil sections closer to the source.

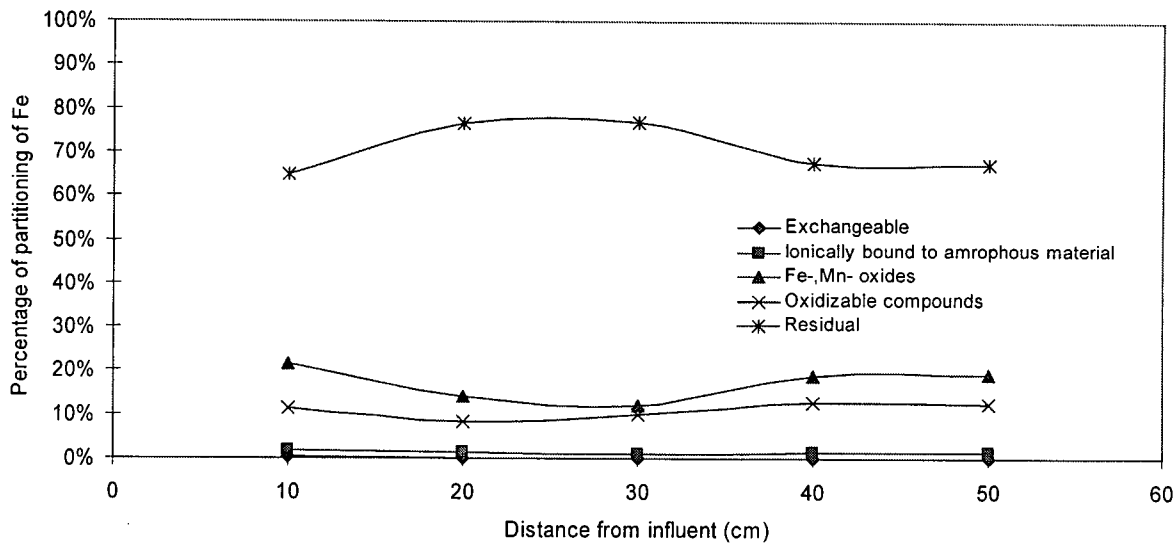

Figure 6.41 Percentage of partitioning of Fe in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizable compounds and residual fraction along the length of the column leaching cell.

About 2 mg of Fe was found in every gram of clinoptilolite. More than 75% of it was present in the residual fraction. Based on mass balance calculation, the amount of Fe from soil extraction far exceeded the amount of Fe that was introduced by the leachate. The excess Fe was derived from the structure of the clinoptilolite. The difference in the extraction is approximately 10% of the total Fe found before subtracting the background concentration of the

pretreated clinoptilolite. An average of the Fe found in the tested clinoptilolite is approximately 2 mg in every gram of soil. Although a correlation does not exist for Fe, it is possible to relate the percentage of Fe partitioning with respect to distance along the column from the influent, and it is shown in Figure 6.41.

Results from Figure 6.36 show that approximately 0.07 mg Mn was found on each gram of clinoptilolite. Retention of Mn on clinoptilolite was dominated by those bound to oxidizable compounds, followed by Fe- & Mn- oxides fraction, then exchangeable and residual portion.

A general trend was observed that Mn content was highest in soils closer to the influent, and gradually decreased along the column (Figure 6.42). However, difficulties have been encountered in the extractions of Mn because of its instability in oxidizing conditions, such as those during the strong acid/oxidizing extractions. This might have caused the inaccuracy in the measurements.

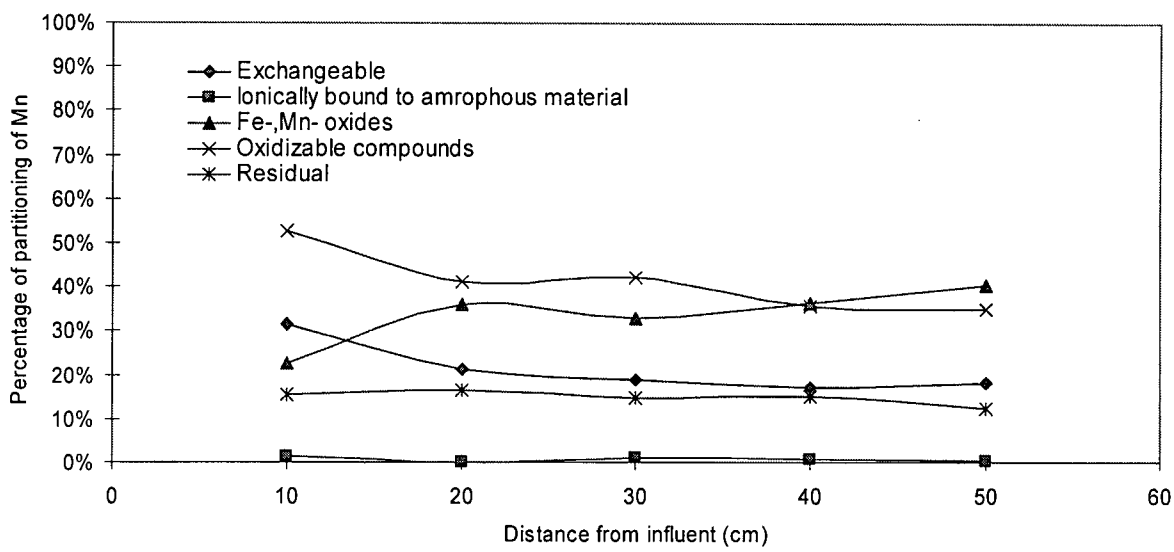

Figure 6.42 Percentage of partitioning of Mn in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizing compounds and residual fraction along the length of the column leaching cell.

The retention of Zn was correlated between the amount of Zn on clinoptilolite and the numbers of pore volumes leached through the column leaching cell are shown in Figure 6.43.

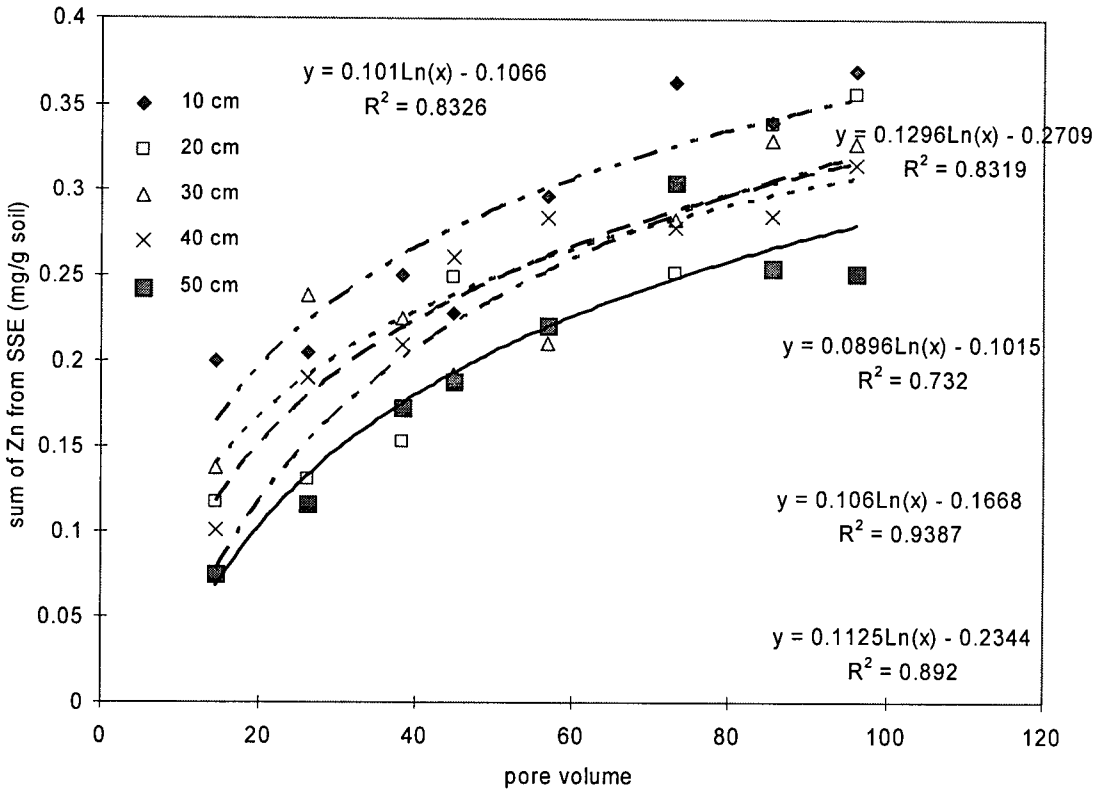

Figure 6.43 Correlations between the sum of amount of Zn from SSE with pore volumes

Table 6.7 Empirical relationships between the sum of the amount of Zn on clinoptilolite with the amount of leachate reacted

Soil section along the leaching cell	Empirical relationships
10 cm	$[Zn]_{10cm}$=0.101 ln(pv) – 0.1066
20 cm	$[Zn]_{20cm}$=0.1296 ln(pv) – 0.2709
30 cm	$[Zn]_{30cm}$=0.0896 ln(pv) – 0.1015
40 cm	$[Zn]_{40cm}$=0.106 ln(pv) – 0.1668
50 cm (effluent port @ end of column)	$[Zn]_{50cm}$=0.1125 ln(pv) – 0.2344

**Note: $[Zn]_{x\text{-}cm}$ denotes the amount of Zn in units of mg/g soil at x cm section along the column leaching cell; pv = number of pore volume of leachate reacted with the soil

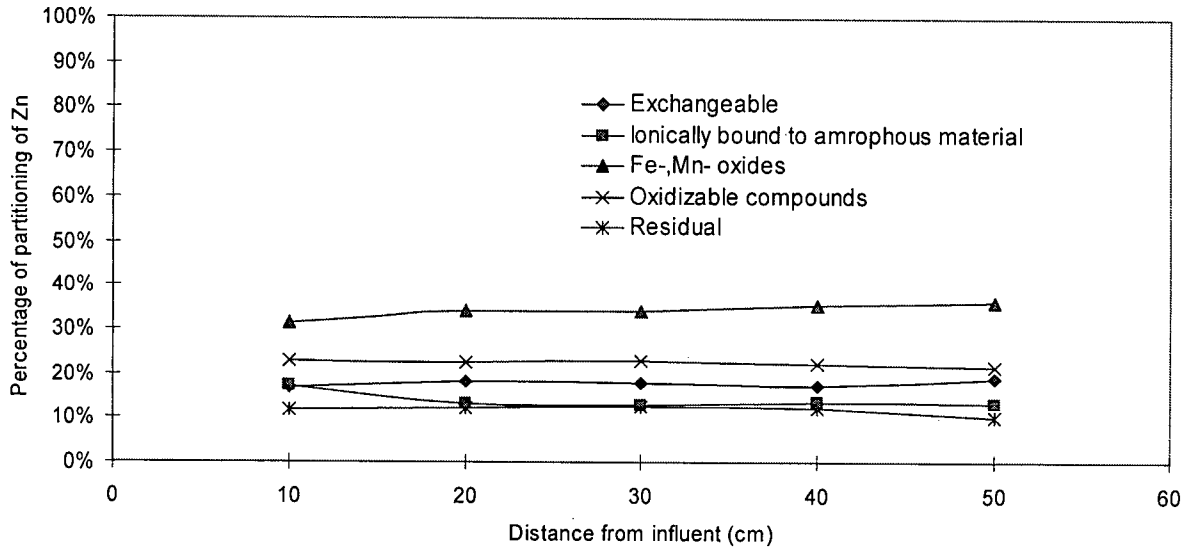

Figure 6.44 Percentage of partitioning of Zn in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxdies, oxidizable compounds and residual fraction along the length of the column leaching cell

Retention of Zn related to the number of pore volumes flowing through the column leaching cells are given by the equations shown in Table 6.7. Results showed a clear trend that more Zn was retained on clinoptilolite located closer to the source, and decreased with distance along the column. The partitioning of Zn on clinoptilolite was preferentially held in the Fe- & Mn-oxides fraction, followed by oxidizable compounds, exchangeable, ionically bound to amorphous materials and in residual portion.

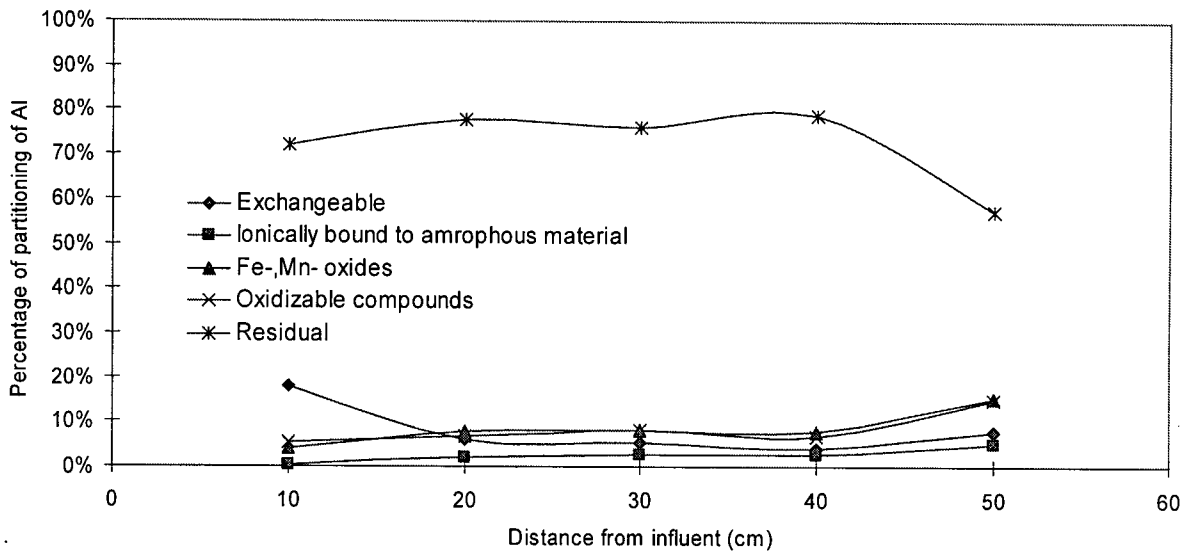

Figure 6.45 Percentage of partitioning of Al in the form of exchangeable, ionically bound to amorphous materials, bound to Fe- & Mn- oxides, oxidizable compounds and residual fraction along the length of the column leaching cell

Figure 6.45 shows that decreasing amount of residual Al was found on the clinoptilolite with distance. A majority of the Al (~70%) was present in the residual form as shown in Figure 6.45. This portion of Al may have come from the structure of the clinoptilolite. It was also indicated that a lesser amount of Al was present in the residual form beyond 40 cm from the source, along the column. The percentages of Al present in other fractions, such as Fe-, Mn-oxides and oxidizable compounds, showed a slight increase. This correlation could be explained that Al was able to attach to other fractions once the amount of Al attachment allowed for the residual portion was exhausted. However, other fractions, excluding residual, remained at constant levels on soil sections up to 40 cm from the source.

6.4 Design of Clinoptilolite Permeable Reactive Barrier System

Permeable reactive barrier (PRB) systems are designed to remove contaminants from a penetrating groundwater plume, providing an effluent with contaminants of concern are at acceptable levels. The proposed use of the clinoptilolite PRB system in this study is to remove metals (Cu and Zn) and neutralize acidic rock drainages from acid-generating mine sites.

6.4.1 Conceptual design of the clinoptilolite permeable reactive barrier

The clinoptilolite PRB is to be used as a treatment system for ARD groundwater. The purpose of the PRB system is to minimize the migration of metal cations and to neutralize the pH of the acid rock drainages. While the PRB serves as a mitigation of metal transport, control of acid generation is also expected to be carried out as a permanent solution for the acid drainage problem.

The clinoptilolite that was chosen to be used as the barrier substrate of the PRB for the treatment of ARD has been tested for its suitability (chemical and physical stability, metal retention capacity) through a series of chemical characterization, batch adsorption tests, and column leaching tests. Summary of the findings were presented in Chapters 4, 5 and 6. Acid rock drainage from the Britannia Mine was used in this study. Information obtained from these tests is representative and applicable to treatment of acidic drainages with similar chemical characteristics and compositions. However, determination of the amount of substrate needed and the thickness of the PRB is dependent on various factors, such as the width and depth of the contaminated plume, groundwater flow condition and the chemical characteristics of the groundwater plume.

6.4.2 Recognition of time frame

The service life of the permeable barrier may depend on the requirement of the installer, the cost restraints, and on-site factors such as available spaces for placement. However, considerations regarding the justification of the expected service life of the permeable reactive barrier system may include:

- The longer the expected service life of the reactive barrier system, the larger the amount of substrate is required. Hence, a larger area is required on-site for the placement of the barrier system. At the time where limited thickness of barrier could be installed on-site, the substrate may have to be removed and replaced more frequently to maintain a groundwater plume that meets the effluent criteria.
- If the designated service life of the barrier system is too long and the thickness of the barrier system becomes too large, it is possible that clogging of the barrier system may occur at the rear end of the barrier system, , creating a plug to the flow of an ARD plume. The reason is that at the rear end of the barrier system, where the groundwater plume is being introduced, may be exhausted in surface exchange and adsorption, and that precipitants has started to build up enough to clog the pores within the barrier material. Hence, itt is recommended that monitoring of the groundwater quality and flow conditions be conducted throughout the course of treatment period, and along the thickness of the barrier system.
- Although it may be more costly on a unit basis for a barrier system with smaller thickness than that of a greater thickness, it is suggested that a barrier system be designed to handle a contaminated plume for a defined time, rather than to serve for an infinite life-time. This will ensure that the effluent meets the regulatory criteria and does not affect flow conditions at the study site.

6.4.3 Design parameters

Design of the clinoptilolite PRB is mainly based on the mass loading of the clinoptilolite in accordance with the flow rates and the metal concentrations in the contaminant plume. The retentions of metals in column leaching cells with various flow rates and concentrations of leachate, flow time, breakthrough of chemical species, and the amount of metals retained on the clinoptilolite in the column leaching cells were discussed in Sections 6.2 to 6.3.

In summary, correlations were observed for the retention of Cu and Zn onto the clinoptilolite in the column leaching cells. The relationship between the total amount of metals retained on clinoptilolite to the amount of metals that has passed through the column is shown in Figure 6.46. It indicated that concentrations of Cu and Zn were proportional to the mass loading; the empirical relationships are presented in Table 6.8.

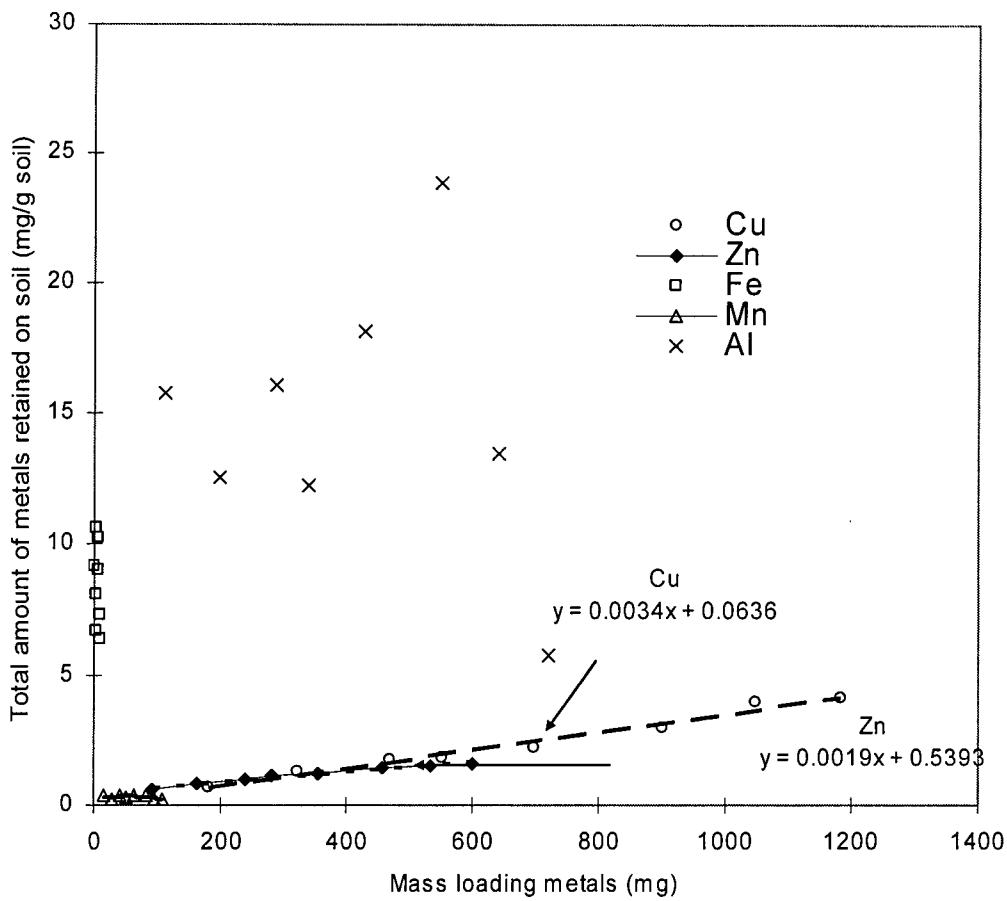

Figure 6.46 Correlations between mass loading and the amount of metals on soils

Table 6.8 Empirical relationships between the total amount of Cu and Zn retained on clinoptilolite with mass loading in the column leaching cell

Metals	Empirical relationships
Cu	$[Cu]_{total} = 0.0034 \times$ [mass loading] + 0.0636
Zn	$[Zn]_{total} = 0.0019 \times$ [mass loading] + 0.5393

**Note: $[Cu]_{total}$ denotes the total amount of Cu in units of mg/g soil in the column leaching cell; [mass loading] = total amount of metals passed through the column = number of pore volumes × concentration of influent, mg

In determining the amount of substrate that is needed in a permeable reactive barrier system, the above relationship could be used to estimate the amount of metals that could be retained on the soil when the mass loading (concentration × volume of leachate) requirement is given. From the amount of metals that would be retained on the clinoptilolite, and from the effluent requirement, the amount of substrate could be determined.

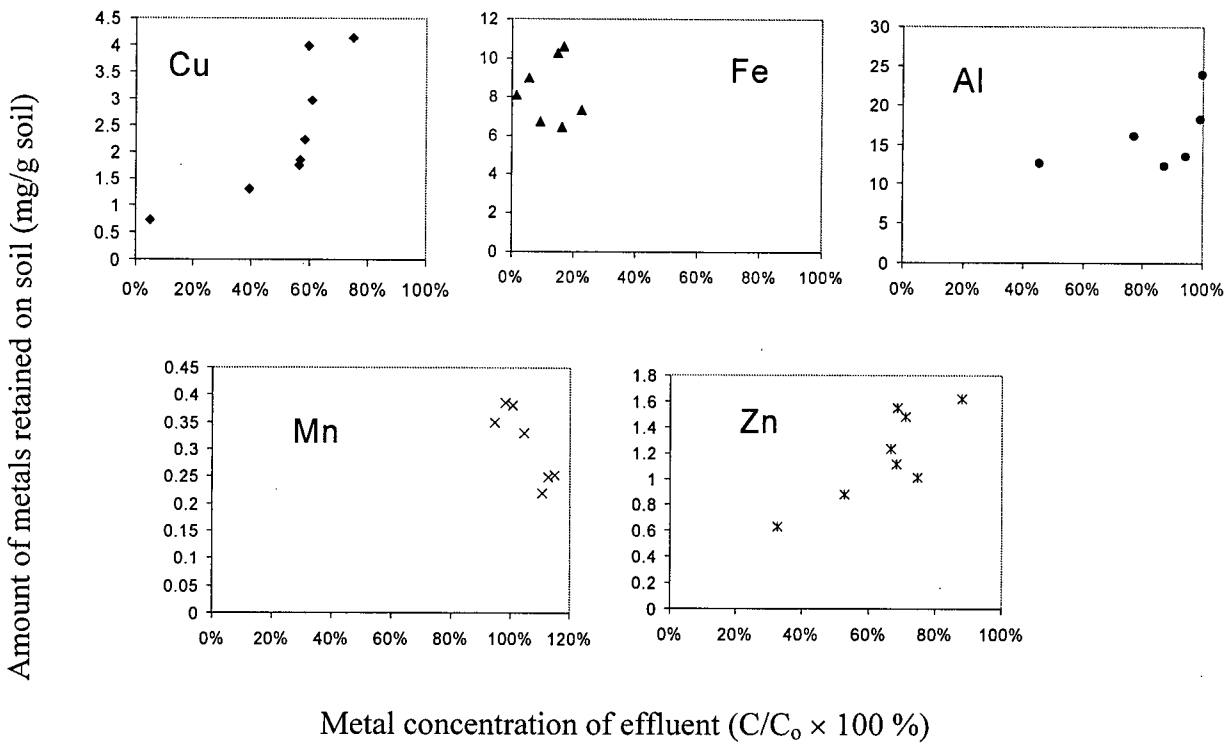

Figure 6.47 Relationship of the amount of metals retained on clinoptilolite to the metal concentrations in the effluent in column leaching cells

Shown in Figure 6.47 are the relationships of the amount of metals that were retained on the clinoptilolite at various effluent concentrations obtained from column leaching tests. In the design of a barrier system, for example, if the mass loading of Cu was 1000 mg, from Figure 6.45 or Table 6.8, the amount of Cu that could be retained on the clinoptilolite would be about 3.46 mg/g of soil. This means that the barrier would require 289 g of soil for the barrier system. As a safety factor, if 500g of clinoptilolite was placed, that means 1000 mg Cu/500 g soil, which is 2 mg Cu/g soil, from Figure 6.47, the effluent concentration would be approximately 45% of the effluent after the plume has passed through the barrier system. In the design of a permeable reactive barrier, the thickness of the reactive barrier wall would be equal to the volume of substrate that is required, divided by the cross-sectional area of the spread of the contaminant plume in the cross-section.

Based on the mass loading (which equals influent concentration, time and volume of flow) and the flow rate, the amount of substrate required in the barrier system could be determined. Subsequently, with the aid of the geochemical model, the breakthrough of the contaminant with the corresponding flow rate, dimensions of the barrier system, retention time, influent concentration, and the amount of materials could be predicted. The geochemical model development is discussed in the following Chapter 7.

6.4.4 Application of clinoptilolite PRB in a hypothetical ARD scenario

A hypothetical scenario is setup to illustrate a possible use of clinoptilolite PRB:

- Effluent Chemical composition comparable to that of the Britannia Mine drainage, concentration of [Cu] = 35 mg/L, [Zn] = 20 mg/L, pH 3.28
- Contaminated groundwater plume of width of 30 m, and depth of 2 m
- Groundwater table at depth of 3 to 4 m
- Required effluent concentration: 1 mg/L of Cu and 1 mg/L Zn (Environment Management Act, BC Approved Water Quality Guidelines criteria for marine aquatic life is 0.003 mg/L for Cu and 0.01 mg/L for Zn), it is anticipated that dilutions would occur when the groundwater plume travels down to the receiving water bodies. It is also assumed that there is no direct receptor from the discharge and the distance to the receptor is significantly away from the discharge.
- Minimum of 10 years of service life (5 years of peak concentration, 5 years of receding flow and concentration), then source of the drainage will be controlled with other means at the source. An illustration of the timeline of the ARD distribution is presented in Figure 6.48.

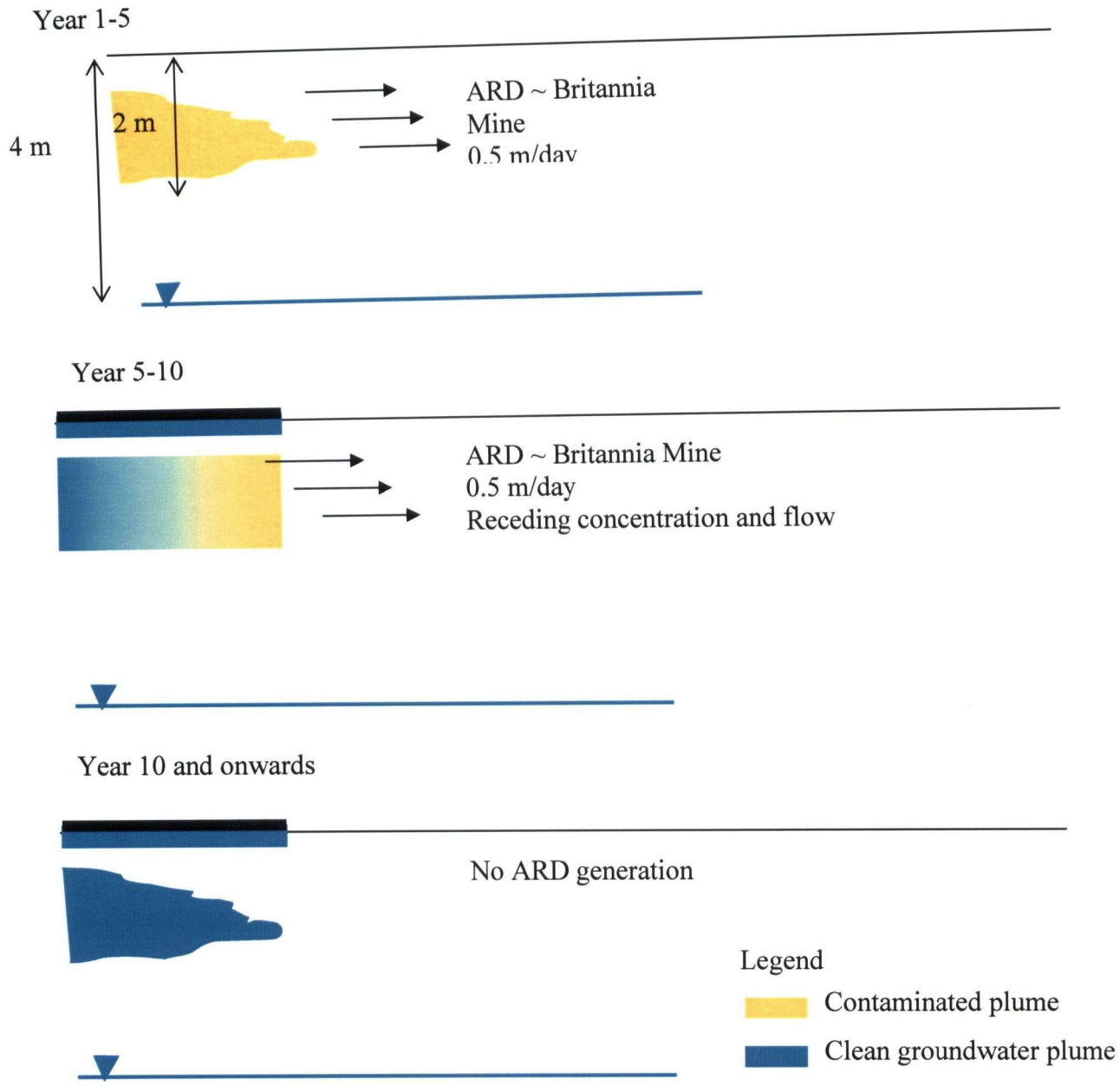

Figure 6.48 Illustration of the hypothetical problematic ARD scenario

The placement of a clinoptilolite PRB is designed to intercept the contaminating plume, while preventing the contaminating plume from intercepting with the clean plume of groundwater. The PRB is designed to be installed at a depth of 3 m. A continuous trench PRB consists of a metal loading zone for intensive metal loading and a refining zone for retaining metals to a concentration as required is configured and presented in the following (Figure 6.49 and Table 6.9):

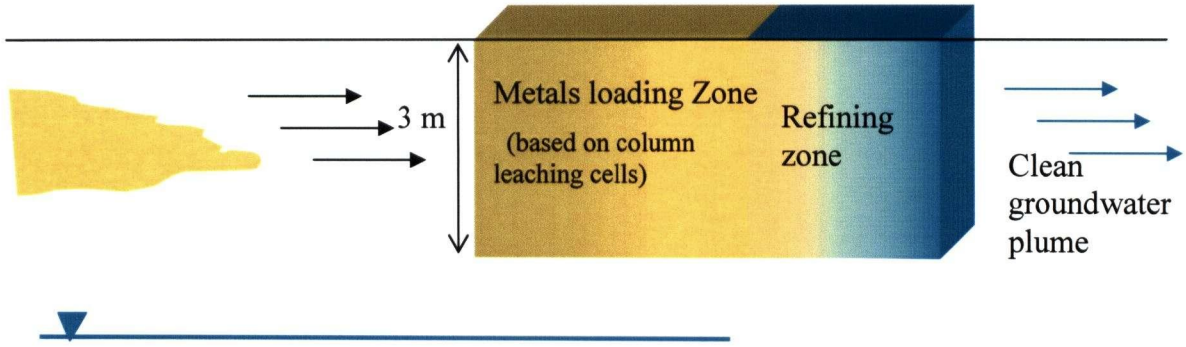

Figure 6.49 Configuration of a clinoptilolite PRB system in a hypothetical problematic ARD scenario

In a clinoptilolite permeable reactive barrier system, the costs of clinoptilolite ranges from $100 to $200 per tonne, which averages to about $150 per tonne. The costs associated with the clinoptilolite permeable reactive barrier may include:

Table 6.9 Costs associated with a clinoptilolite PRB in the hypothetical ARD scenario

	Costs
Amount of clinoptilolite required to handle the mass loading at the flow conditions (average flow rate = 10 L/s, [Cu] = 35 mg/L) are estimated to be: $Cu\ loading = \frac{3.15\times10^5 m^3}{yr}\times\frac{35mg}{L}\times\frac{1000L}{m^3}\times 10yrs = 1.1\times10^{11} mg$ Capacity of the clinoptilolite substrate = $5\frac{mg\ Cu}{g\ soil}$ Amount of clinoptilolite needed to handle the mass loading (obtained from column leaching test at breakthrough, C/C_o = 50%): Placement density = 1127.75 kg/m^3 $\frac{1.1\times10^{11} mg}{5\frac{mg\ Cu}{g\ soil}} = 2.2\times10^{10} g\ soil$ $= 2.2\times10^7 kg\ soil = 2.2\times10^4 tonne\ soil = 1.95\times10^4 m^3 soil$ $\approx$ 20,000 m^3 clinoptilolite Amount of clinoptilolite needed to refine the plume: $\frac{5.5\times10^{10} mg}{0.65\frac{mg\ Cu}{g\ soil}} = 8.48\times10^{10} g\ soil$ $= 8.48\times10^7 kg\ soil = 8.48\times10^4 tonne\ soil = 7.52\times10^4 m^3 soil$	
The cost of clinoptilolite $(2.20\times10^4 + 8.46\times10^4 tonne\ soil)\times\frac{\$150}{tonne}$	\$15.99million
Emplacement costs – ranges from US\$3 –12/ft^2 depending on the emplacement method. The most common emplacement method is the continuous trenching, which costs US\$5-12/ft^2, the maximum depth of the emplacement is around 35-40 ft The cost of installation using continuous trenching method, $(1.95\times10^4 + 7.52\times10^4)m^3 = 3.34\times10^6 ft^3$ Depth of the trench = 10 ft $\frac{3.34\times10^6 ft^3}{10\ ft}\times\frac{\$8.5}{ft^2}$	\$2.84 million
Total cost = cost of soil + emplacement costs	\$18.83 million
Cost per litre (3.15×10^{9}L)	*\$0.00597/L*
cost per gallon (8.32×10^{8}gallons)	*\$0.0226/gallon*

The treatment cost of the ARD per gallon using the PRB system is estimated to be 2.26 cents. If a conventional water treatment facility is to be used for the same flow conditions as described in the hypothetical scenario, the estimated cost incurred are shown as follows:

Table 6.10 Costs associated with a water treatment facility for the hypothetical ARD scenario

	Costs
Construction, equipments (based on flow rate and volume to be handled)	$5.1 million
Collection system	$165,000
Sludge pond (estimated life span 15 years) and sludge disposal	$275,000
Operating – $1.35 million/year (reagent cost, labor)	$13.5 million
Total cost	$19.04 million
Treatment cost per litre	*$0.00604/L*
Treatment cost per gallon	*$0.02288/gallon*

In the economic aspect, the costs of construction incurred with treatment facilities, labor and maintenance in conventional water treatment plant were excluded from the use of permeable reactive barriers. There is a high capital cost for the construction and maintenance of a water treatment facility. However, it is noted that on a long-term basis, since the cost of reagent is low comparable to the cost of PRB substrate, a conventional water treatment facility would provide a more economical feasibly treatment for ARD in high flow rate, concentration and long-term situations. Nevertheless, clinoptilolite PRB would be a more desirable treatment option for scenarios when flow rates and concentration of ARD is considered low, and that the treatment is anticipated to have a short or definite service lifetime. For example, clinoptilolite PRB would be an excellent option for minimizing metal transport in the subsurface while other means of permanent elimination or control of ARD sources are being developed or planned. The use of clinoptilolite PRB system may also prevent some of the on-going post-service maintenance, such as sludge disposal encountered in water treatment facilities. The time to take the reactive barrier to reach its contaminant retention capacity is dependent on the thickness of the barrier, the chemical characteristics, the flow rate, and the contaminant loadings of the contaminant

pluem. When the reactive barrier reaches its contaminant retention capacity, the substrate may be removed for off-site treatment, metal recovery, disposal, or be remain on the site, all depending on the soil and site conditions, as well as the requirement of the regulatory agency. Some of the possible post-service options of the PRB may include:

- Removal of PRB substrate

  Post-service clinoptilolite may be removed from the permeable reactive barrier system for metal recovery by soil washing or similar desorption processes. Since the permeable reactive barrier acts as a retainer/concentrator for metals in the ARD plume, metal recovery from the clinoptilolite is potentially more feasible. In addition, compared to metal recovery directly from acidic drainages, the amount of post-service clinoptilolite to be handled should be significant less than the total amount of drainages to be treated. However, this process requires removal, re-supply and/or replacement of barrier substrate, which may be costly and maintenance-intensive.

  The tested/post-service clinoptilolite may be used in applications such as agricultural purposes. Clinoptilolite has been used as a slow-release fertilizer in soils for various agricultural uses. Since post-service clinoptilolite from permeable reactive barriers for ARD contain some of the essential metals such as Cu for plant growth, and of a slightly acidic pH, it may be a suitable amendment to the soils for certain types of plants, for example, tomato and blueberry plants.

- PBR substrate remain on site

  Depending on the pH, flow rate, ionic strength and the concentration of the groundwater plume, the metal mass loaded in the clinoptilolite substrate may remain in or be washed off from the substrate material of the PRB. It is noted that if the same mineralogical characteristics are present at the site, the matrix and ionic strength of the

groundwater plume would remain the same as that of the contaminated plume; therefore, metal masses on the substrate material are not anticipated to be leached out from the substrate material.

Yet, in cases where pH lowers, ionic strength increases, it is anticipated that only the exchangeable portion that has been retained on the substrate material be leached out. Therefore, even though the barrier substrate may stay in place after 10 years, the amount of metals reloaded into the groundwater plume is expected to be minimal.

- It is recommended that monitoring wells be installed at the PRB system and that soil samples be obtained regularly for the monitoring of soil and groundwater quality. After the service of the clinoptilolite barrier system, if the soil is classified as a special waste, proper relocation of the substrate to the appropriate treatment facility or for metal recovery should be completed. It is also recommended that leachability of contaminants from the soil be conducted using leaching extraction procedures to determine the feasibility of metal recovery.

6.4.5 Design recommendations

It should be noted that the PRB system is not a permanent solution to ARD. It is a means of treatment of acidic drainage plume by removing metals cation and increasing the pH of the contaminated plume. It may also help minimize the environmental impact of the receiving groundwater and the receptors in the receiving water bodies. The performance of the PRB is dependent on the mineralogy of the native rocks, the chemical composition of the acidic drainage, as well as the seasonal variation in flow rate of the drainages.

It is recommended that preliminary tests be at least conducted in the design stage of the PRB system for the compatibility between the clinoptilolite substrate with the acidic drainages. During this study, the maximum retention capacity of the substrate was obtained from the batch

tests, whereas the retention of metals when a constant plume of groundwater penetrates the PRB system was obtained from the column-leaching tests. This simulation of flow conditions provided conservative estimation on the retention ability of the clinoptilolite as anticipated in field conditions. Although batch adsorption test may provide an estimate of the adsorption capacity in a much shorter time and simpler process than that of the column leaching tests, it may provide an over-estimation of the retention capacity of the substrate. In cases where a column leaching test is not accessible, a factor of 0.03 could be used for the estimation of Cu retention from batch test results. Therefore, as in the field application, results obtained from column leaching tests may provide a more representative estimation on the performance of the clinoptilolite as a PRB substrate.

It is also assumed that service life of the PRB would be longer than the anticipated service life calculated from the column leaching test results. This is because column leaching tests experiment was based on continuous flow of acidic drainages through the barrier system, whereas in field situations, fluctuation of flow rate and concentrations of metals in the acidic drainages is commonly encountered. In those cases, residence time of leachate in the PRB may vary and affect the performance of the PRB system because it may take time to define the capacity of the substrate. Hence, the results obtained from experimental testing at maximum concentration and flow rates are likely to under-estimate the performances of the PRB system, which gives a safety factor to the system when it is being placed on-site. Yet, preliminary tests for the compatibility of the substrate and the leachate should also be conducted.

CHAPTER 7 GEOCHEMICAL MODEL

7.1 Data Collection

The purpose of the geochemical model is to predict the chemical breakthrough of the permeable reactive barrier system with acid rock drainage. Results obtained from the experimental study were applied in the calibration of the geochemical model. Data required for the model calibration include: characteristics of the solid media (clinoptilolite), the properties of the leaching solution (ARD), the type of reactions and the respective reaction constants, and the configurations of the column leaching cell.

The overall aim was to apply the results from chemical analyses of the groundwater (ARD), the thickness of the permeable reactive barrier and the flow rate to determine the chemical breakthrough time of a plume that would pass through a permeable reactive barrier.

7.1.1 Characterization of solid media

The composition of the solid media, clinoptilolite, is defined using the EXCHANGE, SURFACE and EQUILIBRIUM_PHASES data blocks. The chemical and mineral compositions of clinoptilolite were obtained from x-ray fluorescence and x-ray diffraction analyses respectively, as reported in Section 3.2.2.

Composition and properties of solid media

Clinoptilolite was used as the solid media in the column-leaching tests. The chemical composition and the physio-chemical properties of the clinoptilolite were described in Section 4.2. In the geochemical model, the solid media is defined according to its retention characteristics. Retention of metals on the clinoptilolite include: (i) ion exchange on permanent

charge surfaces, which is defined within the EXCHANGE data block, and (ii) surface complexation on variable-charge surfaces and precipitation, which are defined within the SURFACE data block. Ion-exchange calculations involve small cationic species, such as Cu^{2+}, Na^{+} and Al^{3+}. The clinoptilolite exchanger is defined having a fixed cation-exchange capacity (CEC) of 121.56 meq/100g as reported in Section 4.2.

Mineral compositions

The mineral composition of the clinoptilolite is defined within the EQUILIBRIUM_PHASES data block. The mineral composition of the clinoptilolite was determined by the x-ray diffraction analysis as described in Section 3.2.2.

7.1.2 Characterization of groundwater

Analysis of the groundwater, in this case ARD was conducted as described in Appendix A-2. Chemical composition of solutions was defined in the SOLUTION data block. The leaching solution through the column is defined as SOLUTION 0 and SOLUTION 1-5, and represents the solution present within the pores of the solid media in cells 1 to 5. Parameters included in the SOLUTION data block include the pH, pe, temperature and the major ionic concentrations.

7.1.3 Assumptions in the model

The assumptions made in the construction of the model included:

- The leaching column is divided into five cells in the model, each of the cell measures 0.11 m in length. One liter of water is present in each cell and the amount of solid media in each cell is proportionalized to the volume of the pore water;

- The Langmuir isotherm equilibrium constant is equivalent to the single-site

surface-complex-formation constant. The Langmuir adsorption model ignores speciation, pH, competing ions, and redox states. It also describes both adsorption and precipitation.

- PHREEQC uses the ion-association and Debye-Huckel expressions to account for the non-ideality of aqueous solutions. This type of aqueous model is adequate at low ionic strength but may break down with higher ion strengths. The range of applicability has been used to extend the range of the aqueous model through the use of an ionic-strength term in the Debye- Huckel expressions. Theses terms have been set to the major ions using chloride mean-salt activity-coefficient data. Thus, in a sodium chloride dominated system, as found in the initial condition (NaCl pretreated clinoptilolite) in the leaching column in this study, the model may be reliable at higher ionic strength.

7.2 Construction of the model algorithm

7.2.1 Components included in the model

The organization of the algorithm in the geochemical model strongly depends on the type of geochemical reactions and the interactions between the components in the chemical system. The three main components in this geochemical model include:

- Solid media – clinoptilolite;
- Leaching solution and pore water – ARD and leachate; and
- Column leaching cell.

7.2.2 Types of geochemical reactions included in the model

EQUILIBRATE

The keyword EQUILIBRATE indicates that the exchange or surface assemblage is defined to be in equilibrium with a given solution composition. When an assemblage is placed in contact with a solution during a batch reaction, both the exchange composition and the solution composition will adjust to reach a new equilibrium.

EXCHANGE

From selective sequential extractions, it is indicated that the main retention mechanism for the major cations in the leaching solution on the clinoptilolite is by cation exchange. The EXCHANGE data block in the model defines that the clinoptilolite acts as an ion exchanger that possesses a cation-exchange capacity. The amount and the composition of the exchangers were defined based on the results obtained from the cation-exchange capacity (CEC) and the composition of extractable cations in the CEC determination.

SURFACE

The SURFACE data block takes into account the surface complexation reactions on the variable charge surfaces, such as on Fe, Mn, Al, Si - oxides and hydroxides, carbonates, sulphides and clay edges. The amount of hydrous ferrous oxide (Hfo) is defined in the SURFACE data block. Surface adsorption sites include Langmuir adsorption sites and hydrous ferric oxide. Langmuir isotherm rate constants of reaction were applied according to the results obtained from the multiple-species batch-adsorption-equilibrium tests of clinoptilolite with ARD background.

EQUILIBRIUM_PHASES

The data block EQUILIBIRUM PHASES defines the amounts of the assemblage of pure phases that can react reversibly with the aqueous phase, in this case, phillipsite. Since clinoptilolite is not included in the WATEQ4F database, phillipsite was used as the substitute for clinoptilolite in the EQUILIBRIUM_PHASES data block. Phillipsite was chosen because it is the most similar mineral to clinoptilolite listed in the WATEQ4F database. Phillipsite is a sub-category of zeolite, which also possesses similar cation selectivities as clinoptilolite (Ming and Mumpton 1989). Phillipsite is represented by the unit-cell formula of $(Na,K)_5\{Al_5Si_{11}O_{32}\}\cdot 20H_2O$. The major exchangeable cations of phillipsite are Na and K, which are the same as that of clinoptilolite—$(Na_3K_3)\{Al_6Si_{30}O_{72}\}\cdot 24H_2O$. Although phillipsite has a different proportion of Na and K in unit-cell formula than clinoptilolite, it was chosen in place of clinoptilolite because it provides equilibrium phase reaction constant information.

TRANSPORT

The TRANSPORT data block simulates 1-Dimensional (1-D) transport process that includes advection and dispersion, diffusion and diffusion into stagnant zones adjacent to the 1-D flow system. The advective-dispersive transport capabilities of PHREEQC are derived from a formulation of 1-D, advective-dispersive transport presented by Appelo and Postma (1993). The 1-D column is defined by a series of cells, each of which has the same pore volume (1 liter/cell). Cell lengths are defined for each cell and the time step gives the time necessary for a pore volume of water to move through each cell. Thus the velocity of water in each cell is determined by the length of the cell divided by the time step. At each shift, advection is simulated by moving solution in Cell 1 out of the column, solutions in Cell 2 to Cell 1, and so on, until the initial solution (Solution 0) is moved to Cell 1 (upwind scheme). With flux-type boundary conditions, the dispersion steps follow the advective shift and are alternated. After

each advective shift and dispersion step, chemical equilibria are calculated. The moles of pure phases and the compositions of the exchange assemblage and surface assemblage in each cell are updated after each chemical equilibration. At the end of advective-dispersive transport simulation, all the physical and chemical data (such as the compositions of solutions, equilibrium-phase assemblages, surface, and exchangers) are saved and identified by the cell number in which they reside for subsequent simulations within a single run.

7.2.3 Selection of model thermodynamic and kinetic data

The WATEQ4F database was used in this geochemical model. The file WATEQ4F.dat contains thermodynamic data for the aqueous species and gas mineral phases. The reason for using WATEQ4F instead of the PHREEQC database is that the WATEQ4F database contains additional data for the elements in the PHREEQC database file. The WATEQ4F database also contains additional equilibrium phase minerals such as phillipsite, which is not included in the PHREEQC database. Cation exchange data from Appelo and Postma, (1993) as well as surface complexation reactions from Dzombak and Morel (1990), are also included. In addition, the rate expressions in PHREEQC.dat were contained in the WATEQ4F.dat file. Therefore, the WATEQ4F was chosen as the database file in this study.

7.3 Script development of the conceptual model

An algorithm of the geochemical model designed for the leaching column experiment of clinoptilolite with acid rock drainage was developed. The model consists of six reaction data blocks. The algorithm first describes the chemical characteristics of the leaching solution (SOLUTION 0), which is acid rock drainage. The pretreatment solution (1M NaCl) is defined as the initial solution present in the clinoptilolite (SOLUTION 1-5). The amount of exchange

sites for cations, the amount and type of surface assemblage are defined explicitly in the EXCHANGE and SURFACE data blocks respectively. The amount and composition of the exchangers were defined based on the results from the cation exchange capacity and the type of exchangeable ions on the exchangers (clinoptilolite). The exchangers and the surfaces were programmed to equilibrate with the leaching solution (SOLUTION 0 – ARD); subsequently, transport of the remaining free chemical species was simulated. The script of the PHREEQC model for clinoptilolite leaching cell is listed in Table 7.1.

Table 7.1 PHREEQC script to calculate the concentration of metals from outlet of a clinoptilolite leaching cell

```
SOLUTION_SPECIES; H2O + 0.01e- = H2O-0.01; -log_k -9
TITLE clinoptilolite model
SOLUTION 0 ARD
    temp    20
    pH  3.28
    pe  13.22   units   ppm
    Ca  356.6;Cu    35.7;   Mg  64.7;  Al   24.6;   Fe  3.031;Mn    3.829;
    Na  8.8;S(6)    1140  as SO4;S(-2) 560.9  as S;Zn 24.2;   F   2.1;

END

SOLUTION 1-5 initial solution
    temp    25.0
    pH  7.58  charge
    units    ppm
    Na  10000;Cl    10000
end

EQUILIBRIUM_PHASES 1-5
    phillipsite  1.0 3.108
    pyrite
    quartz  1.0  1.76
    kmica   1.0  1.32
    jarosite-K 0 0
    jarosite-Na 0 0
    jarositeH  0 0
SAVE solution 1-5
END

EXCHANGE 1-5
    X   3.108
SAVE solution 1-5
end
```

```
SURFACE_MASTER_SPECIES
    L   L
SURFACE_SPECIES
    L = L
    log_k   0.0
#Langmuir: q=(L-1)*C/K1
    L + Cu+2 = LCu+2
        log_k   2.1186
    L + Fe+3 = LFe+3
        log_k   2.301
    L + Mn+2 = LMn+2
        log_k   2.0939
    L + Zn+2 = LZn+2
        log_k   2.5382
    L + Al+3 = LAl+3
        log_k   2.5379


SURFACE 1-5
    L   3.101       63.844  2557.73
    Hfo_s   0.0041  954.4 2773.069
    Hfo_w 0.164     954.4 2773.069
    no_edl
end

PRINT; -reset false
TRANSPORT
 -cells 5
  -length 5*0.11
  -shifts 500
  -time_step  17280
  -flow_direction  forward
  -boundary_conditions  flux flux
  -diffc  0.3e-9
  -dispersivity  5*0.00077
 -correct_disp  true
 -diff 0
  -punch 5
   -punch_frequency 1
  -warnings false


USER_GRAPH
-headings  PV Cu Fe Zn Al Mn pH
-chart_title "clinoptilolite"
-axis_titles "pore volume""ppm""pH"
-axis_scale x_axis 0   100 10  1
-axis_scale y_axis 0   50  10  1
-initial_solutions false
-plot_concentration_vs time
-start
-connect_simulations
10 graph_x (step_no+0.5)/5
20 graph_y
```

```
tot("Cu")*63546,tot("Fe")*55847,tot("Zn")*65370,tot("Al")*26982,tot("M
n")*54938
30 graph_sy -LA("H+")
-end
```

Description of the model codes and calibration of variables in the data blocks are described in Appendix K. The script shown in Table 7.1 was composed for column leaching cells of 0.5 m/day flow rate, using non-filtered ARD and pretreated clinoptilolite. Under different leaching conditions, values in the data blocks can be modified for the designated specifications.

7.4 Interpretation of modeling results

Chemical compositions at each effluent port were reported in the output of the model. 100 pore volumes of leachate were simulated to pass through the column. Modeling results are presented in Appendix K-2 and Figure 7.1.

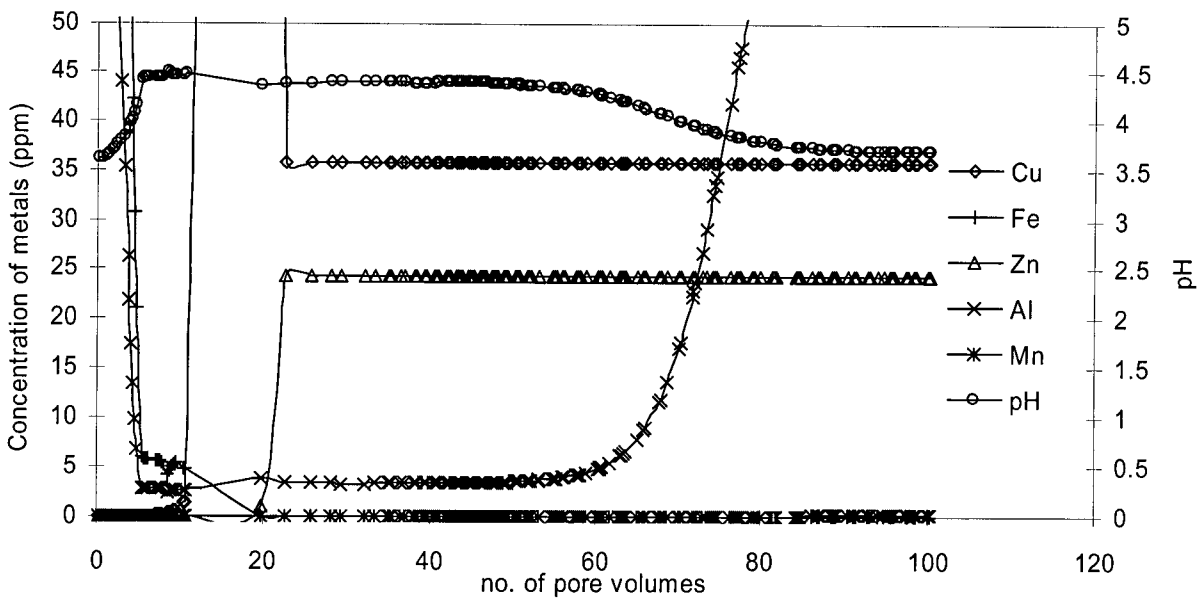

Figure 7.1 Model predictions for 0.5 m/day, non-filtered ARD leaching column with treated clinoptilolite.

Results from the geochemical model indicated that breakthrough of Cu occurred at 16 pore volumes, and approximately 32 pv from experiments under a flowrate of 0.5 m/day with natural ARD in a column leaching cell setting. A higher retention of Cu was detected in the experiment than that predicted in the geochemical model. The discrepancy between the predicted and observed results is an indication that some factors, other than cation exchange and surface complexation, were inhibiting the mobility of Cu ion in the experimental column leaching cell, these were not included in the algorithm of the geochemical model. Retention mechanisms that may have occurred in the experiment but were not accounted for in the geochemical model include: surface complexation of metals onto secondary minerals and attachments of metals onto precipitants formed during the sorption process (such as MnO). These were not included in the model algorithm of the clinoptilolite column.

The breakthrough of Zn occurred at about 20 pore volumes from geochemical model prediction. This agreed and was consistent with the experimental results.

The breakthrough of Mn from geochemical model prediction occurred at approximately 94 pore volumes; whereas in experimental study, breakthrough of Mn occurred at 75 pv. It indicated that either some factors were inhibiting the transport of Mn in the geochemical model, or other mechanisms might have enhanced the leaching of Mn in the experimental study.

The breakthrough time of Al from geochemical model prediction occurred at 70 pore volumes, whereas from experiments was at about 20 pore volumes. However, in the geochemical model prediction, Al concentration started to increase constantly after 60 pore volumes, even to a concentration higher than that of the influent concentration. This observation may have resulted from the drop of pH in the ambient solution and because Al was anticipated to be dissociated from the mineral structure. The concentration of Fe was

maintained at minimal concentration throughout the leaching cycle. This agreed with experimental results, as described in Chapter 6, that Fe was retained, by precipitation or other retention mechanisms in the system. The effluent reached an equilibrium pH of around 3.7, which agreed with the experimental results. A comparison of the breakthrough times obtained from the experiment and geochemical model is presented in Table 7.2.

Table 7.2 Comparison of the breakthrough volumes from geochemical model and experimental results

Element	**# of pore volumes at chemical breakthrough**	
	Geochemical model	**Experimental**
Cu	16	32
Zn	20	20
Fe	-	-
Mn	94	7.5
Al	60	20

7.5 Model predictions

The purpose of the geochemical model was to predict the chemical breakthrough within the clinoptilolite permeable reactive barrier system when leached with acid-rock drainage. Validation of the model was conducted by applying design parameters and the respective values from experimental column leaching tests into the model algorithm, and by comparing the geochemical model results to that obtained from experiments.

A comparison of the experimental and model results confirms that the model produces realistic results with Zn, Fe at the pH level of the effluent. The geochemical model for the clinoptilolite barrier system has under-predicted the capacity of the clinoptilolite to retain Cu. Breakthrough time of the Cu gave an over-conservative estimation of service life of the PRB. However, the prediction of Cu could be estimated by applying an adjustment factor of 2 in the breakthrough volume. The leaching of Mn has been underestimated in the

model, that it takes approximately 10 times longer than the observed experimental breakthrough.

Sensitivity analysis on the geochemical model was conducted by varying: (i) the composition of substrate; (ii) amount or ratio of surface complexation sites of hydrous ferric oxides (HFO); (iii) dispersivity; and (iv) range of concentration of metals that could occur in the ARD of the Britannia Mine drainage (concentration of Cu up to 110 mg/L). Among these factors, the geochemical model was most sensitive to the definition of the composition of clinoptilolite. The precision with which the clinoptilolite composition was defined could affect the retention of metals associated with the amount of surface or cation exchange sites. This definition of the mineral composition of clinoptilolite sample may also affect the amount and type of secondary minerals, which play an important role in the retention reactions.

Other factors such as the residence time (which is related to the flow rate) of the contaminant within the barrier system, dispersivity, influent concentration and density of the PRB system were also investigated in the sensitivity analysis. The effects of these factors on the retention of metals were significant.

7.6 Limitations and Possible sources of errors

Comparison of the results obtained from the geochemical model and the column leaching cell experiments indicated that there existed some computational gaps between the two. It is known that limitations of the geochemical model and possible sources of errors may exist that have caused the incompleteness of the prediction. They include:

- The equilibrium constants for amorphous ferric ion hydrous oxide (amorphous Hfo) vary in different databases. The availability or absence of equilibrium constants for certain aqueous species and solids in the database produces incorrect modeling results or models. Most databases, including WATEQ4F.dat and PHREEQC.dat, do not have data for metal-organic complexes. Although metals attached to the oxidizing compound in the contaminated soil was found minimal from the experimental selective sequential extractions procedures, the presence of oxidizing compounds may indeed affect the concentrations of metals in the predictions.
- For solutions with high Al and sulphate concentrations, the solubility controls on Al^{3+} and SO_4^{2-} may not be correctly modeled because no equilibrium constants are available for Al-sulphate phases in the WATEQ4F database.
- The use of phillipsite has replaced the clinoptilolite (as used in clinoptilolite) in the geochemical model due to the limitations of the available minerals in the database, may have resulted inaccuracies in the retention calculation.
- Input constraints, such as accuracy and completeness of analytical data in the input of the model, may also influence the results of the geochemical model.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

The following discussions outline the conclusions of this study and recommendations for further investigations are proposed.

8.1 Conclusions

- The clinoptilolite used in this study is a suitable substrate for a permeable reactive barrier wall. Experimental results have shown that clinoptilolite is chemically stable in acidic mine drainage environments at pHs of 1.5 or higher. The clinoptilolite is able to maintain a hydraulic conductivity for handling flow rates of contaminated plumes for typical groundwater conditions at the Britannia Mine.
- The clinoptilolite studied was able to remove metal cations from natural ARD at the Britannia Mine. Adsorption isotherms obtained from batch adsorption tests of 0-1000 mg/L multiple species (Cu,Fe,Al,Zn) solutions with natural ARD background (pH 3.28) showed that the selectivity sequence of the metal ions on the clinoptilolite is $Cu^{2+} > Fe^{3+} > Al^{3+} > Zn^{2+}$. In batch equilibrium adsorption tests, there were 130.6 mg Cu/kg soil (63.8% of Cu), 22.65 mg Fe/kg soil (82.1% of Fe), 158 mg Zn/kg soil (39.5% of Zn) and 215.4 mg Al/kg soil (89.7% of Al) removal by clinoptilolite from the ARD (pH 3.28) of original concentrations of metals from the Britannia Mine.
- Mn was displaced from the surface of the bulk clinoptilolite when it was placed in acidic environment. The leaching of the surface metal ions was minimized by soil pretreatment using 1 M NaCl solution.
- Under field conditions (flow rate = 0.5 m/day, leached with natural non-filtered ARD) using clinoptilolite pretreated with 1M NaCl, the breakthrough time (50% of influent concentration) of Cu in a 0.5m long column leaching cell occurred at approximately 60 pore

volumes. The breakthrough volume for Mn, Zn and Al were 13, 45, and 38 pore volumes respectively. Fe concentration in the leachate was low, mainly due to precipitation of Fe_2O_3.

- Adsorption of metals on the clinoptilolite was found to be dependent on flow rates, influent concentration and pretreatments. The results from batch adsorption tests are approximately 40% higher for retention of solute from the solution than using a column leaching test with the flow rate simulated to maximum field conditions (2 m/day). This over-estimation by the batch adsorption test may lead to an under-estimation of the thickness of the materials that is required for a permeable reactive barrier, and hence there is an over-estimation of the service-life of the barrier system. The kinetics of retention must be carefully considered in the design of a reliable and cost-effective reactive barrier system. The comparison of the concentration effect in the leaching solution showed that there were no differences in the amount of metal adsorption on the soil until after the first hour of reaction. However, a higher retention of copper was detected after the 24-hour reaction period, with greater Cu concentration in the initial leaching solution. Column leaching tests conducted with 1 M NaCl pretreated clinoptilolite showed that leaching of Mn was reduced. Filtering of ARD prior to entering column leaching cells has shown decreased adsorption of metals on the clinoptilolite. The decrease in adsorption mainly related to the decreased number of adsorption sites associated with the precipitates in ARD such as Fe- and Mn- oxides, as well as the oxidizable compounds in the non-filtered ARD.
- Results from selective sequential metal extractions and total digestion on the tested clinoptilolite indicated that the partitioning of metals in the various depths along the column was distributed uniformly through the column. Copper and zinc were observed to have consistent patterns in metals attenuation, with respect to both time and distance along the column from the influent. Fe was found mainly precipitated in the form of Fe- oxides and

with oxidizable compounds. Al leaching from the structure of the clinoptilolite was detected during metal extraction procedures. Mn retention was minimal because of the low selectivity, the influent concentration of Mn in the ARD composition, and its instability in the oxidizing environment. The retention of Cu and Zn on soil was correlated with the flow rate, concentration of ions in the influent, and the mass loading. Fe was precipitated under the conditions (pH and pe) that occurred in the column leaching cells. Results from the SSE demonstrated that metals that were ionically bound to amorphous material and attached to the oxidizing compounds found on the clinoptilolite sample, were extracted in the weak acid (used to remove carbonates), and strong acid/oxidizing (used to remove organics) extractions procedures, respectively. From column leaching tests, retention of metals on soil was greatly affected by flow rates or the residence time of the leachate within the pores. Slower flow rates provided more time for thorough wetting of the soil surface and adequate time for reactions to take place. A higher amount of metals was found retained on the clinoptilolite in column tests conducted with non-filtered ARD. This is reasoned by the presence of large amounts of complexation agents such as Fe- and Mn- oxides, amorphous materials, as well as an oxidizing fraction, e.g. hydroxides and sulphates in the ARD precipitates.

- Design of the clinoptilolite PRB was based on the mass loading of the clinoptilolite in accordance with the flow rate and the metal concentrations in the contaminant plume. For example, if a PRB system were to be placed for metal treatment for the contaminant plume at the 2200 Portal of the Britannia Mine (mean flow rate of 10 L/s, average Cu concentration of 21 mg/L), the amount of clinoptilolite needed for a PRB wall was estimated to be approximately 602 m^3 (or 1460 tonne). The thickness of the PRB would be a function of the mass of the clinoptilolite for emplacement and dependent on the width and depth of the contaminant plume. After determining the amount of the substrate for emplacement and the thickness of the wall, the breakthrough time of the designed PRB would be estimated using

the algorithm developed in the geochemical model PHREEQC. The prediction of the breakthrough time of Zn, Fe and pH by the geochemical model were comparable to that obtained from the experimental study. A higher retention of Cu was detected in the experiment than that predicted in the geochemical model. However, there were still limitations on the source code of the geochemical program to make precise predictions to the experimental results for Al and Mn.

8.2 Recommendations for further research

In the context of this research, there are a number of points that merit further consideration:

1. Long-term and pilot-scale study

It is recommended that a pilot-scale permeable reactive barrier of clinoptilolite substrate be installed, tested and monitored at the mine site. This would help collect realistic field data on the use of clinoptilolite as a reactive barrier substrate. The field data could also be collaborated with the laboratory data for comparison and prediction purposes. It is recommended that a longer study be conducted, since substrate material would remain on the site for a long period of time, once it is placed as a reactive barrier system.

2. Study on the performance of the barrier with varying flow rates and mass loadings

In this study, experiments were carried out in steady flow rates and with constant influent metals concentrations. However, in real practices, flow rates and metal concentrations in the ARD would vary accordingly with the weather, conditions of the waste rock and other hydrogeological factors. In terms of future designs of the barrier system, from the perspective of leaching with ARD of varying chemical compositions, the retention of metals may be different from the laboratory experiments. It is recommended that the retention of metals in varying flow rates and mass loading conditions be investigated.

3. Reduce Mn leaching and increase its retention on clinoptilolite

It is recommended to investigate and to enhance the stability and retention of Mn in the reactive barrier, although the concentration of Mn present in the contaminating plume does not exceed the effluent limit for mine waste disposal. Since the retained manganese oxides may

be beneficial in the adsorption of some of the trace metals, similar to the function of iron oxides.

4. Extraction of clinoptilolite using hydrofluoric acid

Improvement in the extraction procedures for Al should be investigated. Digestion of the clinoptilolite was conducted using nitric acid. Digestion of the clinoptilolite using hydrofluoric acid (HF) is recommended by the literature, but due to the laboratory limitations, HF digestion was not conducted. It is recommended that the clinoptilolite be digested using the recommended method to see if there are significant difference.

5. Clay fraction of clinoptilolite as liner material

In this study, clinoptilolite was used in its bulk particles sizes to maintain a certain hydraulic conductivity. Since results have shown that this clinoptilolite is effective in removing metal ions, it is suggested that the clay-sized clinoptilolite be separated and be investigated as a liner for other engineering purposes. The retention kinetics and the retention ability in clay-sized clinoptilolite would benefit future work by specifying retention and kinetic constants in the modeling. The model would be able to predict the reactions more accurately if the particle sizes were uniform (similar amount of interactions between soil and leachate on each particle). Physical stability tests, such as tri-axial tests conducted with acidic mine drainage, are suggested to investigate the physical stability of the clinoptilolite.

6. Recovery of metals and use of post-service clinoptilolite

Recovery of metals and re-use of the post-service clinoptilolite are suggested as topics for future researches. Since masses of metals were retained within the structure or on the surface on the clinoptilolite, instead of disposing the post-service clinoptilolite substrate, it is suggested to recover the metals, which were held within the clinoptilolite by back-flushing

(which could be done on-site) or soil-washing (on-site and off-site) to make the clinoptilolite available for re-use in the permeable reactive barrier system.

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APPENDICES

Appendix A Methods of chemical analyses

A-1 Selective sequential extractions on tested clinoptilolite 220
A-2 Water sample analyses.....222

Appendix B Chemical compositions of ARD and residue

B-1 Chemical composition of ARD.....224
B-2 Chemical composition of residues from ARD filtration.....225
B-3 Comparison of chemical compositions between filtered and non-filtered mine drainage from the 4150 Portal 226

Appendix C Mineralogical characteristics of clinoptilolite

C-1 Investigations of the X-Ray Diffractorgrams for semi-quantitative analysis of the mineral composition of clinoptilolite.....227
C-2 Major elements in the clinoptilolite sample by X-Ray Fluorescence (XRF) and Inductive Coupled Plasma (ICP) spectroscopy.....239
C-3 Compaction curve of clinoptilolite..... 242
C-4 Sample calculation for the compaction of material and its compaction properties . 243

Appendix D Langmuir Isotherm and Langmuir constant determination.....245

D-1 Adsorption isotherm of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in single species solutions.....248
D-2 Adsorption isotherm of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in multiple species solutions – Distilled water with nitric acid as background solution.....253
D-3 Adsorption isotherm of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in multiple species solutions – Natural acid rock drainage as background solution.....261

Appendix E Leaching of metals from clinoptilolite.....266

Appendix F Determination of pretreatment methods.....268

Appendix G Column leaching cell tests water sample analyses results.....270

Appendix H Column leaching cell tests soil analyses results

H-1 Results of metal fractionations on soil samples extracted from column leaching cells.....332
H-2 Numerical and graphical presentation of metal fractionations on soil samples after deducting background metal concentrations.....350

Appendix I Results of water sample analyses from Critical Path Analysis column leaching cells.....373

Appendix J Results of soil analyses on tested clinoptilolite from Critical Path Analysis leaching column cells

J-1 Results of metal partitioning on clinoptilolite extracted from leaching cell after 15, 26, 38, 45, 57, 73, 85, and 96 pore volumes.....406
J-2 Numerical and graphical presentation of metal partitioning on clinoptilolite after subtracting background concentration from 1M treated clinoptilolite.....415
J-3 Changes of the amount and percentage partitioning of metals (Cu, Fe, Mn, Zn, Al).....432

Appendix K Geochemical model development

K-1 Description of mode codes.....438
K-2 Model output.....448

Appendix A. Methods of chemical analyses

A-1. Selective sequential extractions on tested clinoptilolite

The chemical reagents used and the procedures are based on 1 gram (dry weight) of clinoptilolite sample.

SSE-0 Initial Rinse

1. initial rinse with 8 ml of distilled water
2. shake for 15 minutes in rotator
3. centrifuge @ 3500 rpm for 20 minutess
4. store supernatant for chemical analysis

SSE-1 Exchangeable cations

1. add 8 ml KCl
2. Agitate for 1 hour
3. centrifuge @ 3500 rpm for 20 minutes
4. keep supernatant for chemical analysis

SSE-2 Weak acid extraction (for removing metals ionically bound to amorphous materials)

1. 8 ml 1M NaOAc of pH 5.0 w/ HAOAc (Acetic acid)
2. agitate for 5 hours
3. centrifuge and keep supernatant for analysis

SSE-3 Weak acid/complexing agent extractions

1. 20 ml of 0.04M $NH_2OH{\cdot}HCl$ in 25% (v/v) HOAc
2. oven heat to 96 ±3°C for 6 hours (cap)
3. manually agitate occasionally for complete iron oxides dissolution
4. let cool and centrifuge and keep supernatant for analysis

SSE-4 Strong acid extraction (for removing metals attached to oxidizable compounds)

1. 3 ml 0.02M HNO_3 + 5 ml of 30% H_2O_2 adjusted to pH 2 with HNO_3 → put in oven @ 85 ±2°C for 2 hours w/ occasional agitation
2. 3 ml 30% H_2O_2 adjusted to pH 2 with HNO_3 → oven @ 85±2°C for 3 hours with intermittent agitation
3. after cooling → add 5 ml of 3.2M NH_4OAc in 20% (v/v) HOAc → dilute to 20 ml and agitate continuously for 30 minutes
4. centrifuge and keep supernatant for analysis

SSE-5 Residual Fraction -- Microwave application for acid extraction (Application Note EW-9, Revision 8-23-89) for sample type: soils & sediments

1. prepare 1:1 (v/v) solution of HNO_3:H_2O
2. transfer 1 g of sample into a vessel and add 20 ml of HNO_3:H_2O
3. place the sealing ring and cap on the vessel and then tighten the cap using the capping station → place the vessel in the turnable and attach a venting tube
4. turn the MDS-81D exhaust on to the maximum fan speed. Activate the turnable so that it is rotating
5. program time for 30 minutes and the power for 100%, press START key and allow to heat for 30 minutes (might try 50% power for 5 minutes first, if see red fume, turn off and let ventilate & cool, then turn on again)
6. allow vessels to cool to room temperature and then manually vent & relief excess pressure. [wear rubber glove when loosening ferrule to vent excess pressure to avoid acid burns from the fumes that released]
7. open vessels and quantitatively filter the solutions into containers for further analysis

A-2. Water sample analyses

pH of solution

The pH was measured using an Orion model 420A pH meter and VWR Symphony pH electrode. Calibration of the pH meter was conducted using pH 2, 4, 7, and 10 buffer solutions.

Reduction oxidation potential

Reduction-oxidation potential was measures using an Accumet pH meter 50 (Fisher Scientific, USA) and an ORP (oxidation reduction potential) electrode (Broadley James Corporation, Irvine, CA, USA).

Electrical conductivity

Electrical conductivity of water sample was measured using an Oakton CON 10 TDS/conductivity/^{o}C meter (Oakton Instruments, USA). The electrical conductivity meter was calibrated against standard 0.01 M KCl solution. Measurements were corrected to 25 ^{o}C.

Sulphates

Sulphates concentration was determined by the automated methythymol blue method (method no. 4500-SO_4^{2-}) using a Lachat QuikChem 8000 Automated Ion Analyser (Zellweger Anlaytical Inc, Lachate Instrucments Division, USA).

Dissolved oxygen

Dissolved oxygen content was determined by using Wrinkler method with azide modification method (method no. 4500-O) as described in the Standard methods for water and wastewater.

Chemical analysis – metal concentrations

Water samples were filtered out by using 0.45 μm pore-size membrane filter papers or obtained from soil-water mixture by centrifugation to separate particulates greater than 0.45 μm for metal analyses. Samples were acidified using 1:1 nitric acid:distilled water. Copper, iron, zinc, manganese and aluminum concentrations were determined by flame adsorption using a Thermo Jarrell Ash Video 22 Atomic Absorption Spectrophotometer (TJA Solutions, Franklin, MA, USA) and/or a SpectrAA 220FS Atomic Adsorption Spectrophotometer (Varian Scientific Instruments, manufactured in Mulgrave, Victoria, Australia). The concentration of potassium was determined from atomic emission (AE) (SpectrAA 220FS Atomic Adsorption Spectrometer, Varian Scientific Instruments manufactured in Mulgrave, Victoria, Australia).

Appendix B Chemical compositions of ARD and residue

Appendix B-1 Chemical composition of ARD

	Maximum design concentration Non-filtered		Maximum design concentration Filtered	
	Design concentration	Used in PTB 13,14	Used in PTB 3,4	Used in PTB11,12
Cu, mg/L	115	109.87	116.08	110.075
Fe, mg/L	56	49.46	29.21	8.712
Mn, mg/L	9.2	8.763	9.317	8.669
Zn, mg/L	49	44.4735	50.038	47.654
Al, mg/L	74	68.8	83.1	68.3
pH	2.7	2.93	2.68	2.96
Redox potential, mV		589.1	534.6	575.1
Specific conductivity, mS/cm		3.06	3.24	2.99

010902 ARD	Non-filtered			Filtered
	Non-filtered ARD	Used in NTNFC1,PTB1C1	Used in PTB15, 18	Used in PTB5,6,8,9,17
Cu, mg/L	35.679	34.86	36.23025	36.042
Fe, mg/L	5.467	11.23	10.74475	0.488
Mn, mg/L	3.284	4.21	3.61675	2.634
Zn, mg/L	23.3259	24.54	23.91685	23.57
Al, mg/L	32.74	--	34.85	30.71
pH	3.25	3.11	3.14	3.09
Redox potential, mV	526.4	512	504.9	476.3
Specific conductivity, mS/cm	2.08	2.05	1.988	2.05

Used in Critical Path Analysis columns		
	Field measurement At 4100 Portal (from PSC lab)	Filtered and adjusted ARD obtained from 4100 Portal
Cu, mg/L	23.6	37.991
Fe, mg/L	5.15	0.323
Mn, mg/L	4.69	3.475
Zn, mg/L	22.5	19.2104
Al, mg/L	30	23.17
pH	3.49	3.27
Redox potential, mV	392	560.5
Specific conductivity, mS/cm	2.3	2.31
Dissolved oxygen, mg/L	3.3	7

Appendix B-2 Chemical compositions of residues from ARD filtration

Element	Unit	Mine drainage residue
SiO_2	%	1.55
Al_2O_3	%	1.17
Fe_2O_3	%	64.16
MgO	%	0.16
CaO	%	0.17
Na_2O	%	< .01
K_2O	%	0.05
TiO_2	%	0.02
P_2O_5	%	0.13
MnO	%	< .01
Cr_2O_3	%	0.002
Ba	ppm	32
Ni	ppm	< 20
Sc	ppm	< 1
LOI	%	32.6
TOT/C	%	0.23
TOT/S	%	4.84
SUM	%	100.01

Element	Unit	Mine drainge residue
Co	ppm	< .5
Cs	ppm	0.1
Ga	ppm	4.8
Hf	ppm	< .5
Nb	ppm	< .5
Rb	ppm	1.1
Sn	ppm	< 1
Sr	ppm	10.2
Ta	ppm	< .1
Th	ppm	0.5
U	ppm	< .1
V	ppm	6
W	ppm	0.9
Zr	ppm	4.5
Y	ppm	2.1
La	ppm	1
Ce	ppm	6.5
Pr	ppm	0.53
Nd	ppm	3.1
Sm	ppm	0.8
Eu	ppm	0.14
Gd	ppm	0.73
Tb	ppm	0.12
Dy	ppm	0.62
Ho	ppm	0.1
Er	ppm	0.31
Tm	ppm	< .05
Yb	ppm	0.24
Lu	ppm	0.04
Mo	ppm	17.3
Cu	ppm	1258.9
Pb	ppm	40.9
Zn	ppm	77
Ni	ppm	0.3
As	ppm	29.8
Cd	ppm	0.2
Sb	ppm	4
Bi	ppm	0.1
Ag	ppm	0.3
Au	ppb	3.5
Hg	ppm	0.03
Tl	ppm	< .1
Se	ppm	0.7

Appendix B-3 Comparison of chemical compositions between filtered and non-filtered mine drainage from the 4150 Portal

Parameter	Unit	Filtered ARD	Non-filtered ARD	Percent Difference, %
pH	pH units	3.07	3.07	**0**
Hardness Total -T	mg/L	889	859	**3.49**
Sulfate	mg/L	1200	1210	**-0.83**
Aluminum	mg/L	40.3	39.7	**1.51**
Antimony	mg/L	< 0.05	< 0.05	--
Arsenic	mg/L	< 0.05	< 0.05	--
Barium	mg/L	0.01	0.031	**-67.74**
Beryllium	mg/L	0.0018	0.0018	**0**
Bismuth	mg/L	< 0.05	< 0.05	--
Boron	mg/L	0.118	0.116	**1.72**
Cadmium	mg/L	0.119	0.117	**1.71**
Calcium	mg/L	255	246	**3.66**
Chromium	mg/L	0.009	0.009	**0**
Cobalt	mg/L	0.066	0.064	**3.13**
Copper	mg/L	37.9	36.8	**2.99**
Iron	mg/L	1.06	17	**-93.76**
Lead	mg/L	0.05	0.05	**0**
Magnesium	mg/L	61.2	59.4	**3.03**
Manganese	mg/L	3.96	3.88	**2.06**
Molybdenum	mg/L	< 0.005	< 0.005	--
Nickel	mg/L	0.05	0.051	**-1.96**
Phosphorus	mg/L	< 0.1	< 0.1	--
Potassium	mg/L	< 1	< 1	--
Selenium	mg/L	< 0.03	< 0.03	--
Silver	mg/L	< 0.01	< 0.01	--
Sodium	mg/L	6.81	6.53	**4.29**
Strontium	mg/L	1.26	1.21	**4.13**
Sulfur	mg/L	443	396	**11.87**
Tellurium	mg/L	< 0.05	< 0.05	--
Thallium	mg/L	< 0.03	< 0.03	--
Tin	mg/L	< 0.02	< 0.02	--
Titanium	mg/L	< 0.003	< 0.003	--
Vanadium	mg/L	< 0.005	< 0.005	--
Zinc	mg/L	25.7	24.9	**3.21**
Zirconium	mg/L	< 0.005	< 0.005	--

Appendix C Mineralogical characteristics of clinoptilolite

Appendix C-1 Investigations of the X-Ray Diffractograms for semi-quantitative analysis of the mineral composition of clinoptilolite

Particle size range	**<2um**		**2-50um**		**>50um**
Treatment type	*bulk*	*water/ARD treated*	*bulk*	*water/ARD treated*	*Both water/ARD treated*
quartz	10	10	5	5	10
clinoptilolite+mica	65	20	65	65	75
feldspar	10	10	15	15	10
vermiculite	-	40	10	10	-
other	15	20	5	5	-

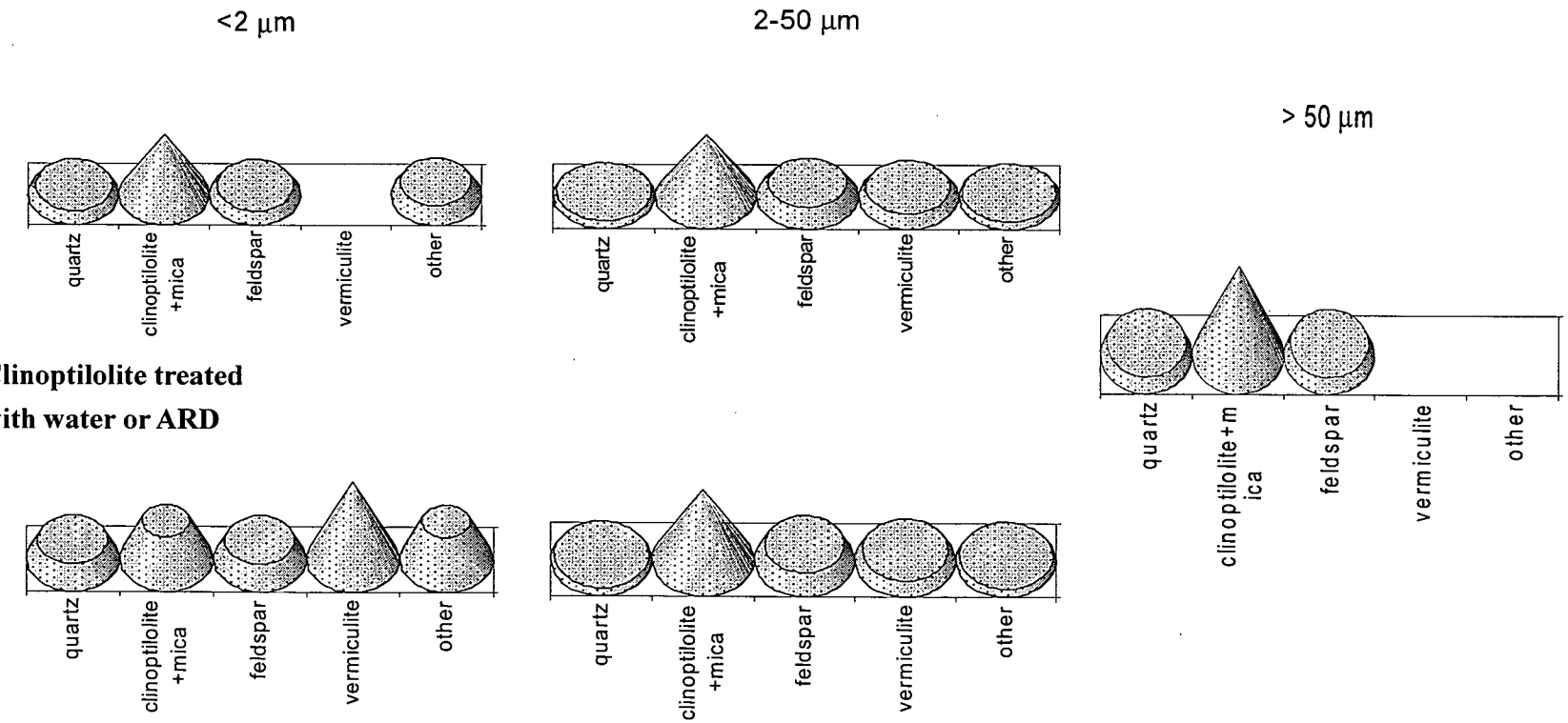
The X-Ray Diffractograms of the clinoptilolite sample were presented. It was observed that some peaks increased in sharpness, and a number of other minerals showed up after water or ARD treatment, therefore, semi-quantitative analysis of the clinoptilolite sample was suggested.

Results show that only the major minerals with highest peaks were encountered, which are: quartz, feldspar, clinoptilolite, mica and vermiculite. The amounts of each mineral shown above are only an approximate since there are other minerals which are also present in the sample, but in trace amount, which is not significant for semi-quantitative analysis.

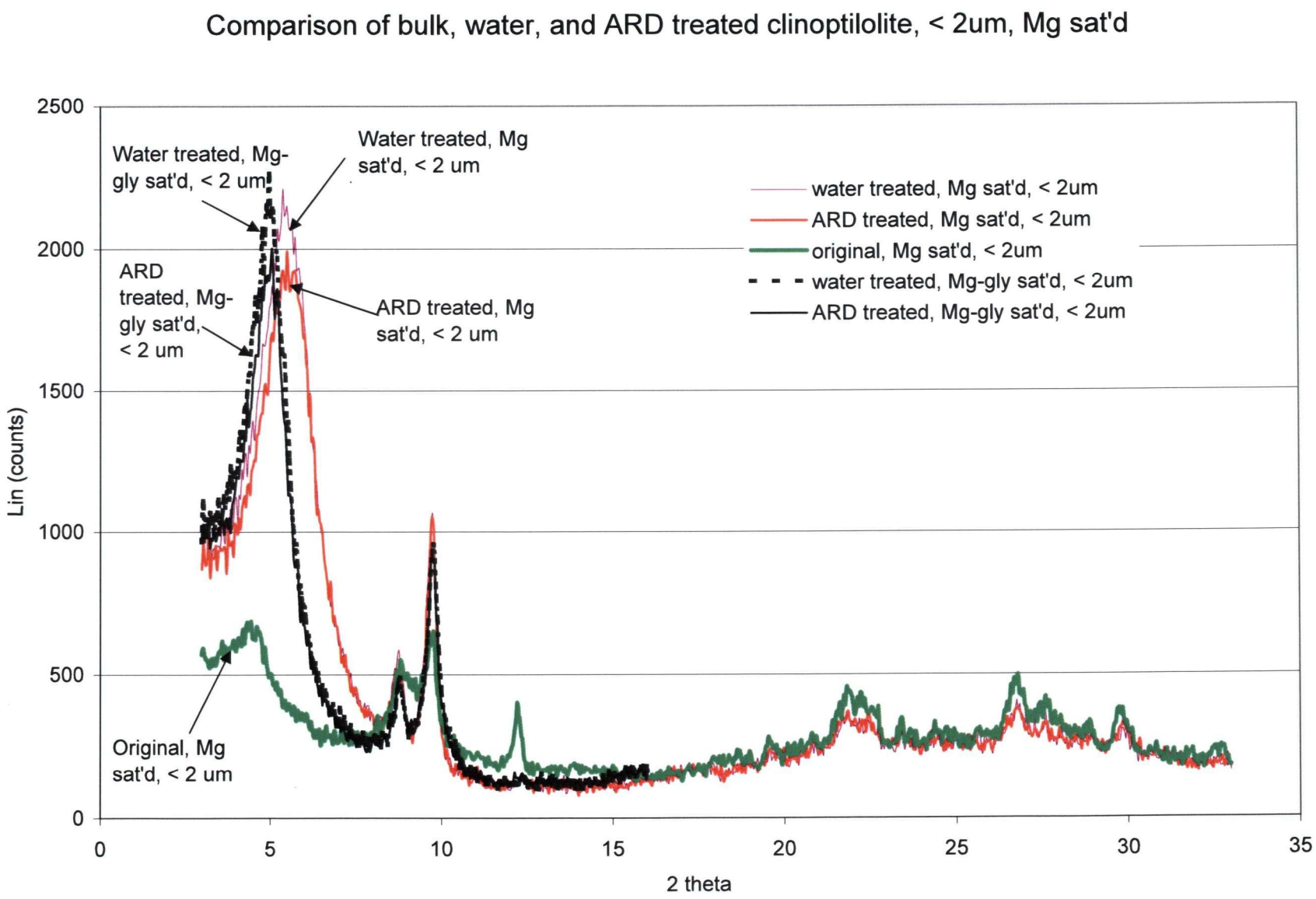
From the above results the composition of the minerals are relative to the bulk sample. It indicated that after water or ARD treatment, some of the minerals that were not detected from the non-treated sample appeared because the amorphous materials were being washed out during the treatment.

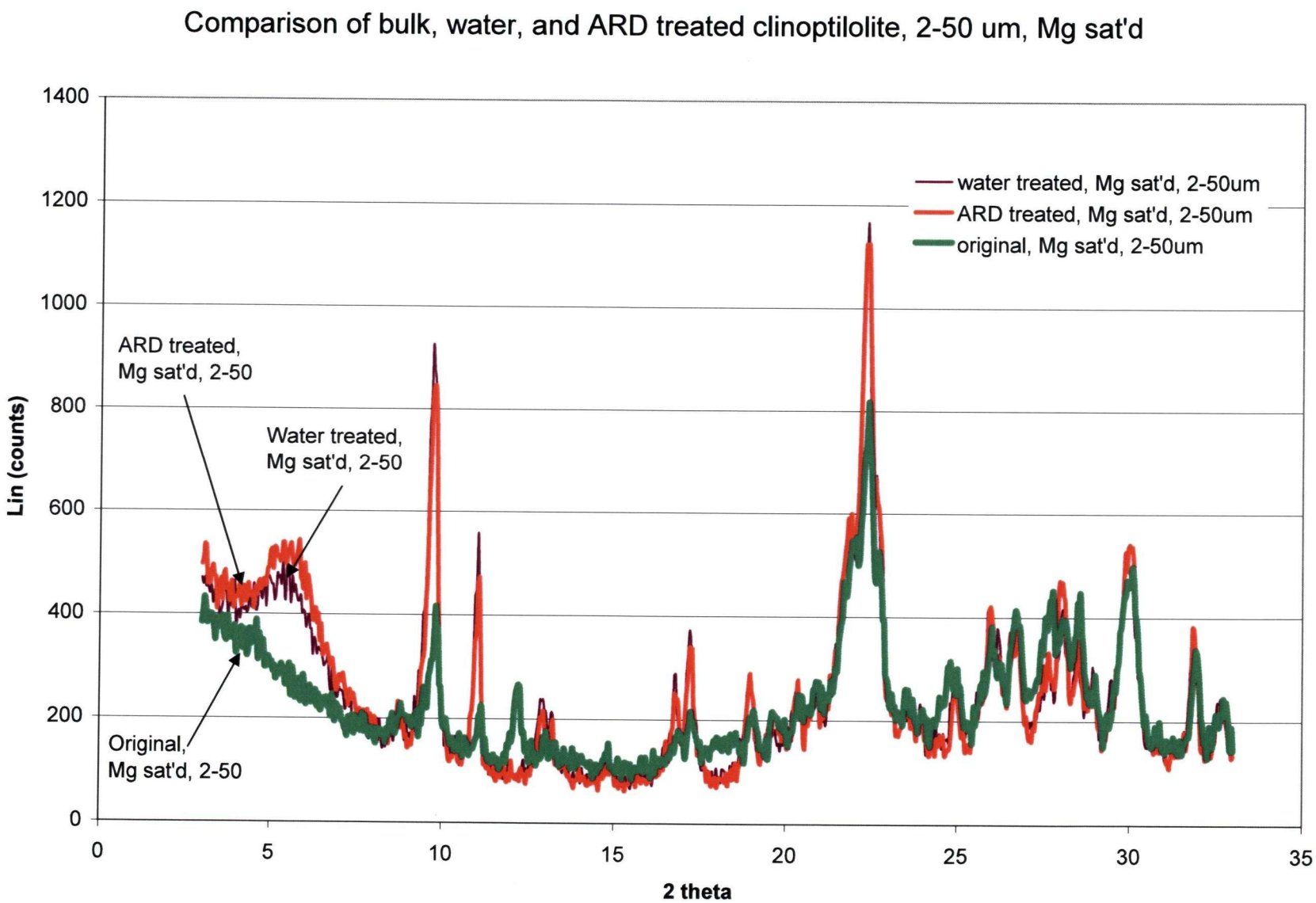
Graphical illustration of the distribution of mineral composition of the zeolite clinoptilolite sample in <2 μm, 2-50 μm, and >50 μm particle size portions and treatments

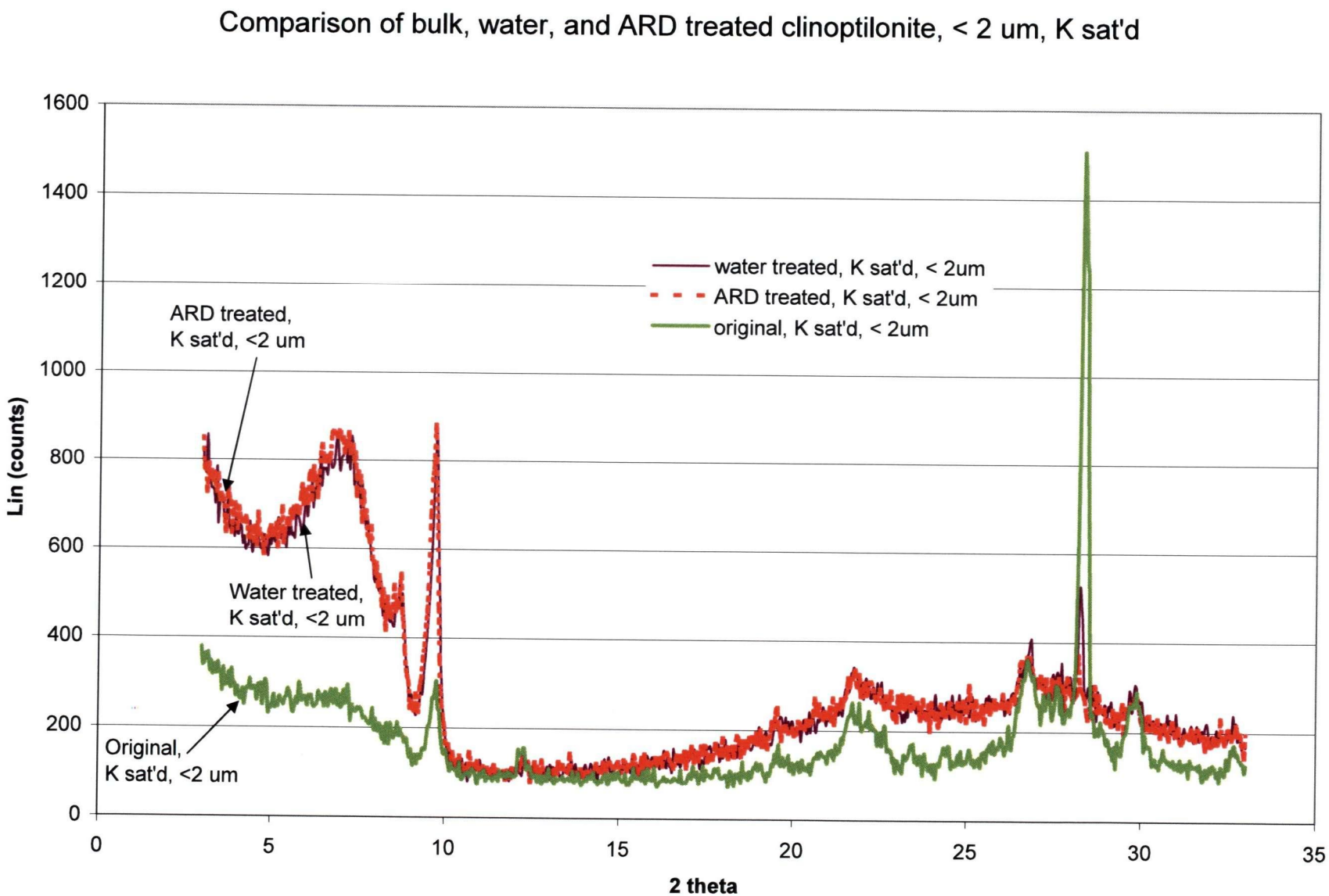
Bulk clinoptilolite
(no treatment)

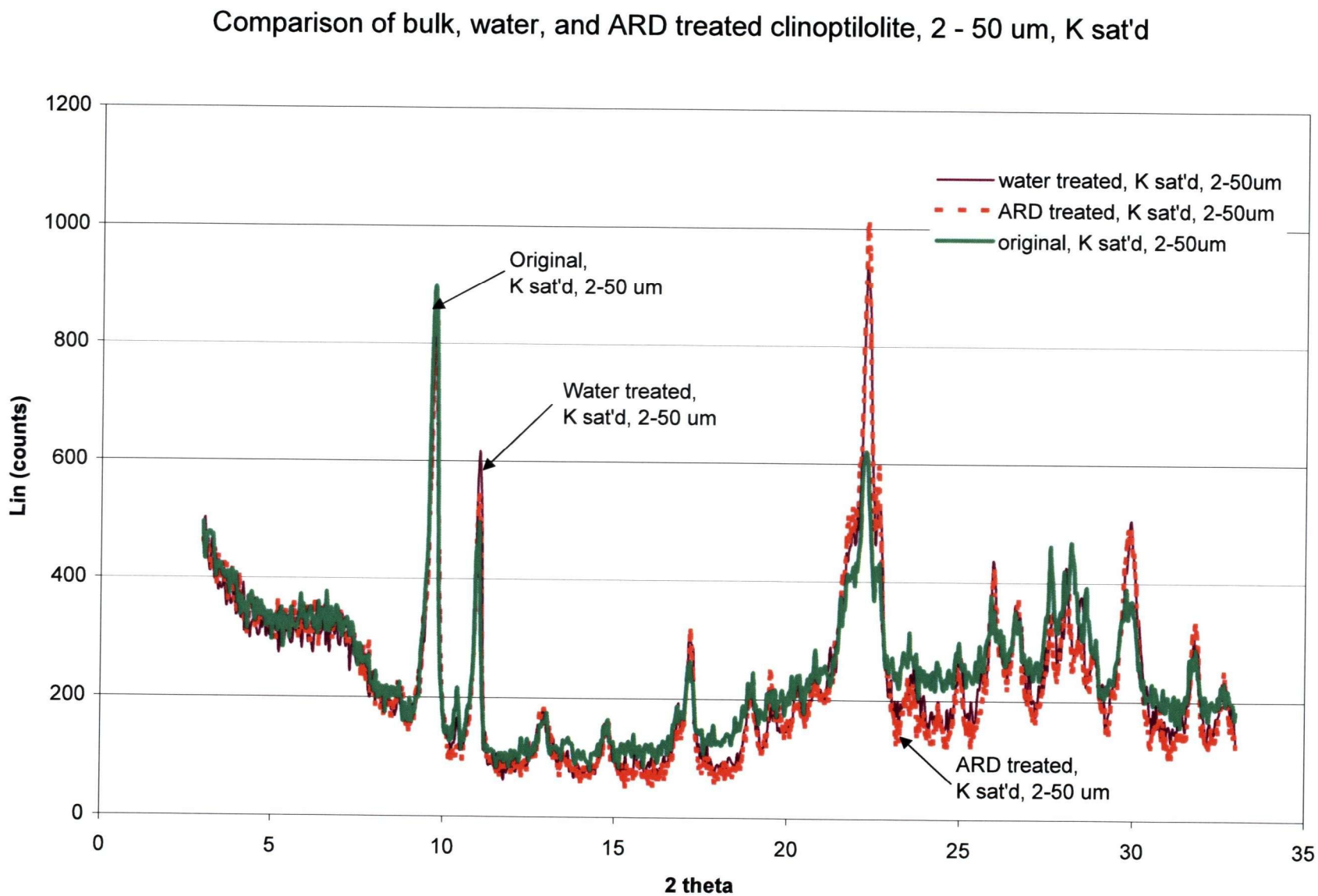


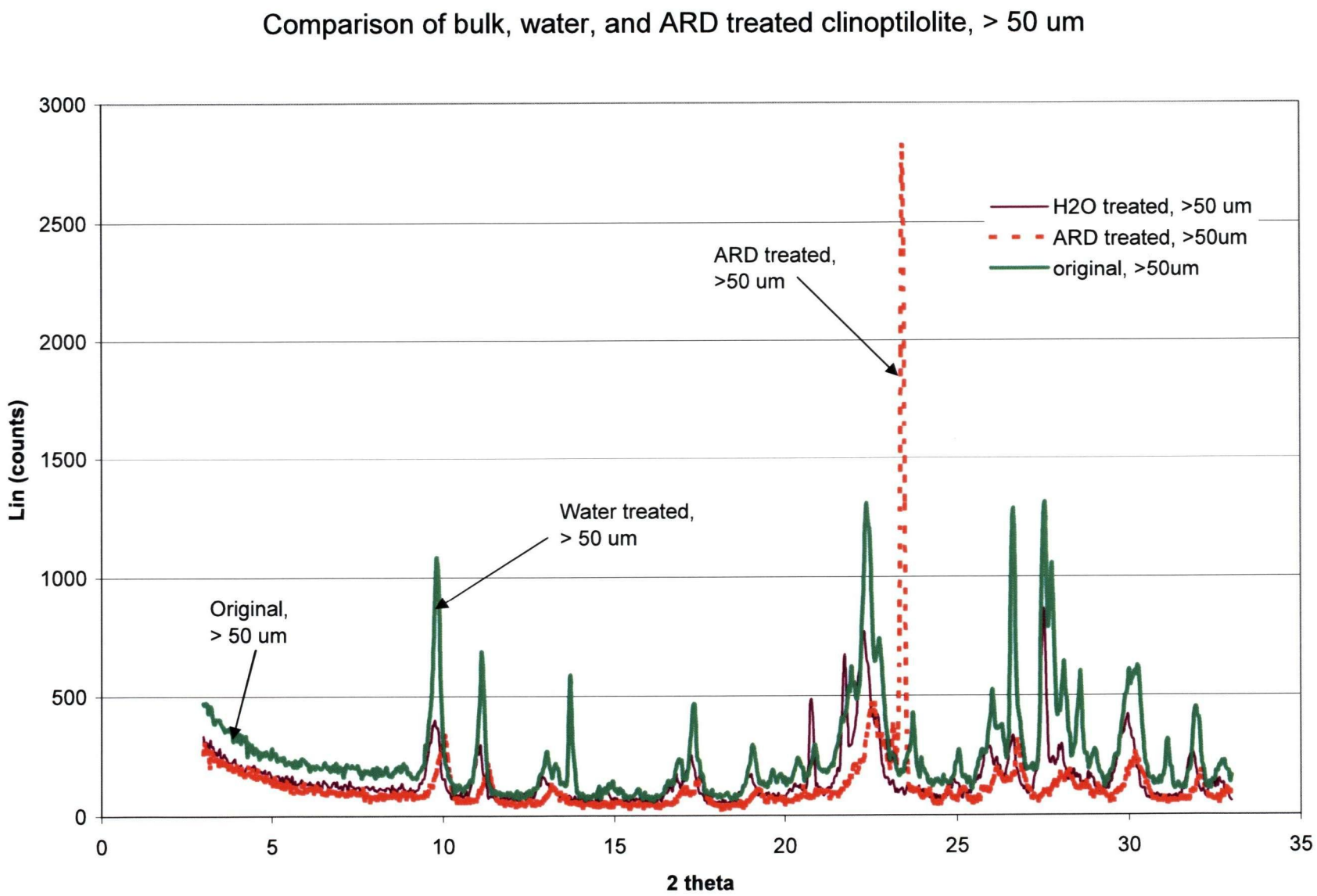
Clinoptilolite treated
with water or ARD


Comparison of bulk, water, and ARD treated clinoptilolite, < 2um, Mg sat'd
Water treated, Mg-gly sat'd, < 2 um
Water treated, Mg sat'd, < 2 um
ARD treated, Mg-gly sat'd, < 2 um
ARD treated, Mg sat'd, < 2 um
Original, Mg sat'd, < 2 um
water treated, Mg sat'd, < 2um
ARD treated, Mg sat'd, < 2um
original, Mg sat'd, < 2um
water treated, Mg-gly sat'd, < 2um
ARD treated, Mg-gly sat'd, < 2um
Lin (counts)
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
2 theta


Comparison of bulk, water, and ARD treated clinoptilolite, 2-50 um, Mg sat'd
water treated, Mg sat'd, 2-50um
ARD treated, Mg sat'd, 2-50um
original, Mg sat'd, 2-50um
ARD treated, Mg sat'd, 2-50
Water treated, Mg sat'd, 2-50
Original, Mg sat'd, 2-50
Lin (counts)
2 theta
0
200
400
600
800
1000
1200
1400
0
5
10
15
20
25
30
35


Comparison of bulk, water, and ARD treated clinoptilonite, < 2 um, K sat'd
1600
1400
1200
1000
800
600
400
200
0
Lin (counts)
0
5
10
15
20
25
30
35
2 theta
water treated, K sat'd, < 2um
ARD treated, K sat'd, < 2um
original, K sat'd, < 2um
ARD treated,
K sat'd, <2 um
Water treated,
K sat'd, <2 um
Original,
K sat'd, <2 um


Comparison of bulk, water, and ARD treated clinoptilolite, 2 - 50 um, K sat'd
water treated, K sat'd, 2-50um
ARD treated, K sat'd, 2-50um
original, K sat'd, 2-50um
Original,
K sat'd, 2-50 um
Water treated,
K sat'd, 2-50 um
ARD treated,
K sat'd, 2-50 um
Lin (counts)
2 theta
0
200
400
600
800
1000
1200
0
5
10
15
20
25
30
35


Comparison of bulk, water, and ARD treated clinoptilolite, > 50 um
Lin (counts)
2 theta
H2O treated, >50 um
ARD treated, >50um
original, >50um
ARD treated, >50 um
Water treated, > 50 um
Original, > 50 um
0
500
1000
1500
2000
2500
3000
0
5
10
15
20
25
30
35

Clinoptilolite – bulk, water, ARD treatment -- XRD
Copper K Alpha (1,2)
Lambda=1.541838

<2, K sat'd					clay minerals & phyllosilicates	other silicates	oxides & hydroxides	carbonates, chlorides, fluorides, phosphates, sulphates, sulphides, etc
d spacing (A)	2 theta	ht. Bulk	ht. Water	ht. ARD				
12.62	7	250	851	851	vermiculite			
10.14061081	8.72	34	51	126	-mica			
9.136979548	9.68	145	566	647		9.05-98.97 heulandite-clinoptilolite		
4.076877728	21.8	81	71	85		Ca-feldspar		
3.32654142	26.8	110	150	120	3.36-3.19 micas	3.31-3.29 k-feldspars	Akaganeite; 3.34 Quartz, low	Baryte; Carnallite
3.155726916	28.28	1242	198	106	Heulandite-clinoptilolite	3.21-3.15 Na and Ca feldspars	Magadiite	Sylvite; fluorite
2.994207797	29.84	139	98	69			2.99-2.96 Heulandite-clinoptilolite; 2.99 K-feldspar	2.99-2.96 Alunite

2-50 um, K sat'd

d spacing (A)	2 theta	ht. Bulk	ht. Water	ht. ARD	clay minerals & phyllosilicates	other silicates	oxides & hydroxides	carbonates, chlorides, fluorides, phosphates, sulphates, sulphides, etc
9.136979548	9.68	737	632	592	mica		Heulandite-clinoptilolite	
8.505980943	10.4	84	57	19	?	(amphibole)?		
8.043329827	11	379	504	428	chlorite-smectite, regular, glycerol		Heulandite-clinopilolite	
5.167357071	17.16	93	164	180	mica			5.10-5.06 Jarosites
3.997205488	22.24	212	457	517		3.97-3.95 heulandite-clinoptilolite	3.99 Diaspore	
3.23191139	7 27.6	140	51	88		3.26-3.23 K-feldspars		
3.164497107	28.2	146	57	75	3.16 Phlogopite	3.21-3.15 Feldspar	3.16 Boehmite	
2.986383928	29.92	143	348	333		3.02-2.94 Pyroxenes	2.99-2.96 Heulandite-clinoptilolite	2.98 Millisite; pyrrhotite; Griegite

>50 um

d spacing (A)	2 theta	ht. Bulk	ht. Water	ht. ARD	clay minerals & phyllosilicates	other silicates	oxides & hydroxides	carbonates, chlorides, fluorides, phosphates, sulphates, sulphides, etc
8.988767263	9.84	885	272	243		9.05-8.97 Heulandite-clinoptilolite		
7.956799535	11.12	559	211	126		7.94-7.89 Heulandite-clinoptilonite		
6.789245302	13.04	98	58	46		feldspar		6.8 Vivianite
6.454243958	13.72	460	21	5		6.6-6.3 feldspars		
5.119980708	17.32	320	79	18	mica	Heulandite-clinoptilolite		5.10-5.06 Jarosite
4.483935522	19.8	166	58	55	4.49-4.45 Mica, smectite	4.68-4.64 heulandite-clinoptilolite		4.47 Rozenite
4.278704393	20.76	96	384	21			4.26 Quartz, low	4.28-4.27 Gypsum; Brushite
4.0917126	21.72	412	346	87		4.21-4.04 K-Na Feldspars	4.09-4.11 Tridymite, low	
3.976024345	22.36	798	367	226		3.97-3.95 heulandite-clinoptilolite	4.10-3.96 Nsutite	3.97 Rozenite
3.801613896	23.4	7	12	2597		3.83-3.70 Feldspars		
3.421878604	26.04	265	107	48	Heulandite-clinoptilolite		Quartz	
3.346156163	26.64	1047	160	161			3.34 Quartz, low	
3.236511134	27.56	1092	654	6		3.26-3.23 K-feldspars; 3.25-3.15 Pyroxenes		
3.173317732	28.12	206	70	27	Heulandite-clinoptilolite	feldspar		
3.12114203	28.6	345	22	26		3.13-3.12 Ca-feldspars; Albite		3.13-3.11 Jarosite; 3.12 Pyrite; Szomolnokite
2.967008272	30.12	441	288	161		2.99-2.96 Heulandite-clinoptilolite	2.97-2.95 Magnetite-maghemite	2.99-2.96 Alunites; 2.99-2.93 Plumbogummite group
2.873911062	31.12	187	21	1	2.87 Muscovite	2.91-2.87 Pyroxenes	2.90-2.86 Spinels	2.87 Gypsum
2.800268697	31.96	310	173	93	amphibole	2.81-2.77 Olivine?		2.81-2.77 Fluor-, Hydroxy- and carbonate-apatites

< 2 um, Mg sat'd

d spacing (A)	2 theta	ht. Bulk	ht. Water	ht. ARD	clay minerals & phyllosilicates	other silicates	oxides & hydroxides	carbonates, chlorides, fluorides, phosphates, sulphates, sulphides, etc
10.09439627	8.76	214	255	184	mica			
9.099468475	9.72	224	734	792		9.05-8.97 heulandite-clinoptilolite		9.0 Aluminite
7.254747445	12.2	211	34	34	kaolinite			7.3-7.1 Birnessite
4.062152011	21.88	97	78	78	4.06 Pyrophyllite	4.04-4.02 Na and Ca feldspars	4.10-3.96 Nsutite; 4.05 Cristobalite, low	
3.32654142	26.8	219	114	79	3.36-3.19 Micas	3.31-3.29 K-feldspars	3.34 Quartz, low; 3.32 Akaganeite	3.32 Baryte; Carnallite

2-50um, Mg sat'd

d spacing (A)	2 theta	ht. Bulk	ht. Water	ht. ARD	clay minerals & phyllosilicates	other silicates	oxides & hydroxides	carbonates, chlorides, fluorides, phosphates, sulphates, sulphides, etc
9.136979548	9.68	196	768	696				
8.014277059	11.04	83	416	329	8.0 Chlorite-smectite, regular, glycerol	7.94-7.89 Heulandite-clinoptiolite		8.0 Vivianite
7.20766454	12.28	143	24	28	kaolinite			7.3-7.1 Birnessite
6.830973727	12.96	40	127	105	Feldspar - mordenite			6.80 Vivianite
5.277266001	16.8	36	138	91			5.25 Akaganeite	5.27 Basaluminite; Monohydrocalcite
5.155430029	17.2	90	228	192	2nd order mica, mordenite			5.14 Hexahydrite; 5.10-5.06 Jarosites
4.68065254	18.96	101	123	154	4.68 Berthierine, ferrous; 4.66-4.56 Smectite; 4.66 Talc	4.68-4.64 Heulandite-clinoptilolite	4.76-4.66 Spinels	4.68 Basaluminite
3.983059255	22.32	565	955	921		3.97-3.95 Heulandite-clinoptilonite		
3.590089298	24.8	125	131	122	3.59-3.58 Nacrite; Dickite; Kaolinite; 3.60-3.50 Chlorite; Al-serpentine; 3.60-3.58 Vermiculite	3.67-3.62 Na and Ca-feldspars		
3.213646349	27.76	178	72	72	3.21 Clintonite; Muscovite; 3.2-3.0 Smectite, Mg, Ca, Na	3.21-3.15 Na and Ca feldspars		3.21 Sulphur; Mirabilite; Trona; MnS
3.182189222	28.04	66	178	199	feldspar			3.18 Thenardite
3.125422298	28.56	128	112	112	3.12 Talc	3.13-3.12 Ca-feldspars; Albite, high; 3.13-3.05 Amphiboles		3.12 Pyrite; Szomolnokite; 3.13-3.11 Jarosites
2.970862541	30.08	327	319	365	2.95 smectite, glycerol	2.99-2.96 Heulandite-clinoptilolite; 2.99 k-feldspars; 3.02-2.94 pyroxenes	2.97-2.95 Magnetite-maghemite	2.97 Mackinawite; Whewellite; Vivianite; Celestite
2.807112802	31.88	172	173	230	2.86-2.82 vermiculite; 2.83 smectite			2.81-2.77 fluor-, hydroxy- and carbonate-apatites; 2.80 Bassanite

Appendix C-2 Major elements in the clinoptilolite sample by X-Ray Fluorescence (XRF) and Inductive coupled plasma (ICP) spectroscopy

Element	Unit	Bulk clinoptilolite (ICP)	1M NaCl treated (ICP)	Clinoptilolite ore* (XRF)	Clinoptilolite ore* (ICP)
SiO_2	%	67.14	68.27	66.53	66.37
Al_2O_3	%	12.45	12.6	12.30	12.07
Fe_2O_3	%	2.56	2.61	2.41	2.73
MgO	%	0.84	0.8	0.72	0.76
CaO	%	2.49	1.94	2.08	2.04
Na_2O	%	2.6	3.36	3.38	2.78
K_2O	%	2.35	2.35	2.27	2.21
TiO_2	%	0.26	0.25	0.25	0.22
P_2O_5	%	0.06	0.05	0.05	0.03
MnO	%	0.04	0.04	0.05	0.04
Cr_2O_3	%	< .001	< .001	n/a	n/a
Ba	ppm	1689	1687	1633	1933
Ni	ppm	34	41	n/a	n/a
Sc	ppm	3	3	n/a	n/a
LOI	%	8.6	7.7	n/a	n/a
TOT/C	%	0.09	0.11	n/a	n/a
TOT/S	%	0.03	0.04	n/a	n/a
SUM	%	99.58	100.16	90.21	89.44

*XRF and ICP results were provided by Canmark Resources Inc. on the ore body.

X-Ray Fluorescence Analysis results (Ref: Canmark International Resources Inc., 1993)

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ERI ref: **968978**
Page 2 of 3

	Unlabelled, 'clinoptilolite'
Lithium	23.0
Beryllium	5.4
Boron	20
Sodium	18000
Magnesium	4500
Aluminium	110000
Phosphorus	<500
Potassium	40000
Calcium	7200
Scandium	64.0
Titanium	1360
Vanadium	23.0
Chromium	<50
Manganese	350
Iron	36000
Cobalt	<8
Nickel	32
Copper	70
Zinc	210
Gallium	22.0
Germanium	<2
Arsenic	28
Bromine	<10
Selenium	<2
Rubidium	66
Strontium	580
Yttrium	23
Zirconium	220
Niobium	24
Molybdenum	0.2
Ruthenium	<0.1
Rhodium	<0.05
Silver	0.81
Palladium	0.2
Cadmium	1.4
Tin	7.1
Antimony	1.9
Tellurium	<1
Iodine	<5
Caesium	4.00
Barium	2300
Lanthanum	11
Cerium	34
Praseodymium	4
Neodymium	16
Samarium	3.6
Europium	0.2
Gadolinium	4
Terbium	0.6
Dysprosium	4.2

Results are in micrograms per gram (ppm)

MAJ.CMP = major component. NOT.DET = not determined. MOL.INT = molecular interference.

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	Unlabelled, 'clinoptilolite'
Holmium	0.8
Erbium	2.5
Thulium	0.4
Ytterbium	2.4
Lutetium	0.6
Hafnium	13
Tantalum	2.4
Tungsten	2.0
Rhenium	<0.05
Osmium	<0.05
Iridium	<0.05
Platinum	<0.5
Gold	<0.5
Mercury	<1
Thallium	0.9
Lead	27.0
Bismuth	1.9
Thorium	7.1
Uranium	5.0

Results are in micrograms per gram (ppm)

MAJ.CMP = major component. NOT.DET = not determined.MOL.INT = molecular interference.

Appendix C-3 Compaction Curve of clinoptilolite

Soil sample	Clinoptilolite
	greenish grey color; bulk commercial size; inorganic
Type of test	Standard Proctor
Specific gravity, Gs	2.00151
volume of mold (m^3)	0.0009473
weight of soil (g)	3593

Density

Determination No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Mass mold (g)	3593	3593	3593	3593	3593	3593	3593
Mass mold + compacted soil (g)	4841	4953	5075	5241	5296	5301	5280
Mass compacted soil (g)	1248	1360	1482	1648	1703	1708	1687
Wet density (kg/m^3)	1317.48	1435.72	1564.51	1739.75	1797.81	1803.09	1780.92
Dry density (kg/m^3)	1288.99	1277.86	1329.22	1429.53	1383.98	1404.95	1296.00
Void ratio, e	0.553	0.566	0.506	0.400	0.446	0.425	0.544
Porosity, n	0.356	0.362	0.336	0.286	0.309	0.298	0.352

Water content

Determination No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Container no.	B1	B2	B3	B4	B5	B6	B7
Mass container (g)	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Mass container + wet soil (g)	42.17	36.4	31.54	41.23	55.02	53.01	54.75
Mass container + dry soil (g)	41.28	32.51	26.95	34.06	42.59	41.53	40.12
Mass water (g)	0.89	3.89	4.59	7.17	12.43	11.48	14.63
Wt. Dry soil (g)	40.26	31.49	25.93	33.04	41.57	40.51	39.1
Water content, w (%)	2.21%	12.35%	17.70%	21.70%	29.90%	28.34%	37.42%

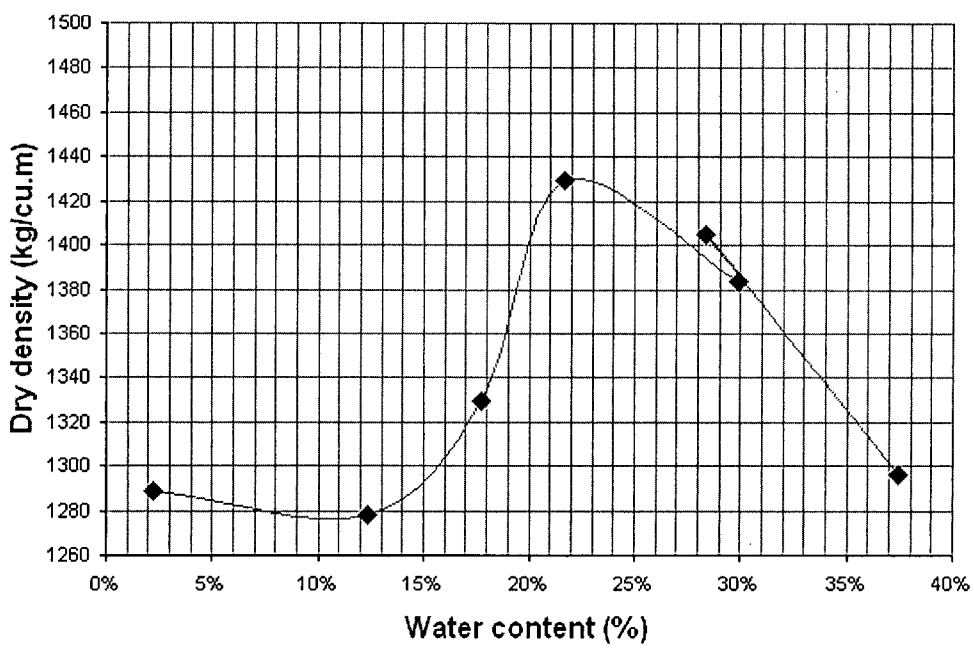


Figure C-3.1 Dry density-water content relationship of clinoptilolite obtained by Standard Proctor Test

Appendix C-4 Sample calculations for the compaction of material and its compaction properties

Specific gravity, Gs	2.00151
Diameter of column, d	4.13 cm
Length of column, h	55 cm
Volume of column, V_{column}	$V_{column} = \frac{\pi d^2}{4} \bullet h$ $= \frac{\pi \cdot (4.13cm)^2}{4} \cdot 55cm$ $= 736.8\ cm^3$ $= 0.0007368\ m^3$
Natural water content, $w\%$	2.82 %
Mass of soil before filling column	1546 g
Mass of soil after filling column	696 g
Mass of soil placed in column	1546g – 696g = 850g

Wet density

$$\rho\left(\frac{kg}{m^3}\right) = \frac{mass\ of\ compacted\ soil\ (g)}{volume\ of\ column\ (m^3)} \cdot \frac{1kg}{1000g}$$

$$= \frac{850g}{0.0007368m^3} \cdot \frac{1kg}{1000g}$$

$$= 1153.63\ \frac{kg}{m^3}$$

Dry density

$$\rho_d\left(\frac{kg}{m^3}\right) = \frac{wet\ density\left(kg/m^3\right)}{1 + w\%}$$

$$= \frac{1153.63\ kg/m^3}{1 + 2.82\%}$$

$$= 1121.99\ \frac{kg}{m^3}$$

Void ratio

$$e = \frac{G_s(1 + w\%)*1000}{\rho} - 1$$

$$= \frac{2.00151\ kg/m^3 (1 + 2.82\%)*1000}{1153.63\ kg/m^3} - 1$$

$$= 0.784$$

Porosity

$$n = \frac{e}{1+e}$$
$$= \frac{0.78}{1+0.78}$$
$$= 0.439$$

Volume of pores

$$V_{pore} = n \cdot V_{column}$$
$$= 0.439 \times 0.000736 m^3$$
$$= 3.238 \times 10^{-4} m^3$$
$$= 323.8\ ml$$

Appendix D. Langmuir Isotherm and Langmuir constant determination

Langmuir Equation is described by the following equation (Sparks 1995):

$$q = \frac{kCb}{1+kC}$$

where

k = constant related to the binding strength [L/mg]

b = maximum amount of adsorptive that can be adsorbed (monolayer coverage) [mg/kg]

q = amount of adsorption, adsorbate per unit mass of adsorbent in mg/kg. In some literature, the weight of the adsorbate per unit weight of adsorbed is plotted in lieu of q.

C = equilibrium concentration of the adsorptive [mg/L]

Rearranging to a linear form, the equation becomes

$$\frac{C}{q} = \frac{1}{kb} + \frac{C}{b}$$

Plotting C/q vs C, the slope is 1/b and the intercept is 1/kb.

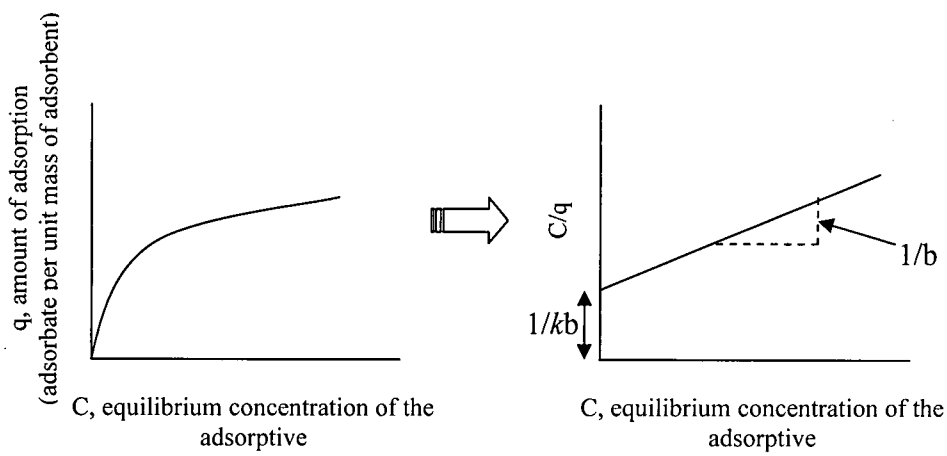


Figure D.1. Conversion of adsorption isotherm to a graph to determine Langmuir adsorption isotherm constants

The constant related to the binding strength for metals (Langmuir *k*) obtained from 24-batch equilibrium adsorption tests in multiple metal species and ARD matrix solution were determined using adsorption isotherm shown in Figure D-2.

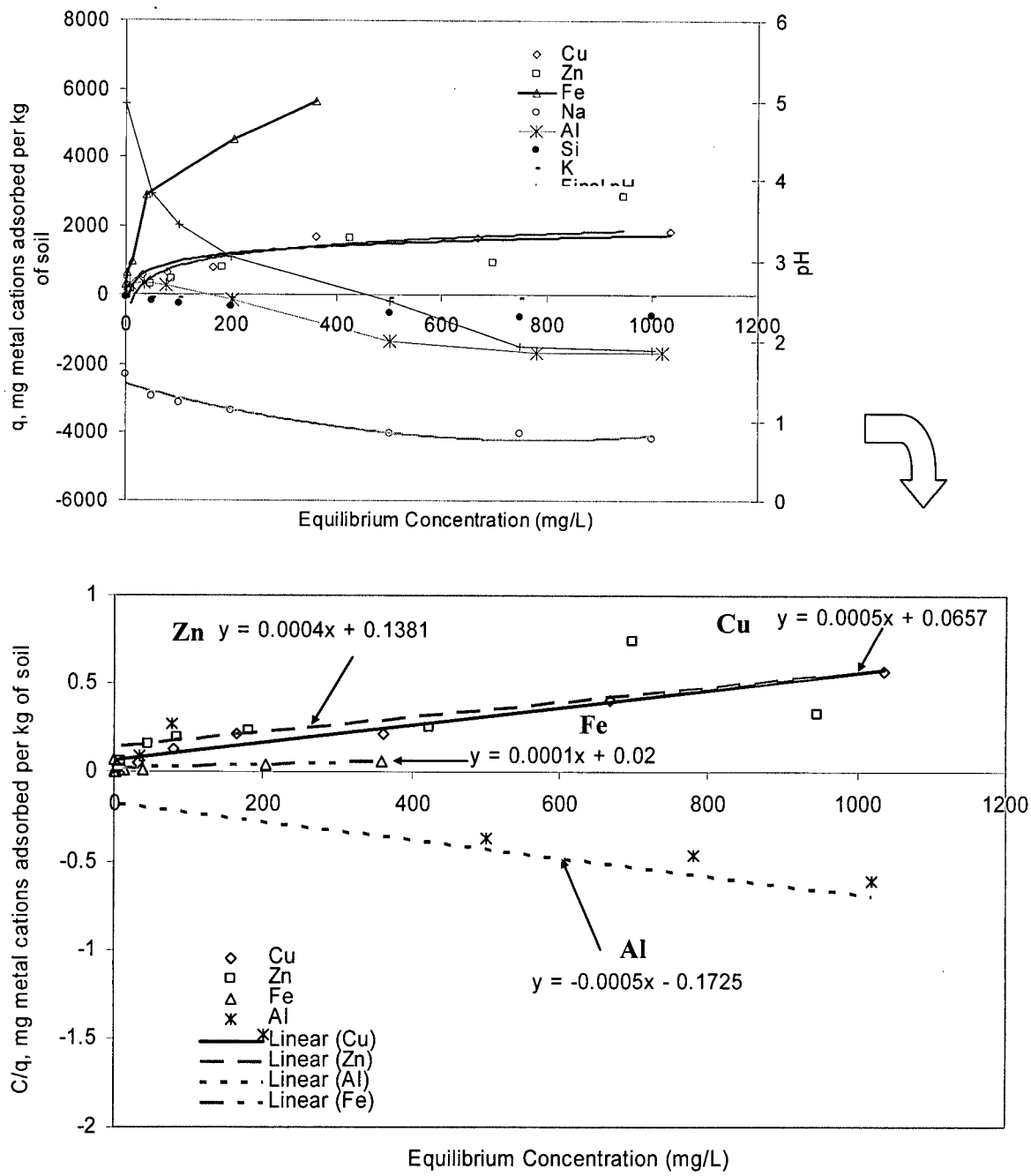


Figure D.2 Plot of C/q vs. C for determining Langmuir constant related to binding strength, *k*

From the equations obtained on the C/q vs. C graph, the Langmuir constant related to the binding strength could be determined.

For example,
the equation for Cu was y = 0.0005x + 0.0657,
the coefficient of x = slope = 1/b = 0.0005, $\therefore$ b = 2000 mg/kg
the 1/kb = y-intercept value = 0.0657, $\therefore$ k = 7.61×10^{-3} L/mg

The k values for the other metals are obtained using the same method:
k(Zn) = 2.896×10^{-3} L/mg
k(Cu) = 7.61×10^{-3} L/mg
k(Fe) = 0.005 L/mg
k(Al) = 2.898×10^{-3} L/mg
k(Mn) = 8.054×10^{-3} L/mg

For PHREEQC, the *k* used in the data block refers to $\log_k = \log\left(\frac{1}{K}\right)$ where *K* is the Langmuir isotherm equilibrium constant.

For copper,

$$\log_k = \log\frac{1}{7.61\times10^{-3}} = 2.1186$$

For iron,

$$\log_k = \log\frac{1}{0.005} = 2.301$$

For zinc,

$$\log_k = \log\frac{1}{2.896\times10^{-3}} = 2.5382$$

For aluminum,

$$\log_k = \log\frac{1}{2.898\times10^{-3}} = 2.5379$$

For manganese,

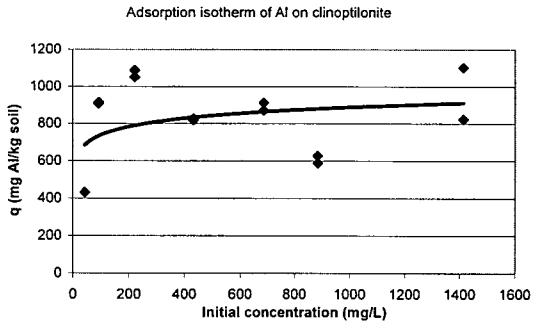
$$\log_k = \log\frac{1}{8.054\times10^{-3}} = 2.0939$$

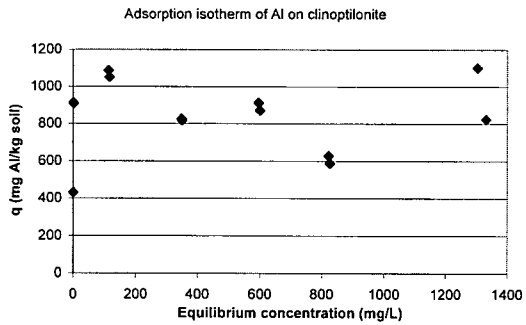
Appendix D-1

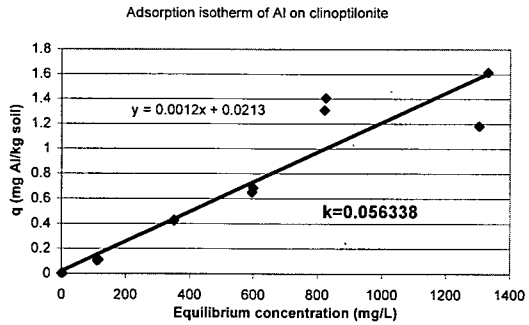
Adsorption isotherms of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in single species solutions

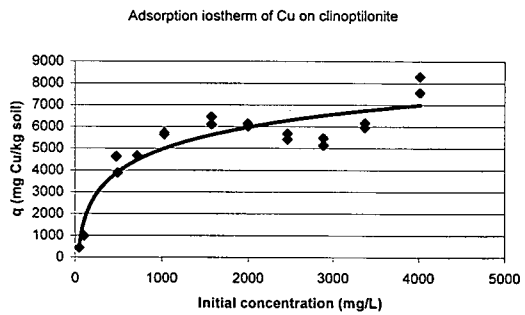
ID	Species	Design conc (ppm)	wt soil (g)	init conc dilution	AAS	Init conc mg/L	mmol/L	Initial pH	dilution	AAS	Conc mg/L	Adsorbed mg/L	Adsorbed mg/kg	mmol/kg	Final pH	diff pH
1	Al	50	4.0039	1	43.2	43.2	1.601095	3.61	1	0	0	43.2	431.5792	15.99535	4.91	1.3
2	Al	50	4.0003	1	43.2	43.2	1.601095	3.61	1	0	0	43.2	431.9676	16.00975	5.03	1.42
3	Al	100	4.0009	10	9.29	92.9	3.443095	3.56	1	1.43	1.43	91.47	914.4942	33.89333	4	0.44
4	Al	100	3.9972	10	9.29	92.9	3.443095	3.56	1	2.25	2.25	90.65	907.135	33.62058	4.01	0.45
5	Al	250	3.9956	10	22.11	221.1	8.194492	3.45	10	11.25	112.5	108.6	1087.196	40.29407	3.52	0.07
6	Al	250	3.9987	10	22.11	221.1	8.194492	3.45	10	11.6	116	105.1	1051.342	38.96522	3.49	0.04
7	Al	500	3.9982	10	43.25	432.5	16.02948	3.35	10	35.07	350.7	81.8	818.3683	30.33067	3.3	-0.05
8	Al	500	3.9996	10	43.25	432.5	16.02948	3.35	10	34.98	349.8	82.7	827.0827	30.65365	3.39	0.04
9	Al	750	3.9916	20	34.32	686.4	25.43962	3.28	20	29.97	599.4	87	871.8308	32.31212	3.29	0.01
10	Al	750	3.9952	20	34.32	686.4	25.43962	3.28	20	29.76	595.2	91.2	913.0957	33.8415	3.29	0.01
11	Al	1000	4.0029	20	44.21	884.2	32.77055	3.18	20	41.07	821.4	62.8	627.545	23.25831	3.3	0.12
12	Al	1000	4.0048	20	44.21	884.2	32.77055	3.18	20	41.27	825.4	58.8	587.2952	21.76656	3.26	0.08
13	Al	1500	3.9925	40	35.34	1413.6	52.39138	3.07	40	32.59	1303.6	110	1102.066	40.8452	3.13	0.06
14	Al	1500	3.9988	40	35.34	1413.6	52.39138	3.07	40	33.28	1331.2	82.4	824.2473	30.54856	3.15	0.08
15	Cu	50	4.007	2	23.93	47.86	0.753155	5.22	1	3.85	3.85	44.01	439.3312	6.913593	7.32	2.1
16	Cu	50	3.9924	2	23.93	47.86	0.753155	5.22	1	4.06	4.06	43.8	438.8338	6.905766	7.39	2.17
17	Cu	100	4.0005	10	10.35	103.5	1.628741	4.82	1	5.39	5.39	98.11	980.9774	15.43728	6.56	1.74
18	Cu	100	4.0089	10	10.35	103.5	1.628741	4.82	1	4.63	4.63	98.87	986.505	15.52427	6.61	1.79
19	Cu	250	3.998	20	23.6	472	7.42769	4.34	1	10.21	10.21	461.79	4620.21	72.70654	5.82	1.48
20	Cu	250	3.9921	20	23.6	472	7.42769	4.34	1	9.47	9.47	462.53	4634.453	72.93068	5.67	1.33
21	Cu	500	4.001	20	24.5	490	7.71095	3.95	10	10.3	103	387	3869.033	60.88554	5.31	1.36
22	Cu	500	4.0001	20	24.5	490	7.71095	3.95	10	10.12	101.2	388.8	3887.903	61.18249	5.35	1.4
23	Cu	750	4.0018	20	35.62	712.4	11.21078	3.78	10	24.6	246	466.4	4661.902	73.36264	5.06	1.28
24	Cu	750	4.0018	20	35.62	712.4	11.21078	3.78	10	24.56	245.6	466.8	4665.9	73.42556	5.05	1.27
25	Cu	1000	3.9946	40	25.71	1028.4	16.18355	3.59	20	23.28	465.6	562.8	5635.608	88.68549	4.89	1.3
26	Cu	1000	3.999	40	25.71	1028.4	16.18355	3.59	20	22.75	455	573.4	5735.434	90.25641	4.73	1.14
27	Cu	1500	3.9917	40	39.31	1572.4	24.74428	3.96	40	24.05	962	610.4	6116.692	96.25613	4.72	0.76
28	Cu	1500	3.995	40	39.31	1572.4	24.74428	3.96	40	23.17	926.8	645.6	6464.08	101.7228	4.62	0.66
29	Cu	2000	3.9988	100	19.95	1995	31.39458	3.6	40	34.52	1380.8	614.2	6143.843	96.6834	4.58	0.98
30	Cu	2000	3.9955	100	19.95	1995	31.39458	3.6	40	34.85	1394	601	6016.769	94.68368	4.52	0.92
31	Cu	2500	4.004	100	24.63	2463	38.75932	3.58	100	18.95	1895	568	5674.326	89.29477	4.52	0.94
32	Cu	2500	4.0035	100	24.63	2463	38.75932	3.58	100	19.21	1921	542	5415.262	85.21798	4.47	0.89
33	Cu	3000	3.998	100	28.87	2887	45.43166	3.69	100	23.73	2373	514	5142.571	80.92675	4.47	0.78
34	Cu	3000	4.0056	100	28.87	2887	45.43166	3.69	100	23.39	2339	548	5472.339	86.11618	4.49	0.8
35	Cu	3500	3.9989	100	33.69	3369	53.01671	3.52	100	27.73	2773	596	5961.639	93.81612	4.4	0.88
36	Cu	3500	3.9931	100	33.69	3369	53.01671	3.52	100	27.53	2753	616	6170.644	97.10516	4.42	0.9
37	Cu	4000	4.0051	100	40.16	4016	63.19831	3.56	100	32.58	3258	758	7570.348	119.1318	4.33	0.77
38	Cu	4000	4.0072	100	40.16	4016	63.19831	3.56	100	31.85	3185	831	8295.069	130.5364	4.4	0.84
39	Zn	50	4.0089	10	4.66	46.6	0.712647	3.66	1	2.22	2.22	44.38	442.8147	6.771903	7.31	3.65
40	Zn	50	3.9967	10	4.66	46.6	0.712647	3.66	1	2.51	2.51	44.09	441.264	6.748188	7.33	3.67
41	Zn	100	4.0038	1	126.9	126.9	1.940664	3.68	1	3.65	3.65	123.25	1231.33	18.83056	7.06	3.38
42	Zn	100	3.9967	1	126.9	126.9	1.940664	3.68	1	3.78	3.78	123.12	1232.217	18.84411	7.07	3.39
43	Zn	250	3.9981	1	309.3	309.3	4.730081	3.64	1	7.73	7.73	301.57	3017.133	46.14059	6.74	3.1
44	Zn	250	4.0092	1	309.3	309.3	4.730081	3.64	1	8.37	8.37	300.93	3002.394	45.91519	6.8	3.16
45	Zn	500	4.0014	1	618.9	618.9	9.46475	3.6	1	76	76	542.9	5427.101	82.99588	6.5	2.9
46	Zn	500	3.9927	1	618.9	618.9	9.46475	3.6	1	72.8	72.8	546.1	5470.985	83.66699	6.35	2.75
47	Zn	750	3.9966	1	842.3	842.3	12.88117	3.57	1	209.4	209.4	632.9	6334.384	96.87084	6.14	2.57

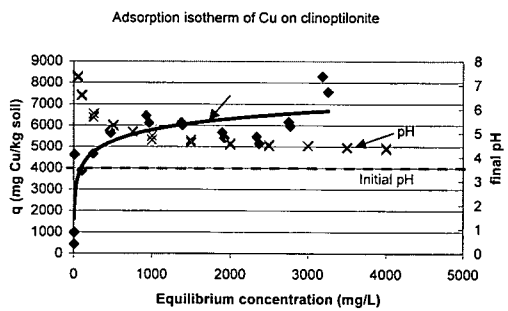
ID	Species	Design conc (ppm)	wt soil (g)	init conc dilution	AAS	Init conc mg/L	mmol/L	Initial pH	dilution	AAS	Conc mg/L	Adsorbed mg/L	Adsorbed mg/kg	mmol/kg	Final pH	diff pH
48	Zn	750	3.9932	1	842.3	842.3	12.88117	3.57	1	209.8	209.8	632.5	6335.771	96.89204	6.04	2.47
49	Zn	1000	4.0001	5	236.8	1184	18.10674	3.58	1	420.5	420.5	763.5	7634.809	116.7581	6.01	2.43
50	Zn	1000	3.9938	5	236.8	1184	18.10674	3.58	1	422.5	422.5	761.5	7626.822	116.6359	5.98	2.4
51	Zn	1500	3.9938	5	376.8	1884	28.81174	3.52	5	166.6	833	1051	10526.32	160.9775	5.59	2.07
52	Zn	1500	4.0046	5	376.8	1884	28.81174	3.52	5	166	830	1054	10527.89	161.0016	5.64	2.12
53	Zn	2000	3.994	5	486.7	2433.5	37.21517	3.67	5	258.7	1293.5	1140	11417.13	174.6005	5.57	1.9
54	Zn	2000	4.0093	5	486.7	2433.5	37.21517	3.67	5	266.7	1333.5	1100	10974.48	167.8312	5.54	1.87
55	Zn	2500	4.0007	5	615.2	3076	47.04083	3.68	5	410.8	2054	1022	10218.21	156.2657	5.53	1.85
56	Zn	2500	4.0009	5	615.2	3076	47.04083	3.68	5	415	2075	1001	10007.75	153.0471	5.53	1.85
57	Zn	3000	4.0019	10	389.6	3896	59.58098	3.59	5	518.2	2591	1305	13043.8	199.477	5.53	1.94
58	Zn	3000	4.0063	10	389.6	3896	59.58098	3.59	5	527.2	2636	1260	12580.19	192.387	5.21	1.62
59	Zn	3500	4.0071	10	415.5	4155	63.54183	3.52	5	598.6	2993	1162	11599.41	177.3881	5.68	2.16
60	Zn	3500	3.9984	10	415.5	4155	63.54183	3.52	5	617.1	3085.5	1069.5	10699.28	163.6226	5.63	2.11
61	Zn	4000	3.9955	10	505.3	5053	77.27481	3.46	5	738.4	3692	1361	13625.33	208.3702	5.53	2.07
62	Zn	4000	3.9904	10	505.3	5053	77.27481	3.46	5	764.6	3823	1230	12329.59	188.5547	5.46	2
63	Fe	50	3.9986	1	58.2	58.2	1.04217	2.87	1	0	0	58.2	582.2038	10.42535	6.66	3.79
64	Fe	50	4.0001	1	58.2	58.2	1.04217	2.87	1	0	0	58.2	581.9855	10.42144	6.6	3.73
65	Fe	100	3.9931	10	13.7	137	2.453219	2.67	1	0	0	137	1372.367	24.57458	5.05	2.38
66	Fe	100	3.9921	10	13.7	137	2.453219	2.67	1	0	0	137	1372.711	24.58073	5.06	2.39
67	Fe	250	3.9925	10	34.8	348	6.231534	24	1	38.8	38.8	309.2	3097.808	55.47154	3.56	-20.44
68	Fe	250	4.0002	10	34.8	348	6.231534	2.4	1	38.3	38.3	309.7	3096.845	55.4543	3.54	1.14
69	Fe	500	3.9911	10	63.9	639	11.44239	2.23	1	60.5	60.5	578.5	5797.9	103.8213	2.6	0.37
70	Fe	500	3.9947	10	63.9	639	11.44239	2.23	1	57.7	57.7	581.3	5820.712	104.2298	2.63	0.4
71	Fe	750	3.9976	10	97.6	976	17.47695	2.12	10	18.4	184	792	7924.755	141.9063	2.26	0.14
72	Fe	750	4.008	10	97.6	976	17.47695	2.12	10	19.9	199	777	7754.491	138.8574	2.23	0.11
73	Fe	1000	3.9919	20	68.2	1364	24.42475	2.12	10	40.1	401	963	9649.54	172.7915	2.12	0
74	Fe	1000	3.9948	20	68.2	1364	24.42475	2.12	10	39.3	393	971	9722.639	174.1004	2.14	0.02
75	Fe	1500	4.0052	20	95.5	1910	34.20181	1.75	10	106.9	1069	841	8399.081	150.3999	1.92	0.17
76	Fe	1500	4.0093	20	95.5	1910	34.20181	1.75	10	100.2	1002	908	9058.938	162.2157	1.91	0.16
77	Fe	2000	4.0052	40	67	2680	47.98997	1.65	20	71.5	1430	1250	12483.77	223.5432	1.76	0.11
78	Fe	2000	4.0032	40	67	2680	47.98997	1.65	20	74.6	1492	1188	11870.5	212.5616	1.75	0.1
79	Fe	2500	3.9986	40	86.6	3464	62.02883	1.6	40	50.6	2024	1440	14405.04	257.9468	1.64	0.04
80	Fe	2500	4.0076	40	86.6	3464	62.02883	1.6	40	49.5	1980	1484	14811.86	265.2316	1.64	0.04

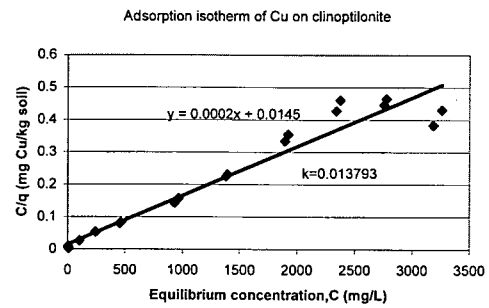

Adsorption isotherm of Al on clinoptilonite
q (mg Al/kg soil)
Initial concentration (mg/L)

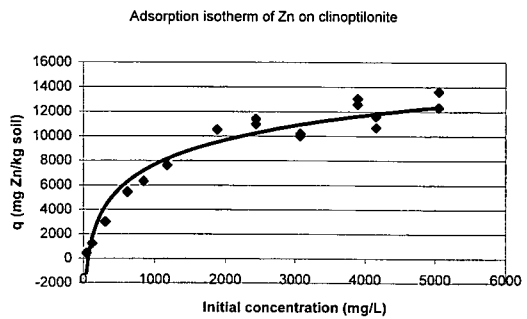

Adsorption isotherm of Al on clinoptilonite
q (mg Al/kg soil)
Equilibrium concentration (mg/L)

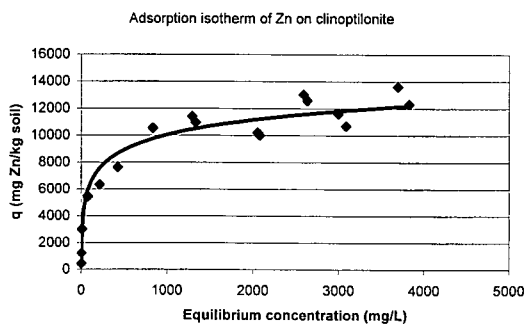

Adsorption isotherm of Al on clinoptilonite
y = 0.0012x + 0.0213
k=0.056338
q (mg Al/kg soil)
Equilibrium concentration (mg/L)

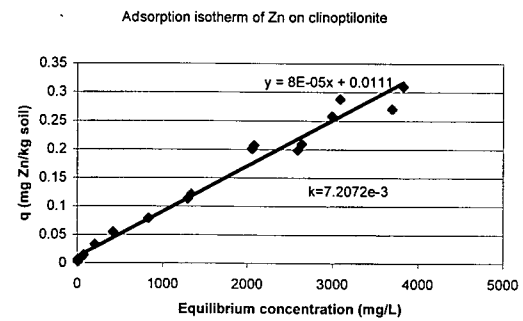

Adsorption iostherm of Cu on clinoptilonite
q (mg Cu/kg soil)
Initial concentration (mg/L)

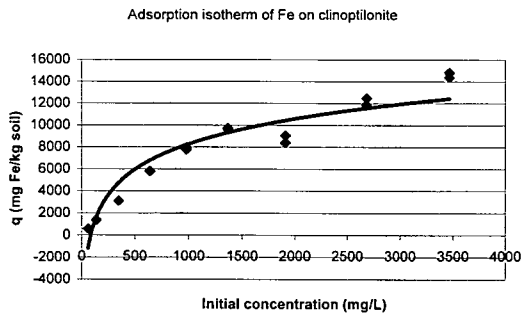

Adsorption isotherm of Cu on clinoptilonite
pH
Initial pH
q (mg Cu/kg soil)
final pH
Equilibrium concentration (mg/L)

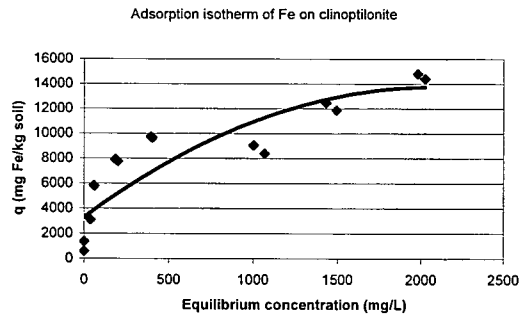

Adsorption isotherm of Cu on clinoptilonite
y = 0.0002x + 0.0145
k=0.013793
C/q (mg Cu/kg soil)
Equilibrium concentration,C (mg/L)

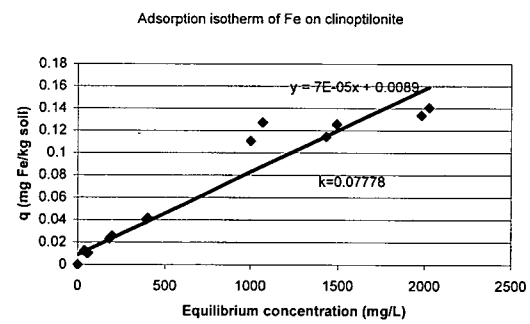

Adsorption isotherm of Zn on clinoptilonite
q (mg Zn/kg soil)
Initial concentration (mg/L)

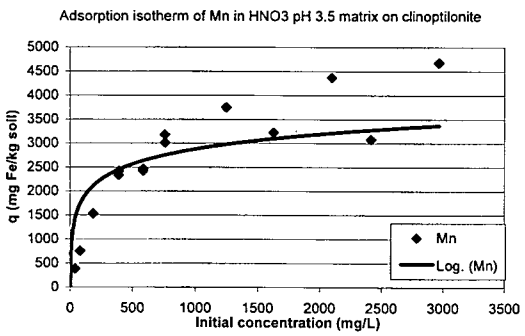

Adsorption isotherm of Zn on clinoptilonite
q (mg Zn/kg soil)
Equilibrium concentration (mg/L)

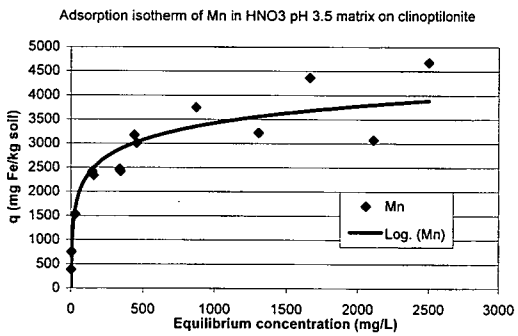

Adsorption isotherm of Zn on clinoptilonite
y = 8E-05x + 0.0111
k=7.2072e-3
q (mg Zn/kg soil)
Equilibrium concentration (mg/L)

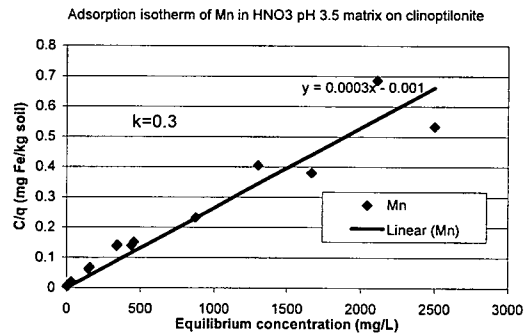

Adsorption isotherm of Fe on clinoptilonite
q (mg Fe/kg soil)
Initial concentration (mg/L)


Adsorption isotherm of Fe on clinoptilonite
q (mg Fe/kg soil)
Equilibrium concentration (mg/L)


Adsorption isotherm of Fe on clinoptilonite
y = 7E-05x + 0.0089
k=0.07778
q (mg Fe/kg soil)
Equilibrium concentration (mg/L)


Adsorption isotherm of Mn in HNO3 pH 3.5 matrix on clinoptilonite
Mn
Log. (Mn)
q (mg Fe/kg soil)
Initial concentration (mg/L)


Adsorption isotherm of Mn in HNO3 pH 3.5 matrix on clinoptilonite
Mn
Log. (Mn)
q (mg Fe/kg soil)
Equilibrium concentration (mg/L)


Adsorption isotherm of Mn in HNO3 pH 3.5 matrix on clinoptilonite
y = 0.0003x - 0.001
k=0.3
Mn
Linear (Mn)
C/q (mg Fe/kg soil)
Equilibrium concentration (mg/L)

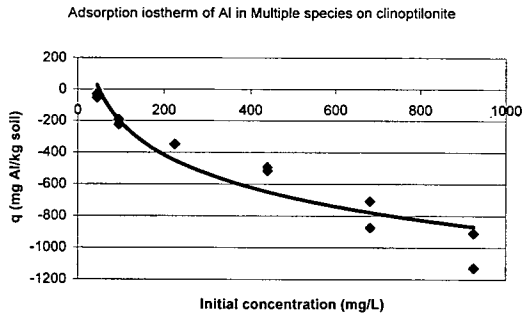
Appendix D-2

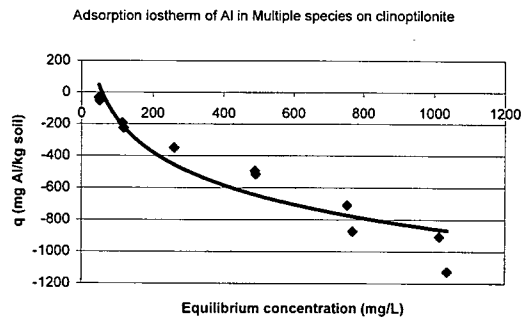
Adsorption isotherms of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in multiple species solutions – Distilled water with nitric acid as background solution

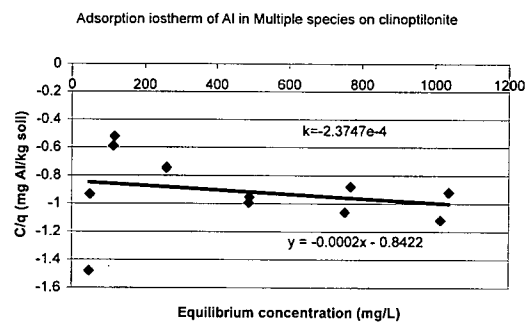
ID	Species	Design conc (ppm)	wt soil (g)	init conc dilution	AAS	Init conc mg/L	mmol/L	Initial pH	dilution	AAS	Conc mg/L	Adsorbed mg/L	Adsorbed mg/kg	mmol/kg	Final pH	diff pH
81	***Al*** CuZnFe	50	4.0096	1	44.72	44.72	1.65743	1.99	1	50.1	50.1	-5.38	-53.67119	-1.989182	2.76	0.77
82	***Al*** CuZnFe	50	3.9939	1	44.72	44.72	1.65743	1.99	1	47.96	47.96	-3.24	-32.44949	-1.202655	2.81	0.82
83	***Al*** CuZnFe	100	3.996	10	9.45	94.5	3.502395	1.95	10	11.38	113.8	-19.3	-193.1932	-7.160199	2.63	0.68
84	***Al*** CuZnFe	100	3.9985	10	9.45	94.5	3.502395	1.95	10	11.69	116.9	-22.4	-224.084	-8.305087	2.62	0.67
85	***Al*** CuZnFe	250	3.9992	10	22.49	224.9	8.335329	1.9	10	25.99	259.9	-35	-350.07	-12.97443	2.41	0.51
86	***Al*** CuZnFe	250	4.0095	10	22.49	224.9	8.335329	1.9	10	25.98	259.8	-34.9	-348.1731	-12.90412	2.43	0.53
87	***Al*** CuZnFe	500	4.0003	10	43.98	439.8	16.30003	1.94	10	48.91	489.1	-49.3	-492.963	-18.27038	2.24	0.3
88	***Al*** CuZnFe	500	4.0053	10	43.98	439.8	16.30003	1.94	10	49.14	491.4	-51.6	-515.3172	-19.09888	2.25	0.31
89	***Al*** CuZnFe	750	3.9934	20	34.08	681.6	25.26172	1.77	20	38.44	768.8	-87.2	-873.4412	-32.37181	2.05	0.28
90	***Al*** CuZnFe	750	3.9952	20	34.08	681.6	25.26172	1.77	20	37.62	752.4	-70.8	-708.8506	-26.27169	2.07	0.3
91	***Al*** CuZnFe	1000	3.9932	20	46.2	924	34.24564	1.67	20	50.73	1014.6	-90.6	-907.5428	-33.6357	2	0.33
92	***Al*** CuZnFe	1000	3.9965	20	46.2	924	34.24564	1.67	20	51.83	1036.6	-112.6	-1126.986	-41.76879	1.97	0.3
81	AlCuZn**Fe**	50	4.0096	1	67.3	67.3	1.205121	1.99	1	18	18	49.3	491.8196	8.80687	2.76	0.77
82	AlCuZn**Fe**	50	3.9939	1	67.3	67.3	1.205121	1.99	1	18	18	49.3	493.753	8.841489	2.81	0.82
83	AlCuZn**Fe**	100	3.996	10	16	160	2.865073	1.95	1	42.5	42.5	117.5	1176.176	21.06144	2.63	0.68
84	AlCuZn**Fe**	100	3.9985	10	16	160	2.865073	1.95	1	50.9	50.9	109.1	1091.409	19.54355	2.62	0.67
85	AlCuZn**Fe**	250	3.9992	10	34.9	349	6.24944	1.9	10	13.5	135	214	2140.428	38.32802	2.41	0.51
86	AlCuZn**Fe**	250	4.0095	10	34.9	349	6.24944	1.9	10	13.2	132	217	2164.858	38.76548	2.43	0.53
87	AlCuZn**Fe**	500	4.0003	10	65.2	652	11.67517	1.94	10	28.1	281	371	3709.722	66.4289	2.24	0.3
88	AlCuZn**Fe**	500	4.0053	10	65.2	652	11.67517	1.94	10	27.1	271	381	3804.958	68.13427	2.25	0.31
89	AlCuZn**Fe**	750	3.9934	10	98.9	989	17.70973	1.77	10	65.2	652	337	3375.57	60.44533	2.05	0.28
90	AlCuZn**Fe**	750	3.9952	10	98.9	989	17.70973	1.77	10	64.5	645	344	3444.133	61.67308	2.07	0.3
91	AlCuZn**Fe**	1000	3.9932	20	68.5	1370	24.53219	1.67	10	108.8	1088	282	2824.802	50.5829	2	0.33
92	AlCuZn**Fe**	1000	3.9965	20	68.5	1370	24.53219	1.67	10	103.7	1037	333	3332.916	59.68155	1.97	0.3
81	Al**Cu**ZnFe	50	4.0096	5	13.45	67.25	1.058288	1.99	1	17.43	17.43	49.82	497.0072	7.821219	2.76	0.77
82	Al**Cu**ZnFe	50	3.9939	5	13.45	67.25	1.058288	1.99	1	17.38	17.38	49.87	499.4617	7.859845	2.81	0.82
83	Al**Cu**ZnFe	100	3.996	5	24.5	122.5	1.927737	1.95	10	5.86	58.6	63.9	639.6396	10.06577	2.63	0.68
84	Al**Cu**ZnFe	100	3.9985	5	24.5	122.5	1.927737	1.95	10	6.02	60.2	62.3	623.2337	9.807599	2.62	0.67
85	Al**Cu**ZnFe	250	3.9992	10	27.46	274.6	4.321279	1.9	10	16.74	167.4	107.2	1072.214	16.87304	2.41	0.51
86	Al**Cu**ZnFe	250	4.0095	10	27.46	274.6	4.321279	1.9	10	16.74	167.4	107.2	1069.46	16.8297	2.43	0.53
87	Al**Cu**ZnFe	500	4.0003	20	28.33	566.6	8.916376	1.94	10	36.66	366.6	200	1999.85	31.4709	2.24	0.3
88	Al**Cu**ZnFe	500	4.0053	20	28.33	566.6	8.916376	1.94	10	35.83	358.3	208.3	2080.244	32.73603	2.25	0.31
89	Al**Cu**ZnFe	750	3.9934	20	42.94	858.8	13.51462	1.77	20	30.91	618.2	240.6	2409.976	37.92491	2.05	0.28
90	Al**Cu**ZnFe	750	3.9952	20	42.94	858.8	13.51462	1.77	20	30.84	616.8	242	2422.907	38.1284	2.07	0.3
91	Al**Cu**ZnFe	1000	3.9932	40	31.7	1268	19.95405	1.67	40	23.21	928.4	339.6	3401.783	53.53261	2	0.33
92	Al**Cu**ZnFe	1000	3.9965	40	31.7	1268	19.95405	1.67	40	23.46	938.4	329.6	3298.887	51.91336	1.97	0.3
81	AlCu**Zn**Fe	50	4.0096	10	4.92	49.2	0.752409	1.99	1	13.84	13.84	35.36	352.7534	5.394608	2.76	0.77
82	AlCu**Zn**Fe	50	3.9939	10	4.92	49.2	0.752409	1.99	1	13.68	13.68	35.52	355.7425	5.44032	2.81	0.82
83	AlCu**Zn**Fe	100	3.996	1	143.2	143.2	2.189937	1.95	10	3.68	36.8	106.4	1065.065	16.28789	2.63	0.68
84	AlCu**Zn**Fe	100	3.9985	1	143.2	143.2	2.189937	1.95	10	3.85	38.5	104.7	1047.393	16.01763	2.62	0.67
85	AlCu**Zn**Fe	250	3.9992	1	293	293	4.480807	1.9	1	130.9	130.9	162.1	1621.324	24.79468	2.41	0.51
86	AlCu**Zn**Fe	250	4.0095	1	293	293	4.480807	1.9	1	128.4	128.4	164.6	1642.1	25.1124	2.43	0.53
87	AlCu**Zn**Fe	500	4.0003	1	590.2	590.2	9.025845	1.94	1	343.9	343.9	246.3	2462.815	37.66349	2.24	0.3
88	AlCu**Zn**Fe	500	4.0053	1	590.2	590.2	9.025845	1.94	1	347.1	347.1	243.1	2427.783	37.12774	2.25	0.31
89	AlCu**Zn**Fe	750	3.9934	1	859.4	859.4	13.14268	1.77	1	608.6	608.6	250.8	2512.145	38.41788	2.05	0.28
90	AlCu**Zn**Fe	750	3.9952	1	859.4	859.4	13.14268	1.77	1	599.5	599.5	259.9	2602.123	39.79389	2.07	0.3
91	AlCu**Zn**Fe	1000	3.9932	5	229.1	1145.5	17.51797	1.67	1	846.9	846.9	298.6	2991.085	45.74224	2	0.33

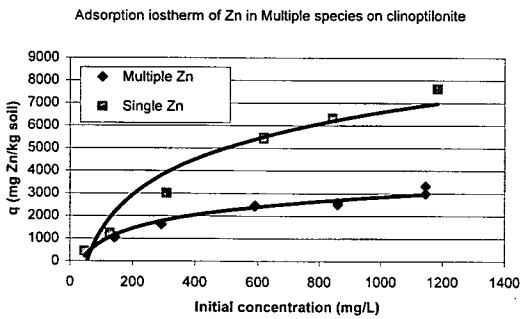
ID	Species	Design conc (ppm)	wt soil (g)	init conc dilution	AAS	Init conc mg/L	mmol/L	Initial pH	dilution	AAS	Conc mg/L	Adsorbed mg/L	Adsorbed mg/kg	mmol/kg	Final pH	diff pH
92	AlCuZnFe	1000	3.9965	5	229.1	1145.5	17.51797	1.67	1	812.8	812.8	332.7	3329.914	50.9239	1.97	0.3
81	AlCuZnFe-Na	50	4.0096	1	20.4	20.4	0.887354	1.99	10	22.6	226	-205.6	-2051.077	-89.21723		
82	AlCuZnFe-Na	50	3.9939	1	20.4	20.4	0.887354	1.99	10	26.5	265	-244.6	-2449.736	-106.558		
83	AlCuZnFe-Na	100	3.996	1	21.7	21.7	0.943901	1.95	10	30.1	301	-279.3	-2795.796	-121.6108		
84	AlCuZnFe-Na	100	3.9985	1	21.7	21.7	0.943901	1.95	10	31.4	314	-292.3	-2924.097	-127.1916		
85	AlCuZnFe-Na	250	3.9992	1	25.8	25.8	1.122242	1.9	10	37.7	377	-351.2	-3512.703	-152.7946		
86	AlCuZnFe-Na	250	4.0095	1	25.8	25.8	1.122242	1.9	10	35.2	352	-326.2	-3254.271	-141.5534		
87	AlCuZnFe-Na	500	4.0003	1	33.5	33.5	1.457174	1.94	10	39.4	394	-360.5	-3604.73	-156.7976		
88	AlCuZnFe-Na	500	4.0053	1	33.5	33.5	1.457174	1.94	10	47.1	471	-437.5	-4369.211	-190.0508		
89	AlCuZnFe-Na	750	3.9934	1	36.8	36.8	1.600717	1.77	10	47.2	472	-435.2	-4359.193	-189.615		
90	AlCuZnFe-Na	750	3.9952	1	36.8	36.8	1.600717	1.77	10	45.1	451	-414.2	-4146.976	-180.3841		
91	AlCuZnFe-Na	1000	3.9932	1	42.7	42.7	1.857354	1.67	10	49.3	493	-450.3	-4510.668	-196.2039		
92	AlCuZnFe-Na	1000	3.9965	1	42.7	42.7	1.857354	1.67	10	49.7	497	-454.3	-4546.979	-197.7833		
81	AlCuZnFe-Si	50	4.0096	1	0.0802	0.0802	0.002856	1.99	1	60.9127	60.9127	-60.8325	-606.8685	-21.60789		
82	AlCuZnFe-Si	50	3.9939	1	0.0802	0.0802	0.002856	1.99	1	60.152	60.152	-60.0718	-601.6355	-21.42157		
83	AlCuZnFe-Si	100	3.996	1	-0.1122	-0.1122	-0.003995	1.95	1	61.8359	61.8359	-61.9481	-620.1011	-22.07905		
84	AlCuZnFe-Si	100	3.9985	1	-0.1122	-0.1122	-0.003995	1.95	1	61.6971	61.6971	-61.8093	-618.3249	-22.0158		
85	AlCuZnFe-Si	250	3.9992	1	-0.0145	-0.0145	-0.000516	1.9	1	63.0754	63.0754	-63.0899	-631.0252	-22.46801		
86	AlCuZnFe-Si	250	4.0095	1	-0.0145	-0.0145	-0.000516	1.9	1	65.8034	65.8034	-65.8179	-656.6195	-23.37931		
87	AlCuZnFe-Si	500	4.0003	1	0.0547	0.0547	0.001948	1.94	1	69.6636	69.6636	-69.6089	-696.0368	-24.78278		
88	AlCuZnFe-Si	500	4.0053	1	0.0547	0.0547	0.001948	1.94	1	70.2227	70.2227	-70.168	-700.7515	-24.95065		
89	AlCuZnFe-Si	750	3.9934	1	0.1114	0.1114	0.003966	1.77	1	77.3113	77.3113	-77.1999	-773.2749	-27.53289		
90	AlCuZnFe-Si	750	3.9952	1	0.1114	0.1114	0.003966	1.77	1	81.2308	81.2308	-81.1194	-812.1686	-28.91772		
91	AlCuZnFe-Si	1000	3.9932	1	0.1571	0.1571	0.005594	1.67	1	88.4599	88.4599	-88.3028	-884.5317	-31.49425		
92	AlCuZnFe-Si	1000	3.9965	1	0.1571	0.1571	0.005594	1.67	1	86.1916	86.1916	-86.0345	-861.0985	-30.65989		
81	AlCuZnFe-K	50	4.0096	1	1.5	1.5	40.5983	1.99	1	11	11	-9.5	-94.77255	-2.423956		
82	AlCuZnFe-K	50	3.9939	1	1.5	1.5	40.5983	1.99	1	11.4	11.4	-9.9	-99.15121	-2.535947		
83	AlCuZnFe-K	100	3.996	1	1.9	1.9	40.9983	1.95	1	13.7	13.7	-11.8	-118.1181	-3.021055		
84	AlCuZnFe-K	100	3.9985	1	1.9	1.9	40.9983	1.95	1	13.7	13.7	-11.8	-118.0443	-3.019166		
85	AlCuZnFe-K	250	3.9992	1	4	4	43.0983	1.9	1	15.8	15.8	-11.8	-118.0236	-3.018638		
86	AlCuZnFe-K	250	4.0095	1	4	4	43.0983	1.9	1	15.5	15.5	-11.5	-114.7275	-2.934335		
87	AlCuZnFe-K	500	4.0003	1	7.9	7.9	46.9983	1.94	1	18.5	18.5	-10.6	-105.9921	-2.710912		
88	AlCuZnFe-K	500	4.0053	1	7.9	7.9	46.9983	1.94	1	19	19	-11.1	-110.8531	-2.835241		
89	AlCuZnFe-K	750	3.9934	1	11.3	11.3	50.3983	1.77	1	21.8	21.8	-10.5	-105.1735	-2.689977		
90	AlCuZnFe-K	750	3.9952	1	11.3	11.3	50.3983	1.77	1	21.7	21.7	-10.4	-104.1249	-2.663158		
91	AlCuZnFe-K	1000	3.9932	1	14.2	14.2	53.2983	1.67	1	25.6	25.6	-11.4	-114.1941	-2.920693		
92	AlCuZnFe-K	1000	3.9965	1	14.2	14.2	53.2983	1.67	1	25.9	25.9	-11.7	-117.1025	-2.995078		

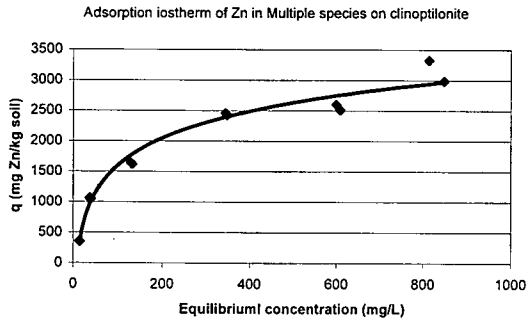
ID	Species	Design conc (ppm)	wt soil (g)	init conc dilution	AAS	Init conc mg/L	mmol/L	Initial pH	dilution	AAS	Conc mg/L	Adsorbed mg/L	Adsorbed mg/kg	mmol/kg	Final pH	diff pH
140	Mn	0	4.00	1	0.21	0.21	0.003822	3.50	1	1.01	1.01	-0.8	-8	-0.145619	8.49	4.99
144	Mn	0	4.00	1	0.21	0.21	0.003822	3.50	1	0.83	0.83	-0.62	-6.2	-0.112854	8.39	4.89
28	Mn	50	4.00	1	40.67	40.67	0.740288	3.50	1	2.32	2.32	38.35	383.5	6.98059	7.82	4.32
113	Mn	50	4.00	1	40.67	40.67	0.740288	3.50	1	2.38	2.38	38.29	382.9	6.969669	7.76	4.26
109	Mn	100	4.00	5	15.93	79.65	1.449815	3.50	1	4.35	4.35	75.3	753	13.70635	7.49	3.99
16	Mn	100	4.00	5	15.93	79.65	1.449815	3.50	1	4.47	4.47	75.18	751.8	13.6845	7.48	3.98
64	Mn	250	4.00	5	36.74	183.7	3.343766	3.50	1	30.27	30.27	153.43	1534.3	27.92782	7	3.5
66	Mn	250	4.00	5	36.74	183.7	3.343766	3.50	1	31.14	31.14	152.56	1525.6	27.76946	7.01	3.51
69	Mn	500	4.00	10	39.15	391.5	7.126209	3.50	5	29.96	149.8	241.7	2417	43.99501	6.75	3.25
107	Mn	500	4.00	10	39.15	391.5	7.126209	3.50	5	31.58	157.9	233.6	2336	42.52062	6.79	3.29
132	Mn	750	4.00	20	29.29	585.8	10.66292	3.50	10	33.92	339.2	246.6	2466	44.88692	6.64	3.14
68	Mn	750	4.00	20	29.29	585.8	10.66292	3.50	10	34.34	343.4	242.4	2424	44.12243	6.65	3.15
134	Mn	1000	4.00	20	37.91	758.2	13.801	3.50	20	22.87	457.4	300.8	3008	54.75258	6.56	3.06
23	Mn	1000	4.00	20	37.91	758.2	13.801	3.50	20	22.02	440.4	317.8	3178	57.84697	6.58	3.08
143	Mn	1500	4.00	40	31.16	1246.4	22.68737	3.50	20	43.56	871.2	375.2	3752	68.29511	6.42	2.92
117	Mn	2000	4.00	40	40.69	1627.6	29.6261	3.50	40	32.64	1305.6	322	3220	58.61147	6.4	2.[illegible]
98	Mn	2500	4.00	40	52.47	2098.8	38.20303	3.50	40	41.55	1662	436.8	4368	79.50774	6.36	2.8[illegible]
27	Mn	3000	4.00	80	30.22	2417.6	44.00593	3.50	40	52.75	2110	307.6	3076	55.99034	6.32	2.8[illegible]
110	Mn	3500	4.00	80	37.09	2967.2	54.00993	3.50	80	31.24	2499.2	468	4680	85.18686	6.28	2.7[illegible]

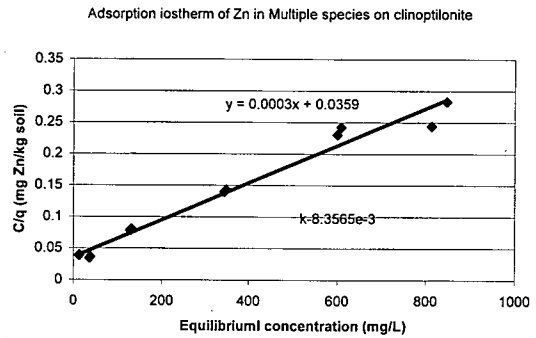

Adsorption iostherm of Al in Multiple species on clinoptilonite
q (mg Al/kg soil)
Initial concentration (mg/L)

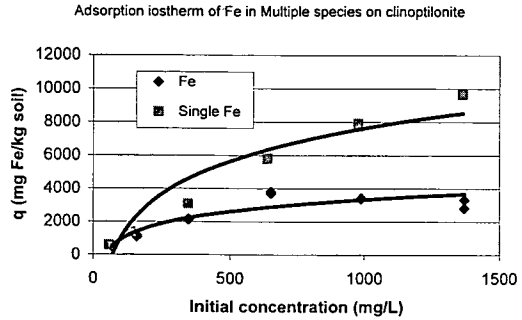

Adsorption iostherm of Al in Multiple species on clinoptilonite
q (mg Al/kg soil)
Equilibrium concentration (mg/L)

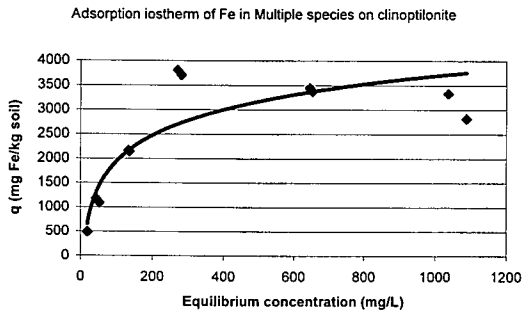

Adsorption iostherm of Al in Multiple species on clinoptilonite
C/q (mg Al/kg soil)
k=-2.3747e-4
y = -0.0002x - 0.8422
Equilibrium concentration (mg/L)

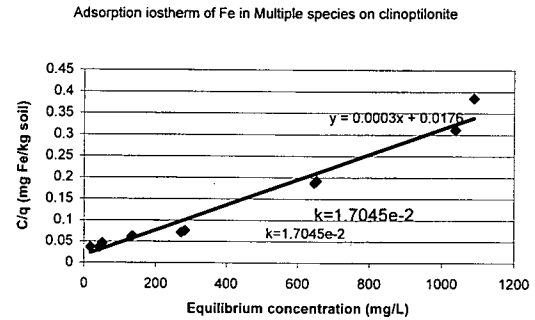

Adsorption iostherm of Zn in Multiple species on clinoptilonite
Multiple Zn
Single Zn
q (mg Zn/kg soil)
Initial concentration (mg/L)

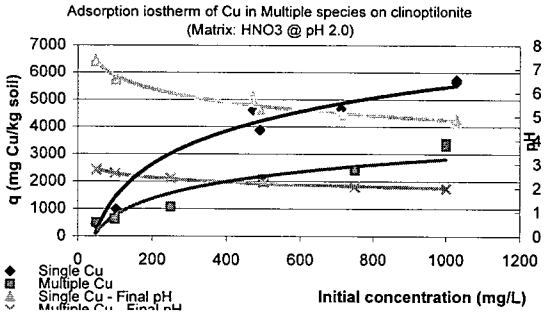

Adsorption iostherm of Zn in Multiple species on clinoptilonite
q (mg Zn/kg soil)
Equilibriuml concentration (mg/L)

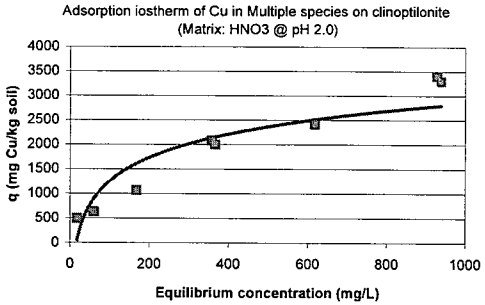

Adsorption iostherm of Zn in Multiple species on clinoptilonite
C/q (mg Zn/kg soil)
y = 0.0003x + 0.0359
k-8.3565e-3
Equilibriuml concentration (mg/L)

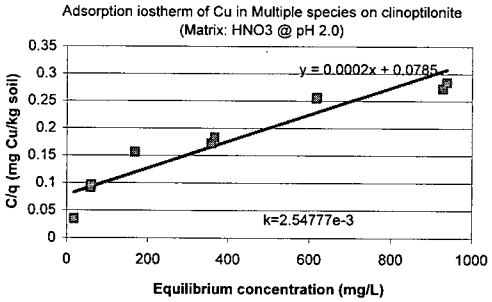

Adsorption iostherm of Fe in Multiple species on clinoptilonite
Fe
Single Fe
q (mg Fe/kg soil)
Initial concentration (mg/L)

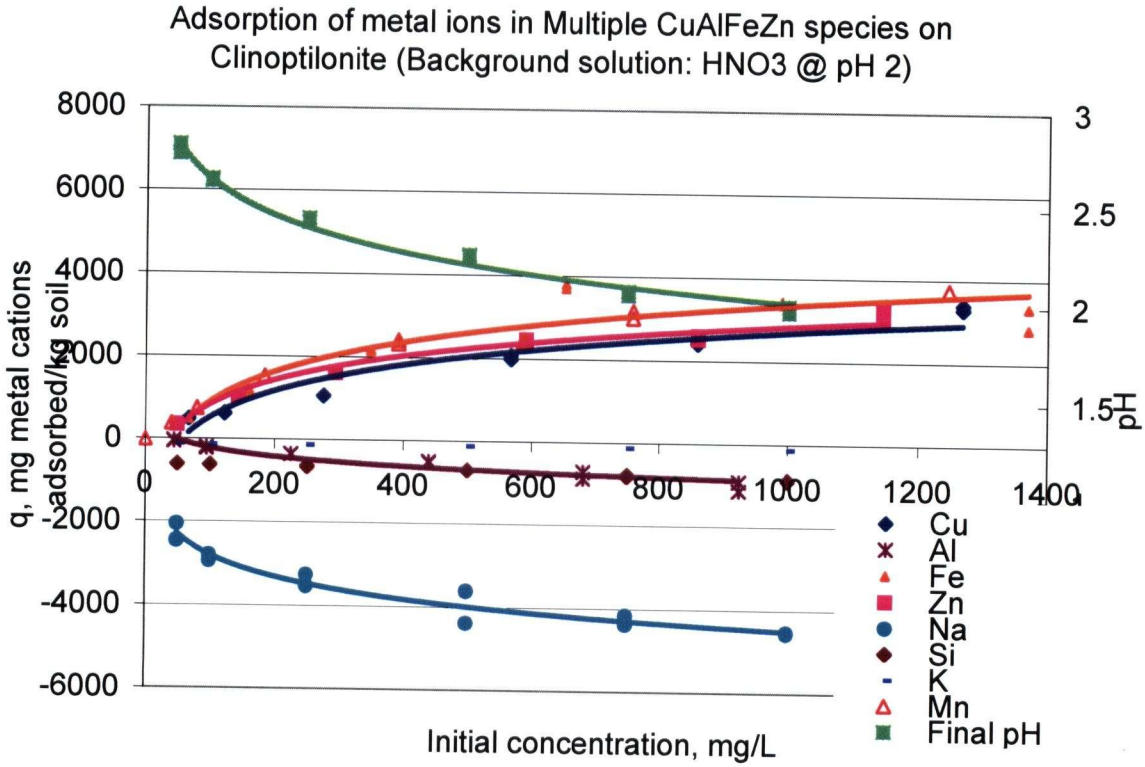

Adsorption iostherm of Fe in Multiple species on clinoptilonite
q (mg Fe/kg soil)
Equilibrium concentration (mg/L)

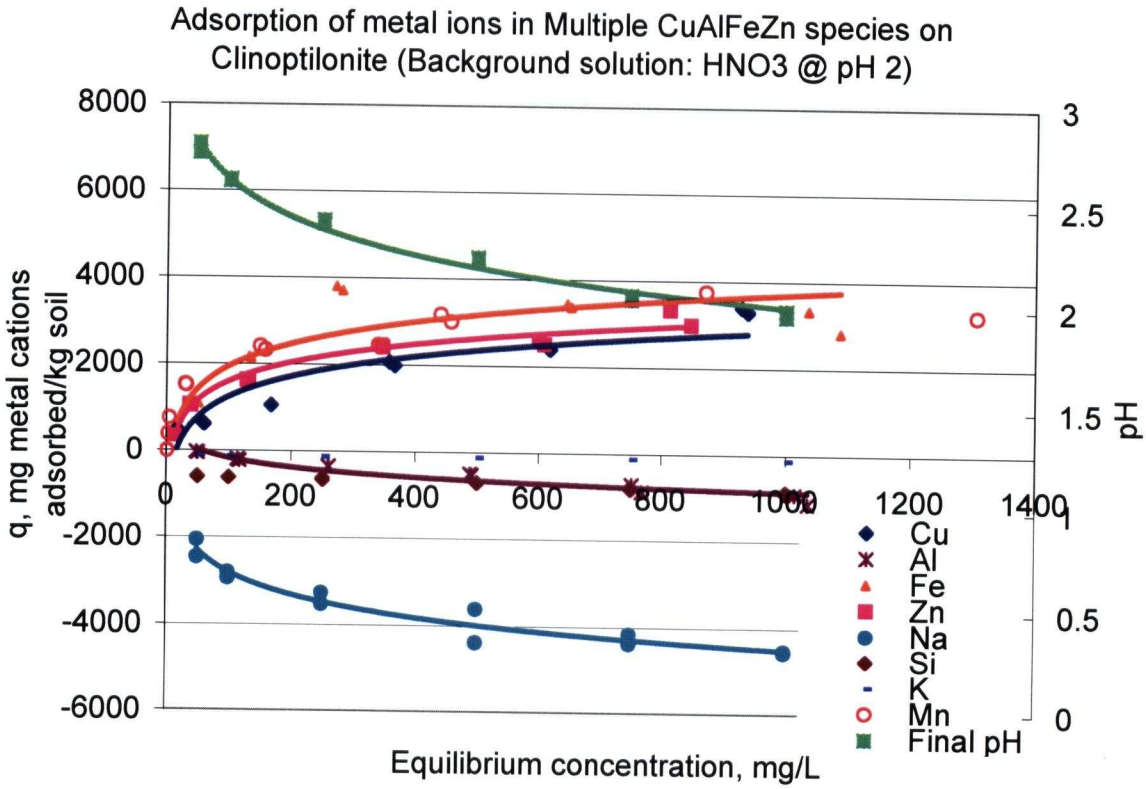

Adsorption iostherm of Fe in Multiple species on clinoptilonite
C/q (mg Fe/kg soil)
y = 0.0003x + 0.0176
k=1.7045e-2
k=1.7045e-2
Equilibrium concentration (mg/L)

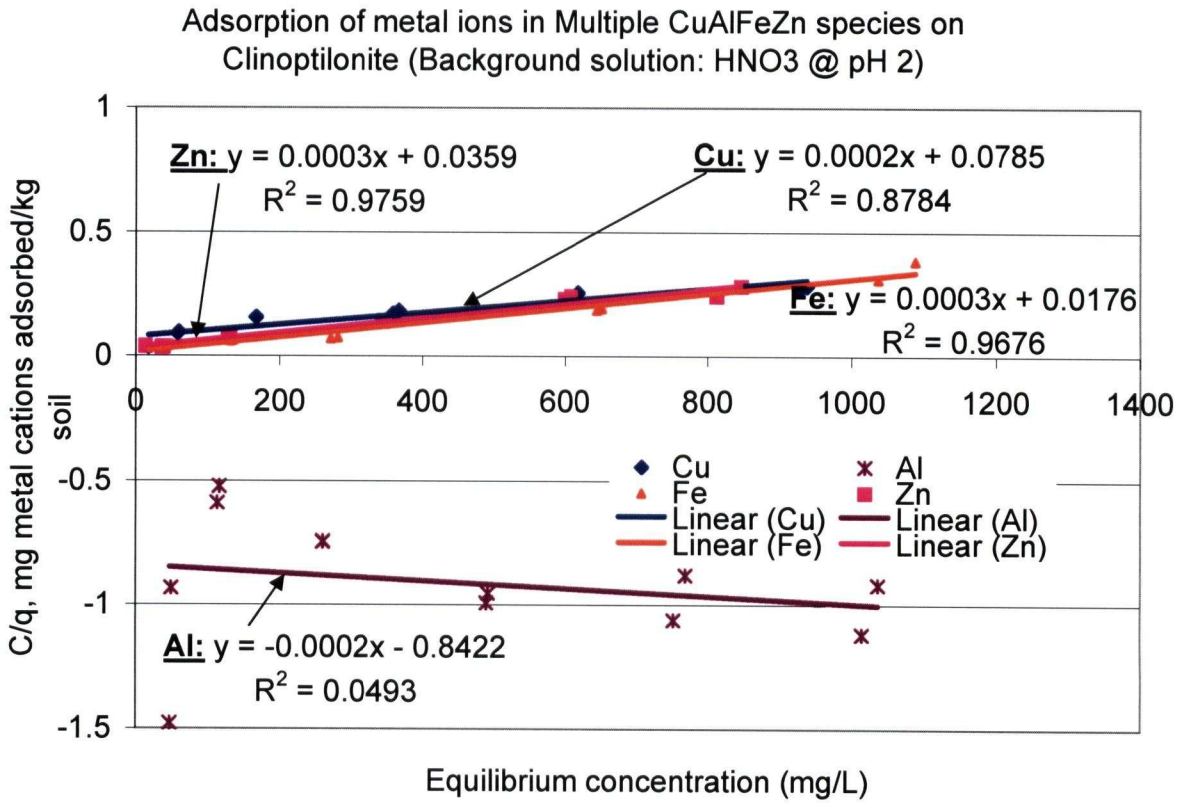

Adsorption iostherm of Cu in Multiple species on clinoptilonite
(Matrix: HNO3 @ pH 2.0)
q (mg Cu/kg soil)
pH
Initial concentration (mg/L)
Single Cu
Multiple Cu
Single Cu - Final pH


Adsorption iostherm of Cu in Multiple species on clinoptilonite
(Matrix: HNO3 @ pH 2.0)
q (mg Cu/kg soil)
Equilibrium concentration (mg/L)


Adsorption iostherm of Cu in Multiple species on clinoptilonite
(Matrix: HNO3 @ pH 2.0)
y = 0.0002x + 0.0785
k=2.54777e-3
C/q (mg Cu/kg soil)
Equilibrium concentration (mg/L)


Adsorption of metal ions in Multiple CuAlFeZn species on Clinoptilonite (Background solution: HNO3 @ pH 2)
q, mg metal cations adsorbed/kg soil
pH
Initial concentration, mg/L
8000
6000
4000
2000
0
-2000
-4000
-6000
3
2.5
2
1.5
1
0
200
400
600
800
1000
1200
1400
Cu
Al
Fe
Zn
Na
Si
K
Mn
Final pH


Adsorption of metal ions in Multiple CuAlFeZn species on Clinoptilonite (Background solution: HNO3 @ pH 2)
q, mg metal cations adsorbed/kg soil
pH
Equilibrium concentration, mg/L
8000
6000
4000
2000
0
-2000
-4000
-6000
3
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1000
1200
1400
Cu
Al
Fe
Zn
Na
Si
K
Mn
Final pH

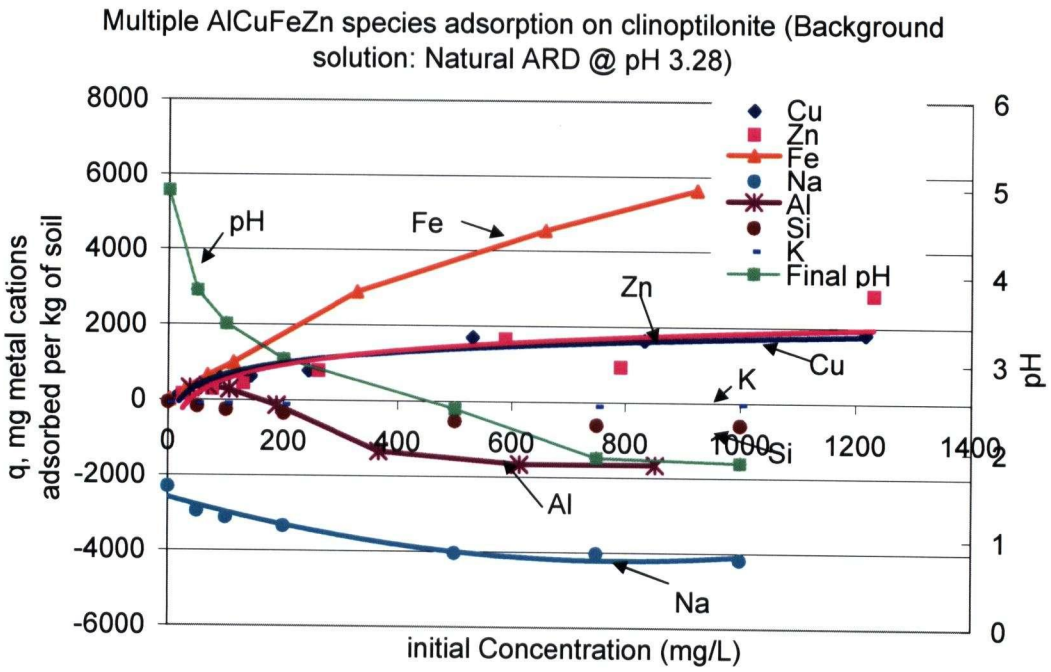

Adsorption of metal ions in Multiple CuAlFeZn species on Clinoptilonite (Background solution: HNO3 @ pH 2)
Zn: y = 0.0003x + 0.0359
R2 = 0.9759
Cu: y = 0.0002x + 0.0785
R2 = 0.8784
Fe: y = 0.0003x + 0.0176
R2 = 0.9676
Al: y = -0.0002x - 0.8422
R2 = 0.0493
Cu
Fe
Al
Zn
Linear (Cu)
Linear (Fe)
Linear (Al)
Linear (Zn)
C/q, mg metal cations adsorbed/kg soil
Equilibrium concentration (mg/L)
1
0.5
0
-0.5
-1
-1.5
0
200
400
600
800
1000
1200
1400

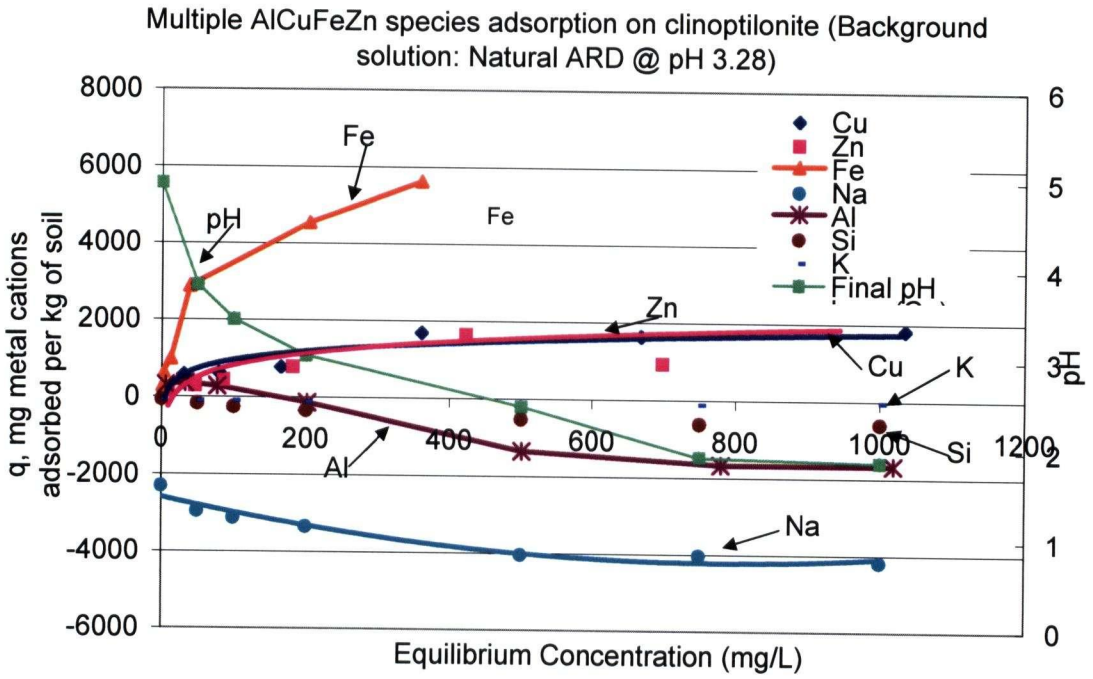
Appendix D-3

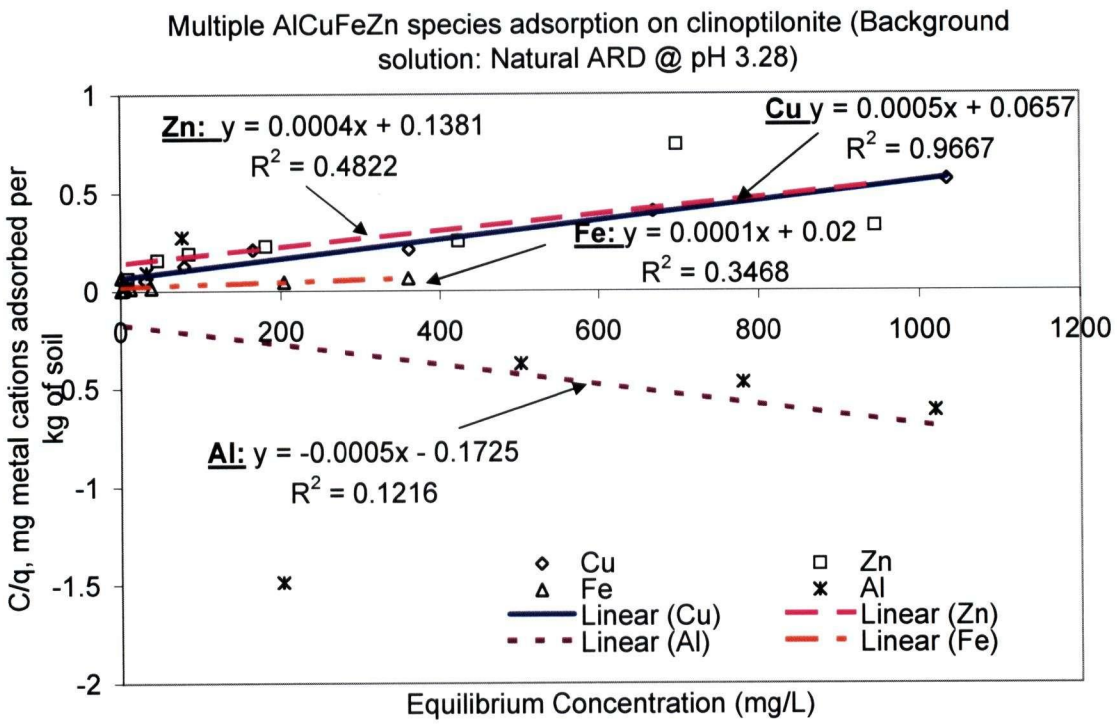
Adsorption isotherms of metals (Cu, Fe, Mn, Zn, Al) on clinoptilolite in multiple species solutions – Natural acid rock drainage background solution

ID	Species	Design conc (ppm)	wt soil (g)	init conc dilution	AAS	Init conc mg/L	mmol/L	Initial pH	dilution	AAS	Conc mg/L	Adsorbed mg/L	Adsorbed mg/kg	mmol/kg	Final pH	diff pH
200	**Al**CuZnFe	0	4.0047	20	1.885	37.7	64.68154	3.28	10	0.6251	6.251	31.449	314.1209	11.64207	4.96	1.68
201	**Al**CuZnFe	50	3.9993	20	3.4517	69.034	96.01554	3.28	10	3.3276	33.276	35.758	357.6426	13.25508	3.82	0.54
202	**Al**CuZnFe	100	3.9971	20	5.2771	105.542	132.5235	3.28	10	7.7426	77.426	28.116	281.364	10.42802	3.44	0.16
203	**Al**CuZnFe	200	3.997	20	9.3956	187.912	214.8935	3.28	20	10.0726	201.452	-13.54	-135.5016	-5.022013	3.04	-0.24
204	**Al**CuZnFe	500	4.0023	20	18.3445	366.89	393.8715	3.28	20	25.0564	501.128	-134.238	-1341.609	-49.7232	2.49	-0.79
205	**Al**CuZnFe	750	3.9986	40	15.3414	613.656	640.6375	3.28	20	39.005	780.1	-166.444	-1665.023	-61.7097	1.94	-1.34
206	**Al**CuZnFe	1000	4.0021	40	21.3147	852.588	879.5695	3.28	20	50.9596	1019.192	-166.604	-1665.166	-61.715	1.89	-1.39
200	Al**Cu**ZnFe	0	4.0047	1	18.91	18.91	0.29758	3.28	1	4.98	4.98	13.93	139.1365	2.18954	4.96	1.68
201	Al**Cu**ZnFe	50	3.9993	10	8.95	89.5	1.408429	3.28	1	31.54	31.54	57.96	579.7014	9.122548	3.82	0.54
202	Al**Cu**ZnFe	100	3.9971	10	14.27	142.7	2.245617	3.28	10	7.99	79.9	62.8	628.4556	9.889775	3.44	0.16
203	Al**Cu**ZnFe	200	3.997	10	24.35	243.5	3.83187	3.28	10	16.51	165.1	78.4	784.5884	12.34678	3.04	-0.24
204	Al**Cu**ZnFe	500	4.0023	20	26.54	530.8	8.353004	3.28	10	36.07	360.7	170.1	1700.022	26.75263	2.49	-0.79
205	Al**Cu**ZnFe	750	3.9986	20	41.64	832.8	13.10547	3.28	20	33.43	668.6	164.2	1642.575	25.8486	1.94	-1.34
206	Al**Cu**ZnFe	1000	4.0021	40	30.43	1217.2	19.15463	3.28	40	25.86	1034.4	182.8	1827.041	28.75147	1.89	-1.39
200	AlCu**Zn**Fe	0	4.0047	1	24.7	24.7	0.377734	3.28	1	9.74	9.74	14.96	149.4244	2.285127	4.96	1.68
201	AlCu**Zn**Fe	50	3.9993	10	7.61	76.1	1.163787	3.28	10	4.67	46.7	29.4	294.0515	4.496887	3.82	0.54
202	AlCu**Zn**Fe	100	3.9971	10	13.03	130.3	1.992659	3.28	10	8.56	85.6	44.7	447.3243	6.840867	3.44	0.16
203	AlCu**Zn**Fe	200	3.997	10	26.02	260.2	3.979202	3.28	20	9.06	181.2	79	790.5929	12.09043	3.04	-0.24
204	AlCu**Zn**Fe	500	4.0023	1	588.1	588.1	8.99373	3.28	1	422.7	422.7	165.4	1653.049	25.27985	2.49	-0.79
205	AlCu**Zn**Fe	750	3.9986	1	791.6	791.6	12.10583	3.28	1	698	698	93.6	936.3277	14.31913	1.94	-1.34
206	AlCu**Zn**Fe	1000	4.0021	2	615.7	1231.4	18.83163	3.28	1	945.1	945.1	286.3	2861.498	43.76048	1.89	-1.39
200	AlCuZn**Fe**	0	4.0047	1	2.444	2.444	0.043764	3.28	1	1	1	1.444	14.42305	0.258269	4.96	1.68
201	AlCuZn**Fe**	50	3.9993	10	3.043	30.43	0.544901	3.28	1	1.055	1.055	29.375	293.8014	5.261016	3.82	0.54
202	AlCuZn**Fe**	100	3.9971	1	68.1	68.1	1.219447	3.28	1	3.265	3.265	64.835	648.8204	11.61824	3.44	0.16
203	AlCuZn**Fe**	200	3.997	10	11.3	113	2.023458	3.28	1	13.3	13.3	99.7	997.7483	17.86639	3.04	-0.24
204	AlCuZn**Fe**	500	4.0023	20	16.4	328	5.8734	3.28	1	39.3	39.3	288.7	2885.341	51.66695	2.49	-0.79
205	AlCuZn**Fe**	750	3.9986	20	32.9	658	11.78261	3.28	10	20.4	204	454	4541.59	81.32491	1.94	-1.34
206	AlCuZn**Fe**	1000	4.0021	40	23.1	924	16.5458	3.28	10	36	360	564	5637.041	100.9408	1.89	-1.39
200	AlCuZnFe-**Na**	0	4.0047	1	25.8	25.8	1.122238	3.28	10	25.6	256	-230.2	-2299.298	-100.014	4.96	1.68
201	AlCuZnFe-**Na**	50	3.9993	1	20	20	0.869952	3.28	10	31.5	315	-295	-2950.516	-128.3404	3.82	0.54
202	AlCuZnFe-**Na**	100	3.9971	1	16.1	16.1	0.700312	3.28	10	32.8	328	-311.9	-3121.263	-135.7675	3.44	0.16
203	AlCuZnFe-**Na**	200	3.997	1	13.3	13.3	0.578518	3.28	10	34.7	347	-333.7	-3339.505	-145.2605	3.04	-0.24
204	AlCuZnFe-**Na**	500	4.0023	1	10.9	10.9	0.474124	3.28	10	41.5	415	-404.1	-4038.678	-175.6728	2.49	-0.79
205	AlCuZnFe-**Na**	750	3.9986	1	12	12	0.521971	3.28	10	41.5	415	-403	-4031.411	-175.3567	1.94	-1.34
206	AlCuZnFe-**Na**	1000	4.0021	1	15.1	15.1	0.656814	3.28	10	43.4	434	-418.9	-4186.802	-182.1159	1.89	-1.39
200	AlCuZnFe-**Si**	0	4.0047	10	1.4582	14.582	0.5192	3.28	1	21.0571	21.0571	-6.4751	-64.67501	-2.30279	4.96	1.68
201	AlCuZnFe-**Si**	50	3.9993	10	1.485	14.85	0.528743	3.28	1	31.975	31.975	-17.125	-171.28	-6.09852	3.82	0.54
202	AlCuZnFe-**Si**	100	3.9971	10	1.432	14.32	0.509872	3.28	1	39.6657	39.6657	-25.3457	-253.6409	-9.031026	3.44	0.16
203	AlCuZnFe-**Si**	200	3.997	10	1.3797	13.797	0.49125	3.28	1	47.7732	47.7732	-33.9762	-340.017	-12.1065	3.04	-0.24
204	AlCuZnFe-**Si**	500	4.0023	20	0.6386	12.772	0.454754	3.28	1	65.0372	65.0372	-52.2652	-522.3516	-18.59862	2.49	-0.79
205	AlCuZnFe-**Si**	750	3.9986	40	0.2622	10.488	0.373431	3.28	1	71.5196	71.5196	-61.0316	-610.5297	-21.73825	1.94	-1.34
206	AlCuZnFe-**Si**	1000	4.0021	40	0.3605	14.42	0.513432	3.28	1	74.2073	74.2073	-59.7873	-597.5593	-21.27643	1.89	-1.39
200	AlCuZnFe-**K**	0	4.0047	1	3.9	3.9	0.099749	3.28	1	11	11	-7.1	-70.91667	-1.813805	4.96	1.68
201	AlCuZnFe-**K**	50	3.9993	1	4.3	4.3	0.109979	3.28	1	13.3	13.3	-9	-90.01575	-2.302293	3.82	0.54
202	AlCuZnFe-**K**	100	3.9971	1	5	5	0.127883	3.28	1	14.5	14.5	-9.5	-95.06892	-2.431536	3.44	0.16
203	AlCuZnFe-**K**	200	3.997	1	5.6	5.6	0.143229	3.28	1	16.6	16.6	-11	-110.0826	-2.815533	3.04	-0.24
204	AlCuZnFe-**K**	500	4.0023	1	9.4	9.4	0.24042	3.28	1	20.4	20.4	-11	-109.9368	-2.811805	2.49	-0.79

ID	Species	Design conc (ppm)	wt soil (g)	init conc dilution	AAS	Init conc mg/L	mmol/L	Initial pH	dilution	AAS	Conc mg/L	Adsorbed mg/L	Adsorbed mg/kg	mmol/kg	Final pH	diff pH
205	AlCuZnFe-K	750	3.9986	1	13	13	0.332495	3.28	1	23.4	23.4	-10.4	-104.0364	-2.660894	1.94	-1.34
206	AlCuZnFe-K	1000	4.0021	1	23	23	0.588261	3.28	1	26.8	26.8	-3.8	-37.98006	-0.971399	1.89	-1.39
96	A-Mn (ARD mat	0	4.00	1	4.3	4.3	0.07827	3.11	1	6.63	6.63	-2.33	-23.3	-0.424114	4.63	1.5
99	A-Mn	0	4.00	1	4.3	4.3	0.07827	3.11	1	6.2	6.2	-1.9	-19	-0.345844	4.63	1.5
35	A-Mn	50	4.00	1	48.87	48.87	0.889547	3.11	1	29.43	29.43	19.44	194.4	3.538531	4.62	1.5
65	A-Mn	100	4.00	2	46.52	93.04	1.693544	3.11	1	59.09	59.09	33.95	339.5	6.179688	4.64	1.5
133	A-Mn	250	4.00	5	45	225	4.095522	3.11	5	28.58	142.9	82.1	821	14.94411	4.65	1.5
100	A-Mn	500	4.00	10	44.71	447.1	8.138258	3.11	10	30.28	302.8	144.3	1443	26.26595	4.4	1.2
21	A-Mn	750	4.00	20	32.89	657.8	11.97349	3.11	10	46.21	462.1	195.7	1957	35.62194	4.4	1.2
101	A-Mn	1000	4.00	20	44.14	882.8	16.06901	3.11	20	31.35	627	255.8	2558	46.56154	4.39	1.2
18	A-Mn	1000	4.00	20	44.14	882.8	16.06901	3.11	20	33.62	672.4	210.4	2104	38.29768	4.42	1.3
137	A-Mn	1500	4.00	40	32.4	1296	23.59021	3.11	20	55.09	1101.8	194.2	1942	35.34891	4.33	1.2
138	A-Mn	2000	4.00	40	43.19	1727.6	31.44633	3.11	40	36.89	1475.6	252	2520	45.86985	4.33	1.2
26	A-Mn	2500	4.00	40	56.29	2251.6	40.98435	3.11	40	45.88	1835.2	416.4	4164	75.79446	4.29	1.1
63	A-Mn	3000	4.00	100	26.04	2604	47.39884	3.11	40	58.36	2334.4	269.6	2696	49.07346	4.29	1.1
29	A-Mn	3500	4.00	100	29.95	2995	54.51595	3.11	80	32.88	2630.4	364.6	3646	66.36566	4.22	1.1


Multiple AlCuFeZn species adsorption on clinoptilonite (Background solution: Natural ARD @ pH 3.28)
q, mg metal cations adsorbed per kg of soil
initial Concentration (mg/L)
pH
Cu
Zn
Fe
Na
Al
Si
K
Final pH
8000
6000
4000
2000
0
-2000
-4000
-6000
0
200
400
600
800
1000
1200
1400
6
5
4
3
2
1
0


Multiple AlCuFeZn species adsorption on clinoptilonite (Background solution: Natural ARD @ pH 3.28)
q, mg metal cations adsorbed per kg of soil
Equilibrium Concentration (mg/L)
pH
Cu
Zn
Fe
Na
Al
Si
K
Final pH
8000
6000
4000
2000
0
-2000
-4000
-6000
0
200
400
600
800
1000
1200
6
5
4
3
2
1
0


Multiple AlCuFeZn species adsorption on clinoptilonite (Background solution: Natural ARD @ pH 3.28)
Zn: y = 0.0004x + 0.1381
R2 = 0.4822
Cu y = 0.0005x + 0.0657
R2 = 0.9667
Fe: y = 0.0001x + 0.02
R2 = 0.3468
Al: y = -0.0005x - 0.1725
R2 = 0.1216
Cu
Zn
Fe
Al
Linear (Cu)
Linear (Zn)
Linear (Al)
Linear (Fe)
C/q, mg metal cations adsorbed per kg of soil
Equilibrium Concentration (mg/L)
1
0.5
0
-0.5
-1
-1.5
-2
0
200
400
600
800
1000
1200

Appendix E. Leaching of metals from clinoptilolite

From both the batch equilibrium adsorption and the column leaching tests, leaching of Manganese from the clinoptilolite has been detected.

A test is conducted to find out the amount of metals which is presence on the surface of the clinoptilolite. A 1:10 soil:0.01 M HCl ratio was used to remove the surface-attached metal species on the clinoptilolite. The results are shown in Figure E.1.

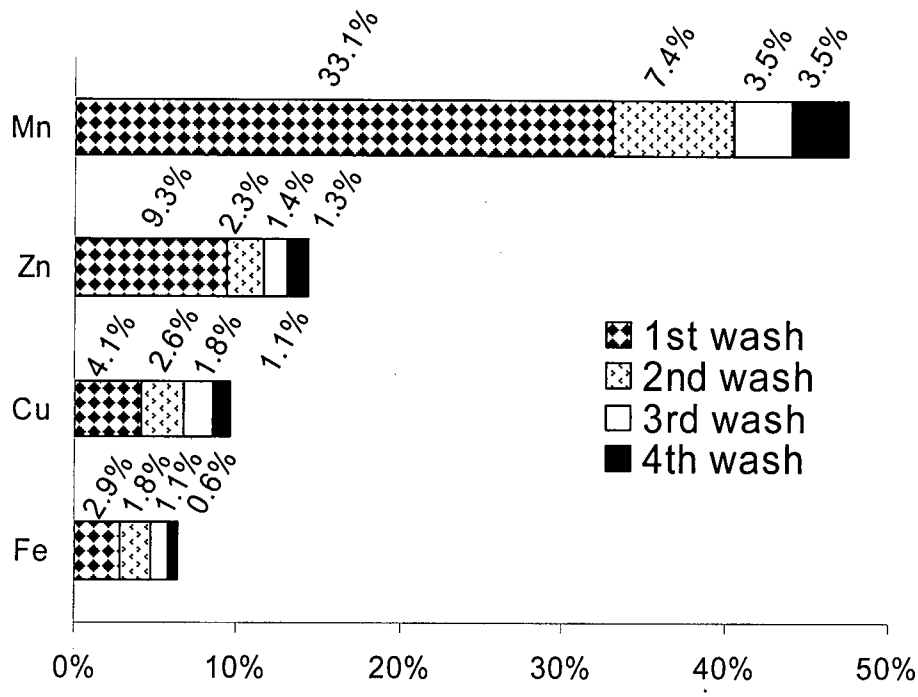


Figure E.1 Metals present on the surface of the clinoptilolite (Percentage to the total metal concentration of the clinoptilolite obtained from XRF analysis)

It is found that 47.51% of the total Mn in the clinoptilolite sample leached out after four washes using 0.01 M HCl solution, whereas only less than 15% of Zn, less than 10% of Cu and less than 7% of Fe was washed out.

This observation could be used to explain the presence of more than three times of Mn concentration as the influent was found at the effluent of the column leaching test. It is because a majority of the Mn species was present in the clinoptilolite as "surface coating" and were easily washed away when the soil is flushed by slightly acidic solution.

In order to achieve the goal of remediating ARD by using clinoptilolite in metal removal treatment and to maximize the removal efficacy, instead of placing metal into the environment, it is necessary to prevent and to minimize the leaching of Mn from the clinoptilolite. One method of doing so is to pretreat the clinoptilolite with another solution, removing impurities from the surface of the soil and turning the surface of the clinoptilolite from hetero-ionic to homo-ionic prior to exposing to the ARD. This way the surface of the clinoptilolite would be covered by only one type of cations, which would lead to an increase in the amount of adsorption sites and to minimize competition between the different types of ions on the surface with the cations in the leaching solution.

Appendix F. Determination of pretreatment methods

The pretreatment reagents considered and tested in treating the clinoptilolite include:

- 2 M NaCl
- 1 M NaCl
- 0.5 M NaCl
- 0.01 M HCl
- 0.01 M NaOH
- Distilled water

For each of the pretreatment reagents, a comparison was also conducted between a distilled water rinse and with no distilled water rinse before exposure to the ARD.

Pretreatment was conducted by mixing one part of soil to ten part of pretreatment reagent, followed by shaking in the rotator for 24 hours. Pretreatment reagents were decanted and the samples were oven-dried at 40°C. The set of samples which required rinsing were placed in the same container with 1:10 soil:distilled water ratio and placed in the shaker for 24 hours. Distilled water was decanted and soil samples were dried. The treated soil was "contaminated" with ARD using the 24-hour batch adsorption test procedures and the concentrations of metals were measured. The results from the various pretreatment methods are presented in Figure F.1.

From Figure F.1, it indicates that the removal of metals are greatest by using 0.01 M NaOH with no rinse, followed by 2 M NaCl with rinse and 1 M NaCl with rinse. Although 0.01 M HCl has been a good reagent in removing surface-attached Mn on the clinoptilolite in the preceding test, it has been found that the pH of the HCl solution was too low, which causes a decrease in the pH of the clinoptilolite. This strongly reduces the capacity of retaining metal cations during the equilibrium adsorption tests. Therefore, HCl is not recommended to be used as a pretreatment reagent.

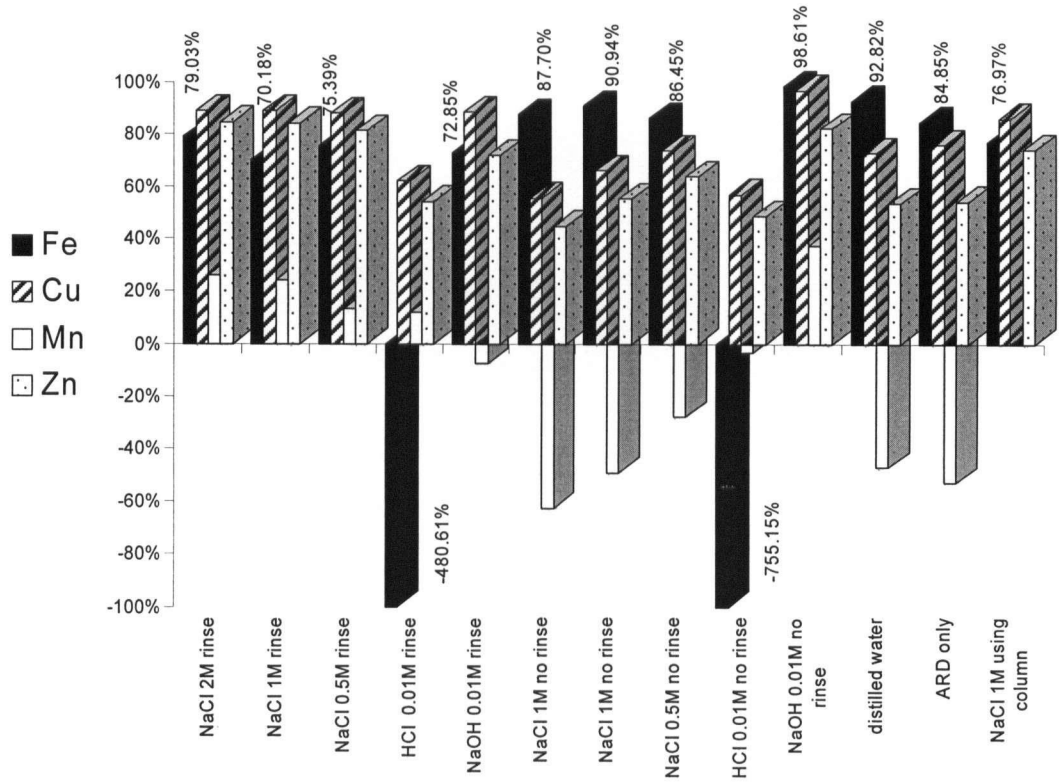


Figure G.1 Removal efficiency of clinoptilolite using different pretreatment methods

Although NaOH pretreatment provides most removal of metals, it is achieved mainly by precipitation because the equilibrium pH is 6.10. In addition, since NaOH is a strong base, it is not recommended as pretreatment solution because it might dissociate some of the Al and Si from the clinoptilolite structure. The high pH of the NaOH solution would lead to Al solubility due to aluminate formation.

The pretreatment reagents of 2 M NaCl and 1M NaCl gives very similar removal of metals, therefore, it is feasible to use 1 M NaCl as the pretreatment solution.

Appendix G. Column leaching cell tests water sample analyses results

Cell ID NTNFC1

wt soil before filling column	1546	g
wt soil after filling column	707	g
wt soil in column	839	g
Date start	Aug14,2002	
leachate	non filtered ARD010902	
pore volume	329.11844	ml
flowrate	1.3280261	L/day
	0.9913602	m/day

initial concentration of metals, Co		
[Cu]o	35.679	mg/L
[Fe]o	5.467	mg/L
[Mn]o	3.284	mg/L
[Zn]o	23.3259	mg/L
[Al]o	32.74	mg/L
pH	3.07	
Redox Pot	526.4	mV
EC	2.08	mS/cm

☑ 1 M NaCl pretreated ☑ No pretreatment

ARD concentration:

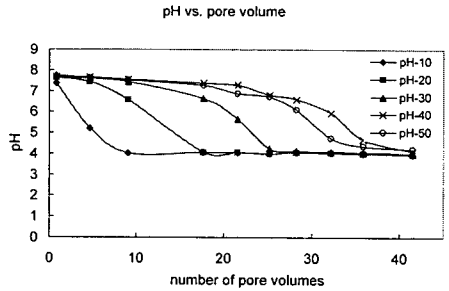
☑ Natural ☐ Maximum design

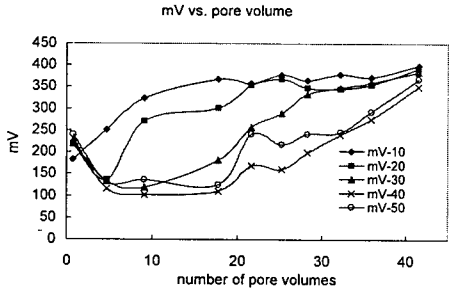
☐ Filtered ☑ Non-filtered

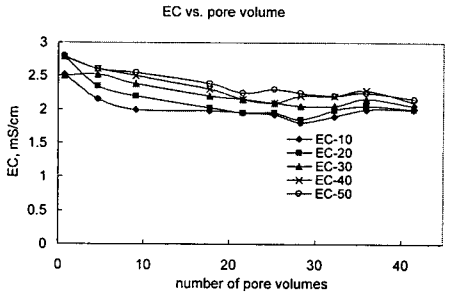
Group	Date	Time	vol effl (ml)	time used hh:mm:ss	(min)	Flowrate L/day	pv/day	#pore vol	10cm Cu-10	Fe-10	Mn-10	Zn-10	Al-10	pH-10	mV-10	EC-10
1	14-Aug	13:15	246	3:15:00	195.00	1.816615	5.51964	0.747451	0.038	0.109	0.216	0.0058	9.26	7.37	183.2	2.52
2	15-Aug	10:30	1285	19:12:19	1152.32	1.605809	4.879121	4.651821	35.46	0.095	5.681	21.9245	10.03	5.2	251.6	2.15
3	16-Aug	10:30	1450	22:11:37	1331.62	1.568019	4.7643	9.05753	30.612	0.193	3.945	21.9455	36.4	4.04	323.4	2
4	19-Aug	8:58	2850	69:21:35	4161.58	0.986163	2.996378	17.71703	34.266	0.44	3.737	22.4666	40.32	4.06	367.1	1.98
5	20-Aug	9:12	1270	21:53:00	1313.00	1.392841	4.232035	21.57582	34.207	0.39	3.599	21.7822	33.8	4.06	358.1	1.95
6	12-Aug	9:15	1200	21:49:16	1309.27	1.319823	4.010176	25.22192	34.81	0.59	3.652	22.0848	36.68	4	377.8	1.92
7	22-Aug	9:15	1000	21:35:57	1295.95	1.111154	3.376152	28.26034	35.501	0.459	3.518	21.8227	35.98	4.05	364.2	1.8
8	23-Aug	9:53	1295	22:58:29	1378.48	1.352791	4.110347	32.1951	34.988	0.205	3.501	22.0214	38.79	4.04	378.7	1.9
9	26-Aug	10:30	1205	69:41:34	4181.57	0.414964	1.260835	35.85639	31.426	0.245	3.992	20.5395	34.38	3.99	371.8	2
10	28-Aug	10:55	1850	25:56:00	1556.00	1.712082	5.202025	41.47747	35.242	0.204	3.394	22.1694	34.89	3.93	398.5	1.12

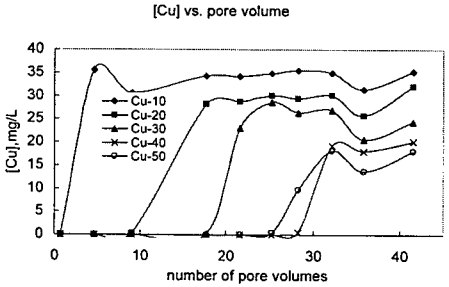
20cm Cu-20	Fe-20	Mn-20	Zn-20	Al-20	pH-20	mV-20	EC-20	30cm Cu-30	Fe-30	Mn-30	Zn-30	Al-30	pH-30	mV-30	EC-30
0.019	0.313	0.03	-0.0103	9.51	7.64	217.4	2.78	-0.007	0.16	0.049	-0.0024	8	7.77	221.7	2.5
-0.002	0.114	0.224	-0.0017	8.95	7.43	136.6	2.35	-0.007	0.077	0.007	-0.0186	3.93	7.62	133.1	2.52
0.253	0.065	9.13	22.1042	5.92	6.57	271.3	2.2	-0.031	0.065	0.305	0.0007	4.6	7.42	119.9	2.38
28.172	0.173	4.375	20.0901	29.89	4.06	300.5	2.02	0.094	-0.064	8.338	19.5479	2.45	6.63	181.1	2.2
28.744	0.123	4.053	20.0561	30.6	4.07	353.9	1.95	23.034	-0.06	6.829	23.5977	-0.92	5.66	256.3	2.15
30.12	0.192	3.908	20.4584	31.81	4	367	1.95	28.566	-0.051	5.886	21.9074	11.68	4.23	289.7	2.1
29.432	0.153	3.83	20.1482	32.55	4.05	347.6	1.85	26.39	0.008	4.994	20.7135	22.65	4.12	334	2.05
30.058	0.091	3.686	20.4799	35.45	4.03	344.6	1.99	26.841	-0.026	4.283	19.758	29.37	4.08	347.4	2.05
25.691	0.51	4.371	17.895	25.48	4.01	355.5	2.05	20.506	0.195	4.988	16.7184	26.28	4.05	359.3	2.15
32.051	0.18	3.503	21.0096	31.14	3.99	391.5	1.1	24.432	0.091	3.702	18.5737	29.52	4	384.1	1.2

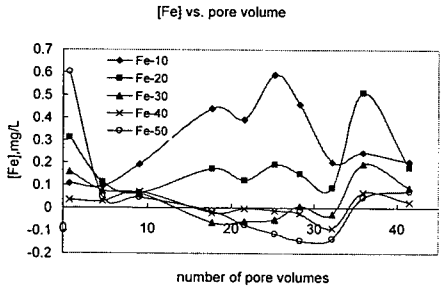
40cm								50cm							
Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-40	mV-40	EC-40	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	pH-50	mV-50	EC-50
0.013	0.037	0.037	-0.0045	10.35	7.68	231.2	2.78	0.019	0.602	0.088	0.011	10.41	7.63	239.9	2.8
0.001	0.03	0.031	-0.0234	6.58	7.66	116.2	2.6	-0.018	0.05	0.032	-0.0237	4.55	7.62	132.4	2.6
-0.002	0.072	0.041	-0.0043	4.56	7.55	102	2.5	-0.036	0.046	0.04	-0.0033	4.78	7.53	136.1	2.55
-0.067	-0.022	0.75	-0.0063	6	7.37	111.1	2.3	-0.023	-0.013	4.496	0.0041	1.89	7.24	124.3	2.38
0.062	-0.002	9.444	0.002	-2.79	7.28	168.3	2.15	0.027	-0.074	7.098	6.2478	-3.81	6.86	241.5	2.25
0.005	-0.01	9.276	12.1171	-2.45	6.81	160.9	2.1	0.368	-0.113	6.846	14.4115	-1.35	6.72	217.7	2.3
0.47	-0.023	8.318	22.415	-0.5	6.6	199.4	2.2	9.679	-0.144	7.021	15.9192	-0.79	6.09	241.9	2.25
19.148	-0.089	6.971	22.0241	-0.48	5.95	239.7	2.2	18.141	-0.135	7.489	17.6684	5.55	4.73	245.1	2.2
18	0.068	7.356	18.0583	6.4	4.68	275.5	2.28	13.646	0.048	6.89	15.1005	11.08	4.36	292.5	2.25
20.082	0.026	4.798	17.7004	19.02	4.11	350	1.2	18.035	0.075	5.072	18.1212	19.15	4.19	367.7	1.2

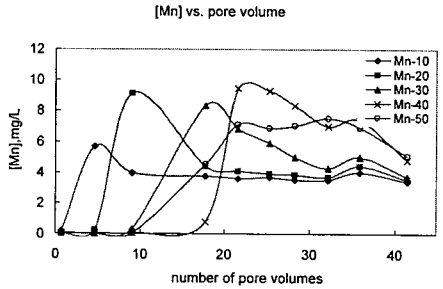

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

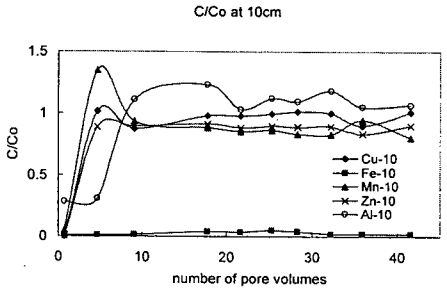

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

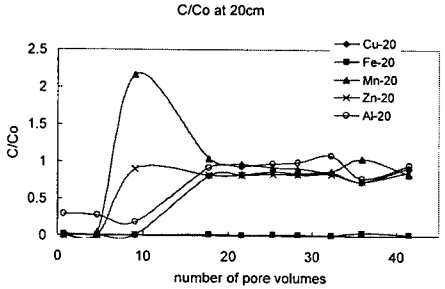

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

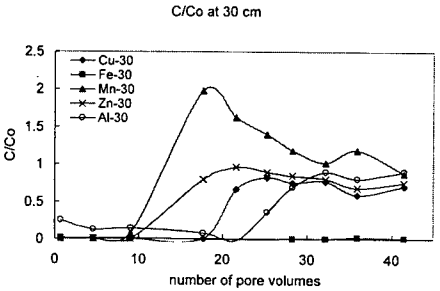

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

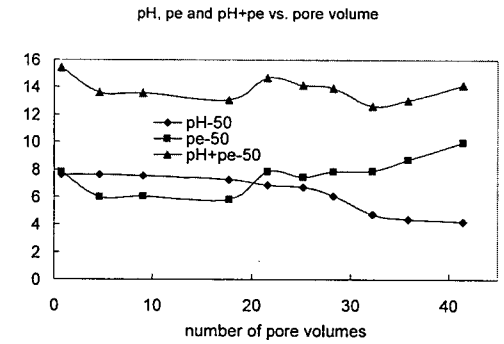

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

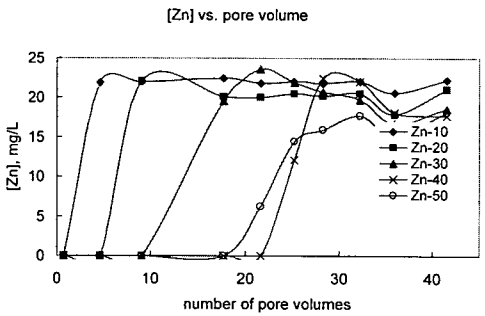

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

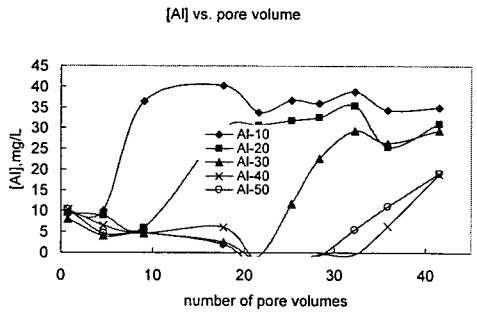

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

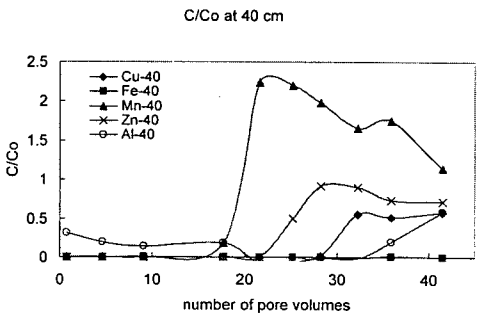

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

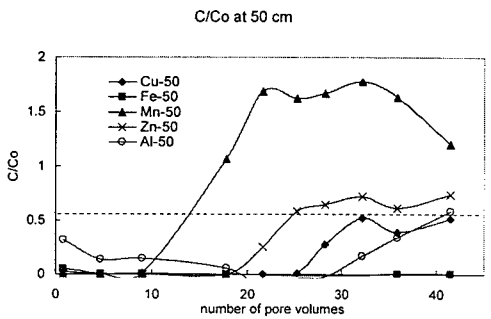

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH+pe vs. pore volume
pH-50
pe-50
pH+pe-50
number of pore volumes


[Zn] vs. pore volume
[Zn], mg/L
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50
number of pore volumes


[Al] vs. pore volume
[Al],mg/L
Al-10
Al-20
Al-30
Al-40
Al-50
number of pore volumes


C/Co at 40 cm
C/Co
Cu-40
Fe-40
Mn-40
Zn-40
Al-40
number of pore volumes


C/Co at 50 cm
C/Co
Cu-50
Fe-50
Mn-50
Zn-50
Al-50
number of pore volumes

Cell ID PTB1C1

wt soil before filling column	1462	g
wt soil after filling column	436	g
wt soil in column	1026	g
Date start	4月29日	
leachate	ARD010902	
pore volume	316.97	ml
flowrate	1.688	L/day
	1.2601	m/day

initial concentration of metals, Co

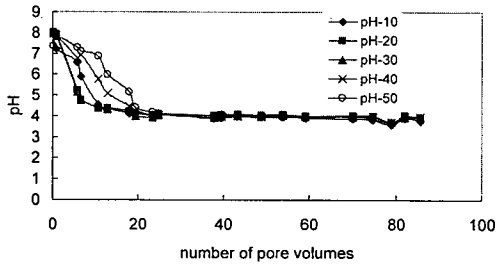
[Cu]o	34.86	mg/L
[Fe]o	11.23	mg/L
[Mn]o	4.21	mg/L
[Zn]o	24.54	mg/L
pH	3.11	
mV	512.2	mV
EC	2.05	mmhos

☑ 1 M NaCl pretreated ☐ No pretreatment
ARD concentration:
☑ Natural ☐ Maximum design
☐ Filtered ☑ Non-filtered

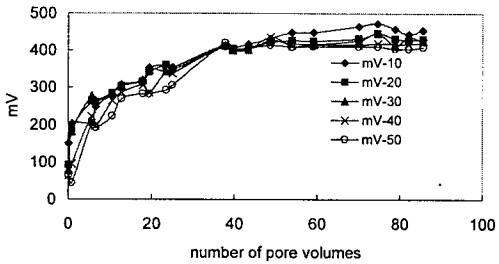
						L/day		10 cm								20cm						
Date	time	group	vol effl	time used	time(min) used	flowrate	pv/day	#pore vo	pH-10	mV-10	EC-10	Cu-10	Fe-10	Mn-10	Zn-10	pH-20	mV-20	EC-20	Cu-20	Fe-20	Mn-20	Zn-20
02/4/29	12:00 PM	1	60	0:55:00	55	1.570909	4.956018	0.18929	7.94	149.4	3.3	0.01	8.39	0.276	0.03	8.03	90.7	3.51	0	8.95	0.308	0.04
02/4/29	3:10 AM	2	225	3:10:00	190	1.705263	5.379888	0.89914	7.23	202.4	2.6	0.03	7.85	1.636	0.56	7.92	188.1	3.15	0.02	15.73	0.442	0.11
02/4/30	9:42 AM	3	1550	18:01:25	1081.417	2.063959	6.511529	5.78919	6.58	204.7	2.82	1.48	4.74	3.377	4.33	5.23	261.8	2.38	5.77	7.24	4.013	7.2
02/4/30	3:50 AM	4	270	5:29:26	329.4333	1.180208	3.723407	6.64101	5.89	248.1	2.25	4.45	0.22	4.379	8.34	4.78	261.3	2.2	9.96	0	4.674	10.93
02/5/1	9:20 AM	5	1280	17:01:09	1021.15	1.805024	5.69462	10.6792	4.55	280.1	2.2	14.28	0.43	4.368	13.36	4.41	283.6	2.2	14.58	0.26	4.368	13.77
02/5/1	3:25 AM	6	710	5:37:00	337	3.033828	9.571341	12.9192	4.36	307.8	2.05	21.56	0.22	4.652	16.53	4.38	304.5	2.13	17.32	0.02	4.452	14.59
02/5/2	9:20 AM	7	1590	17:33:50	1053.833	2.17264	6.854401	17.9355	4.11	317.2	1.98	25.91	0.42	4.779	18.49	4.23	316.1	1.98	20.2	0.12	4.634	15.75
02/5/2	3:55 AM	8	470	5:58:30	358.5	1.887866	5.955977	19.4182	4.09	353.2	1.92	27.08	0.29	4.827	17.78	4.13	340.9	1.95	21.34	0.12	4.742	16.45
02/5/3	9:00 AM	9	1260	16:36:40	996.6667	1.820468	5.743346	23.3934	4.06	358.5	1.98	27.39	0.49	4.336	18.44	4.06	359.7	2.03	23.74	0.13	4.329	17.5
02/5/3	3:40 AM	10	470	6:17:36	377.6	1.792373	5.654708	24.8762	4.12	353.5	2.02	29.38	0.847	4.359	21.2	4.09	348	2.08	25.44	0.482	4.71	19.31
02/5/6	9:40 AM	11	4110	65:33:20	3933.33	1.504679	4.747071	37.8427	4.04	410.7	1.82	29.76	0.285	4.414	20.21	4.03	410.3	1.95	26.67	0	4.404	19.29
02/5/6	4:30 AM	12	550	6:29:54	389.9	2.03129	6.408462	39.5779	4.08	405.4	1.85	31.24	0.406	3.643	20.85	4.05	404.6	1.9	29.71	0.343	3.797	20.01
02/5/7	9:25 AM	13	1200	16:30:00	990	1.745455	5.506687	43.3637	4.08	416.5	1.84	31.87	0.351	3.695	20.05	4.09	403.8	1.89	30.17	0.312	3.767	19.45
02/5/8	9:20 AM	14	1720	23:19:14	1399.233	1.770112	5.584479	48.7901	4.03	432.5	1.9	32.11	0.496	3.999	19.31	4.05	422.4	1.98	30.55	0.587	4.214	19.3
02/5/9	9:30 AM	15	1610	23:49:30	1429.5	1.621826	5.116654	53.8695	4.04	448	2	33.2	0.379	4.361	22.72	4.09	427.6	2	31.18	0.012	4.33	22.27
02/5/10	12:00 AM	16	1650	26:02:40	1562.67	1.520475	4.796904	59.075	3.92	449.1	1.9	33.16	0.586	4.479	21.97	4	425	1.92	32.39	0.2	4.512	21.53
02/5/13	9:37 AM	17	3500	69:12:12	4152.2	1.213814	3.82943	70.117	3.89	465.7	1.95	32.13	0.449	4.473	21.39	4.02	432.1	1.82	32.49	0.428	4.571	20.41
02/5/14	10:30 AM	18	1455	24:25:00	1465	1.430171	4.512006	74.7074	3.83	474	2.1	34.14	0.578	4.41	20.71	3.99	447.5	1.95	33.4	0.192	4.422	21.12
02/5/15	9:43 AM	19	1310	22:55:50	1375.833	1.371096	4.325634	78.8403	3.57	459.3	1.89	32.96	0.623	4.293	22.43	3.71	432.7	1.91	33.44	0.293	4.35	22.88
02/5/16	9:15 AM	20	1037	23:02:26	1382.433	1.080182	3.407838	82.1119	3.91	443.7	1.89	33.05	0.723	4.369	22.36	4.02	427.7	1.92	32.63	0.318	4.3	22.25
02/5/17		21	1120	23:52:30	1432.5	1.125864	3.551957	85.6453	3.76	455.5	2	34.52	0.62	3.933	22.86	3.95	430.6	1.9	35.15	0.287	3.968	23.04

30cm							40cm							50cm									
pH-30	mV-30	EC-30	Cu-30	Fe-30	Mn-30	Zn-30	pH-40	mV-40	EC-40	Cu-40	Fe-40	Mn-40	Zn-40	pH-50	mV-50	EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Eh-50	pe-50	pH+pe-5
7.98	78.6	3.6	0.07	10.06	1.884	0.98	7.92	63.2	4.4	0.07	6.08	0.931	1.25	7.34	63.4	3.32	0.11	0.7	2.017	0.04	265.4	4.498	11.84
7.85	181.8	2.98	0.19	74.54	3.359	1.44	7.88	94.6	3.08	0	20.77	0.687	0.12	7.83	43.9	3.36	0.03	14.97	0.481	0	245.9	4.168	12
5.14	276.8	2.32	6.61	17.09	5.93	10.26	6.78	222.9	2.5	0.47	26.19	3.441	2.09	7.28	202.3	2.72	0	5.31	0.586	0.02	404.3	6.853	14.13
4.76	264	2.18	10.19	12.22	5.939	12.51	6.94	196.7	2.3	0.11	0.13	3.743	3.36	7.1	191.7	2.55	0	0.89	1.4	0.06	393.7	6.673	13.77
4.39	284.3	2.1	16.46	0.13	5.014	15.81	5.76	264.6	2.2	3.3	0.52	4.407	7.49	6.87	222.4	2.42	0.12	0.16	3.248	1.93	424.4	7.193	14.06
4.31	302.3	2.02	18.42	1.9	4.917	16.18	5.08	285.9	2.3	6.97	2.71	4.936	11.32	5.99	268.5	2.3	1.25	0.38	4.936	6.88	470.5	7.975	13.96
4.25	321.4	1.92	20.22	0.14	4.805	17	4.47	304.9	2.12	11.96	0.14	5.211	13.69	5.15	283.1	2.25	5.47	0.71	5.765	10.86	485.1	8.222	13.37
3.99	346.8	2.05	22.07	3.13	5.023	17.15	4.25	286.1	2.13	14.54	0.2	5.372	15.17	4.41	281.8	2.22	9.45	0	5.842	13.61	483.8	8.2	12.61
3.95	344.6	2	23.26	0.65	4.504	17.91	3.99	342	2.18	17.57	1.16	4.724	14.92	4.16	292.7	2.12	12.26	0.06	5.079	13.8	494.7	8.385	12.54
4.05	352.4	2.05	24.17	1.76	4.812	18.37	4.06	336.4	2.1	18.26	1.456	5.072	16.75	4.11	305.1	2.15	14	0.919	5.464	15.58	507.1	8.595	12.7
3.94	414.9	1.82	27.48	1.033	4.687	19.8	3.9	415	1.92	26.03	1.063	4.881	19.34	3.88	420.3	1.9	20.47	0.382	4.881	17.28	622.3	10.55	14.43
3.99	400.1	1.92	29.25	0.456	3.816	20.19	3.97	401.2	1.9	27.57	0.421	3.918	19.16	3.92	404	1.99	23.13	0.406	3.971	17.86	606	10.27	14.19
4.03	401.4	1.9	29.88	0.352	3.963	19.2	3.99	402.8	1.81	28.99	0.652	3.938	19.4	3.97	407.6	1.95	24.44	0.283	3.986	17.29	609.6	10.33	14.3
4	427.5	1.9	30.83	0.45	4.245	19.72	3.98	435.8	1.88	29.51	0.546	4.301	19.49	3.93	413	1.9	24.71	0.42	4.262	18.05	615	10.42	14.35
4.05	417.8	1.9	31.71	0.429	4.523	23.39	4.04	411.7	1.9	31.4	0.147	4.566	22.49	3.94	408.7	1.89	26.81	0	4.514	21.7	610.7	10.35	14.29
3.98	417	1.9	31.89	0.514	4.671	21.48	3.96	415.2	1.95	31.46	0.479	4.772	21.48	3.96	410.8	1.95	26.25	0.193	4.731	19.2	612.8	10.39	14.35
3.98	426.1	1.88	32.29	0.233	4.665	20.67	3.96	414.6	1.78	30.97	0.488	4.665	20.3	3.98	410	1.86	27.94	0.209	4.596	19.11	612	10.37	14.35
3.96	447	1.9	32.49	0.305	4.398	20.71	3.98	418.7	1.9	31.37	0.628	4.512	20.04	3.89	410.3	1.85	28.61	0.204	4.426	19.39	612.3	10.38	14.27
3.73	411.3	1.85	32.65	0.227	4.343	21.9	3.72	417.4	1.82	31.76	0.423	4.462	21.63	3.66	404.3	1.89	30.26	0.174	4.252	21.22	606.3	10.28	13.94
3.95	435.3	2.13	32.51	0.301	4.491	22.08	3.97	417.5	1.92	31.35	0.363	4.298	21.21	3.96	403.4	1.92	29.97	0.08	4.442	20.38	605.4	10.26	14.22
3.95	424.8	1.9	34.42	0.234	4.014	21.87	3.96	420.8	1.9	33.5	0.202	3.994	21.79	3.92	408.9	1.91	31.49	0.198	4.05	20.39	610.9	10.35	14.27

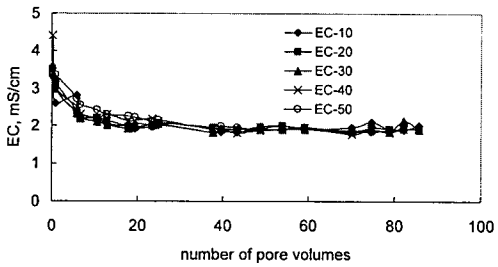
pH vs. pore volume



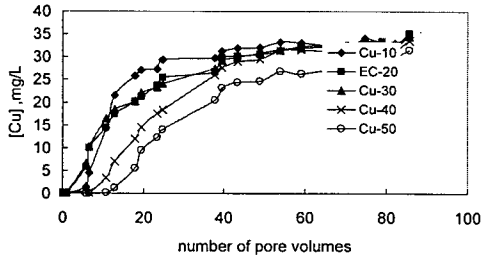
mV vs. pore volume



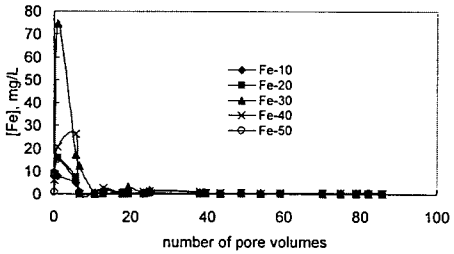
EC vs. pore volume



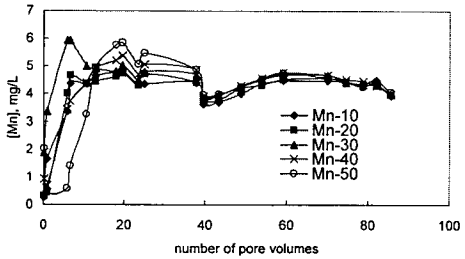
[Cu] vs. pore volume



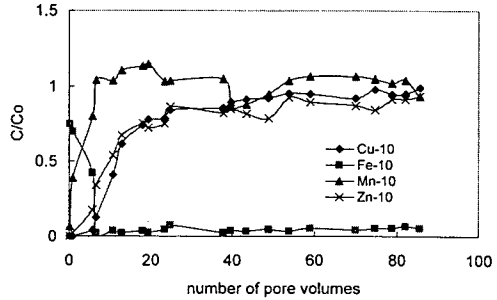
[Fe] vs. pore volume



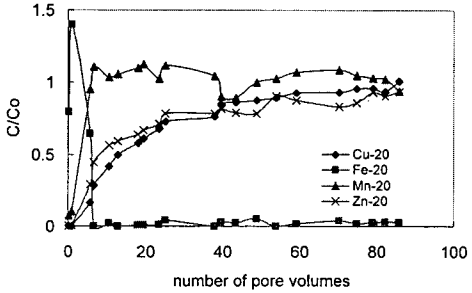
[Mn] vs. pore volume



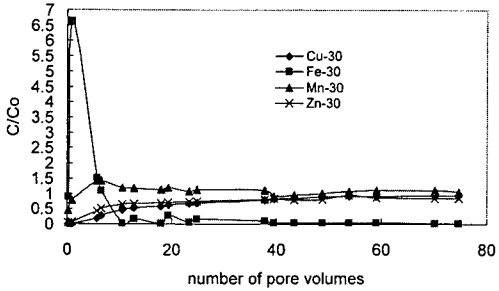
C/Co at 10 cm



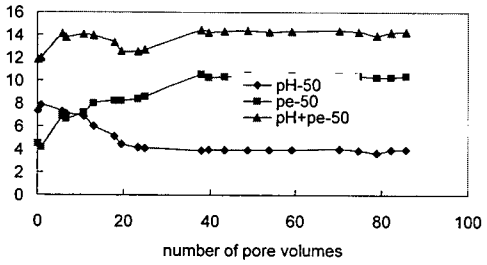
C/Co at 20 cm



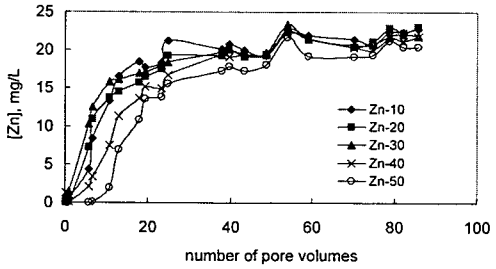
C/Co at 30 cm



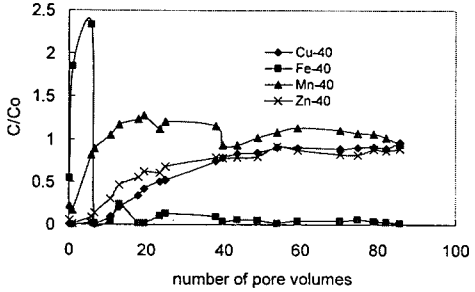
pH, pe and pH+pe vs. pore volume



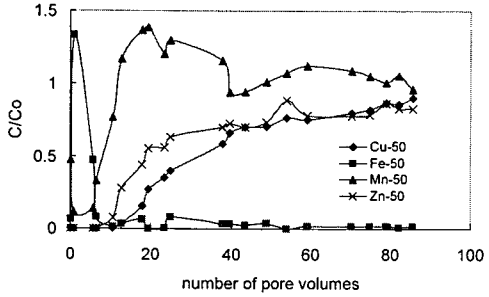
[Zn] vs. pore volume



C/Co at 40 cm



C/Co at 50 cm



Cell ID PTB3

wt soil before filling column	1227.37 g
wt soil after filling column	404.94 g
wt soil in column	822.43 g
Date start	09-30-2002
leachate	ARD Max conc/filtered
pore volume	337.1701 ml
flowrate	1.684658 L/day
	1.257583 m/day

initial concentration of metals, Co

[Cu]o	116.08
[Fe]o	29.21
[Mn]o	9.317
[Zn]o	50.038
[Al]o	83.1
pH	2.68
mV	534.6
EC	3.24

☑ 1 M NaCl pretreated ☐ No pretreatment

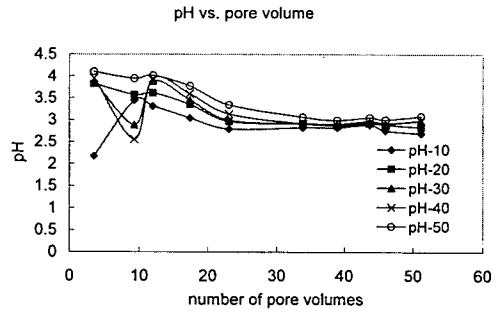
ARD concentration:

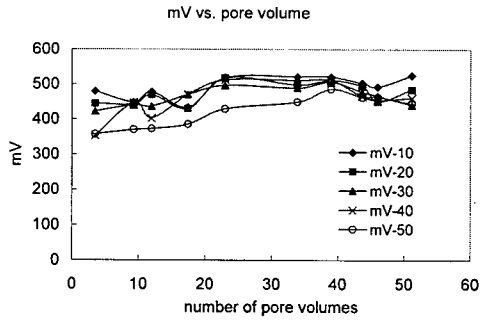
☐ Natural ☑ Maximum design

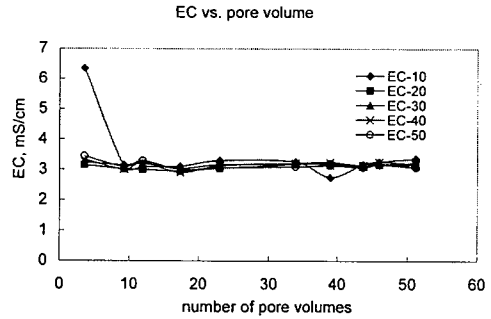
☑ Filtered ☐ Non-filtered

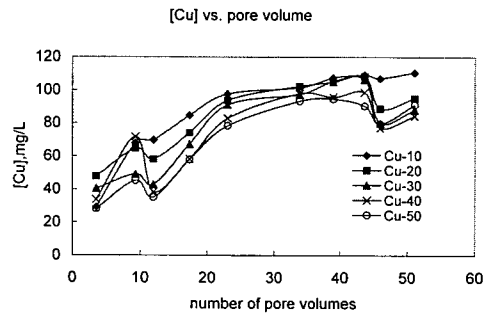
SampleID (Conc)	vol effl (ml	hh:mm:ss	(min)	time used L/day	pv/day	Flowrate #pore vol	Cu-10	Fe-10	10cm Mn-10	Zn-10	Al-10	pH-10	mV-10	EC-10	Cu-20	mmhos Fe-20	20cm Mn-20	Zn-20	Al-20	pH-20	mV-20	EC-20	Cu-30	mmhos Fe-30
1	1185	26:34:00	1594.00	1.070514	3.174998	3.514546	29.34	2.022	5.377	15.158	31.6	2.17	479.6	6.34	47.77	1.691	8.079	28.524	53.7	3.82	444.5	3.14	40.36	1.703
2	1940	24:05:50	1445.83	1.932173	5.730558	9.268318	68.09	1.846	7.687	36.877	65.1	3.45	448.4	3.1	64.68	2.277	8.038	37.524	76.8	3.57	442.7	3.01	49.08	2.051
3	900	22:01:00	1321.00	0.981075	2.909733	11.93759	69.73	3.179	8.006	38.397	71.6	3.31	477.7	3.08	58.08	3.374	7.926	33.099	70.8	3.61	469.3	3	42.72	2.723
4	1830	20:22:48	1222.80	2.155054	6.391592	17.36512	84.71	6.268	8.228	44.126	74.7	3.04	433	3.1	74.09	3.931	8.226	41.158	73.1	3.35	429.6	2.95	67.23	3.975
5	1900	22:48:00	1368.00	2	5.931724	23.00026	97.62	13.567	8.713	47.28	73	2.79	517.9	3.29	93.75	7.308	8.64	45.819	77.1	2.96	518.1	3.04	91.17	7.272
6	3650	44:46:26	2686.43	1.956497	5.802701	33.82565	101.48	16.017	9.095	48.923	74.9	2.82	521.4	3.25	102.26	12.025	8.786	49.748	74.4	2.9	497.9	3.17	97.39	11.757
7	1720	21:04:34	1264.57	1.958616	5.808983	38.92694	107.52	17.718	9.361	48.658	72.5	2.82	520.8	2.74	104.78	15.556	9.38	49.105	73.5	2.86	511	3.2	105.34	14.115
8	1590	18:49:30	1129.50	2.027092	6.012074	43.64266	109.18	14.421	9.056	49.578	72.5	2.88	502.7	3.17	108.25	12.904	8.928	48.56	70.5	2.92	493.5	3.13	106.44	12.031
9	780	23:10:00	1390.00	0.808058	2.396587	45.95603	107.23	12.317	8.906	47.19	74.2	2.75	492.1	3.26	88.78	13.696	8.955	40.729	70.9	2.88	450.5	3.16	79.97	13.412
10	1740	21:20:00	1280.00	1.9575	5.805674	51.11663	110.66	13.76	8.848	47.397	68.6	2.69	524.4	3.36	95.08	13.134	8.74	44.442	70.2	2.83	484.1	3.21	88.08	9.412
11																								
12																								

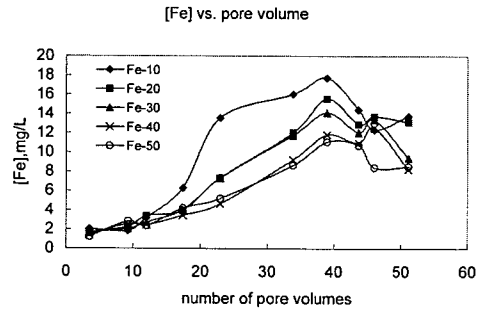
30cm							mmhos	40cm							mmhos	50cm							mmhos	
Mn-30	Zn-30	Al-30	pH-30	mV-30	EC-30	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-40	mV-40	EC-40	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	pH-50	mV-50	EC-50	Eh-50	pe-50	pH+pe-5(
8.011	22.963	48	3.88	422.5	3.23	33.77	1.396	7.682	21.73	41.8	3.95	353.3	3.32	28.08	1.21	7.242	18.874	34.5	4.1	357.1	3.43	559.1	9.47627	13.5763
7.633	28.82	68.1	2.88	440.6	3.14	71.8	2.563	8.471	39.081	77.2	2.55	447.4	3	45.19	2.82	7.74	28.555	68	3.94	370.2	3.09	572.2	9.69831	13.6383
7.355	25.582	59.9	3.88	436.7	3.19	38.23	2.419	7.326	22.337	57.3	3.94	402.7	3.23	34.94	2.351	7.117	21.066	49.2	4.01	372.6	3.28	574.6	9.73898	13.749
7.895	36.963	72.6	3.45	470.1	3.03	58.1	3.428	7.568	33.075	65.5	3.59	469.9	2.9	57.88	4.165	7.564	34.156	67.4	3.77	385.5	3	587.5	9.95763	13.7276
8.594	46.071	80.3	2.99	496.7	3.15	82.89	4.639	8.173	42.939	75.4	3.13	512.2	3.11	78.34	5.171	8.047	41.773	74.9	3.34	429.3	3.05	631.3	10.7	14.04
8.687	47.352	74	2.92	489.5	3.19	97.85	9.219	8.538	47.564	88.8	2.91	511.1	3.2	93.27	8.647	8.394	45.797	79.2	3.06	449.1	3.09	651.1	11.0356	14.0956
9.533	49.277	75.2	2.9	506.5	3.16	95.65	11.838	9.007	46.915	71.1	2.87	510.9	3.24	94.59	11.076	8.62	44.75	69.7	2.99	485.7	3.13	687.7	11.6559	14.6459
8.919	46.559	73.7	2.97	477.4	3.12	98.61	10.945	8.625	43.917	69.9	2.93	464.8	3.13	90.36	10.724	8.969	42.621	69.4	3.05	462.6	3.07	664.6	11.2644	14.3144
8.137	35.62	65.6	2.92	466.5	3.19	77.2	12.553	8.212	33.978	66.9	2.89	454.4	3.25	79.57	8.406	8.345	35.531	65.6	3	463.5	3.16	665.5	11.2797	14.2797
8.223	42.01	64.3	2.97	440.2	3.14	84.43	8.229	8.408	39.11	62.9	2.99	460.4	3.17	91.08	8.5	8.149	41.292	64.2	3.08	443.7	3.07	645.7	10.9441	14.0241
														79.26	8.511	5.439	35.18	86.6	3.11	425.7	3.06	627.7	10.639	13.749
														66.81	7.731	5.809	30.497	74.5	3.24	415.9	3.12	617.9	10.4729	13.7129

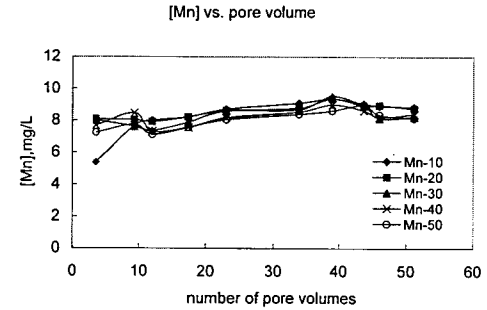

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

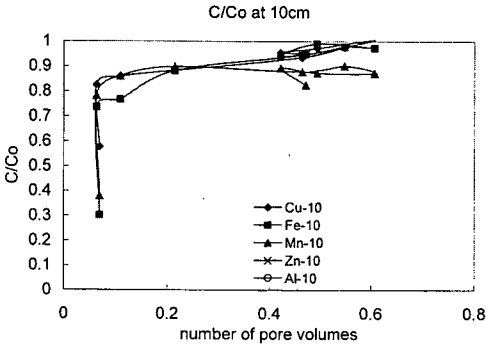

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

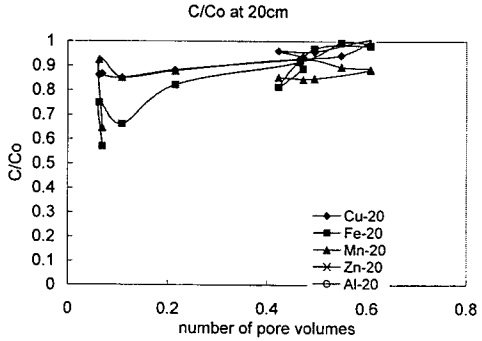

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

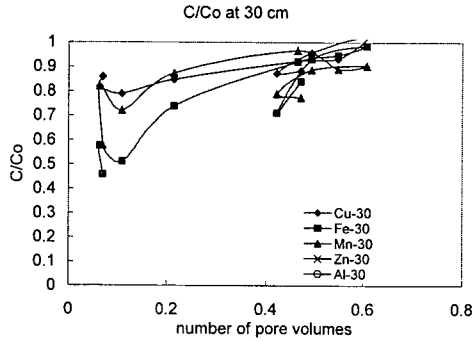

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50


[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

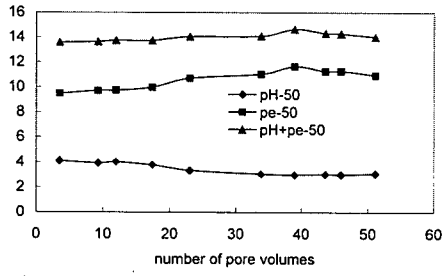

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50


C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

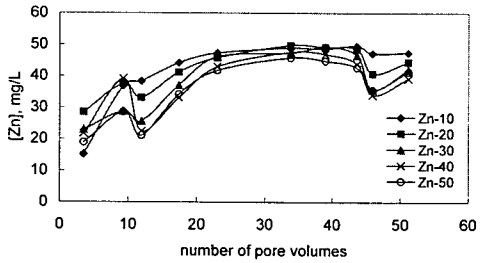

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20


C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30

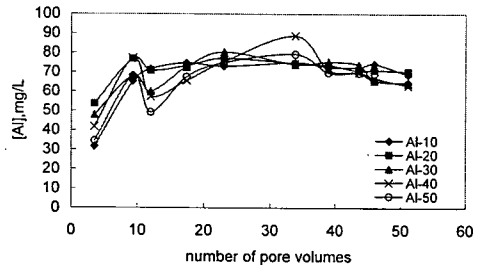
pH, pe and pH+pe vs. pore volume



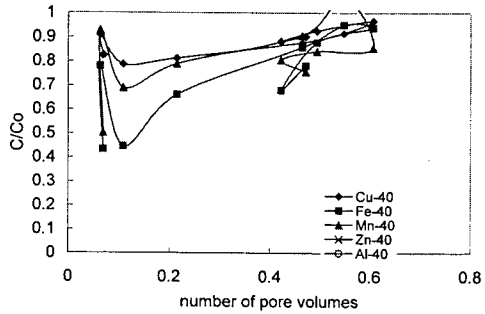
[Zn] vs. pore volume



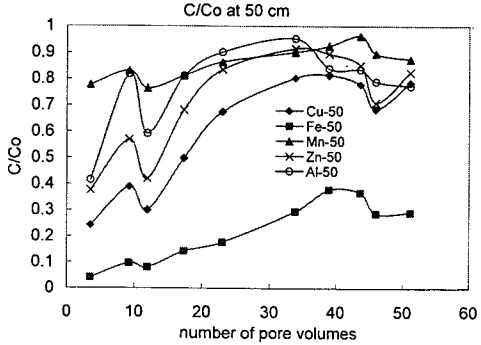
[Al] vs. pore volume



C/Co at 40 cm



C/Co at 50 cm



Cell ID PTB4

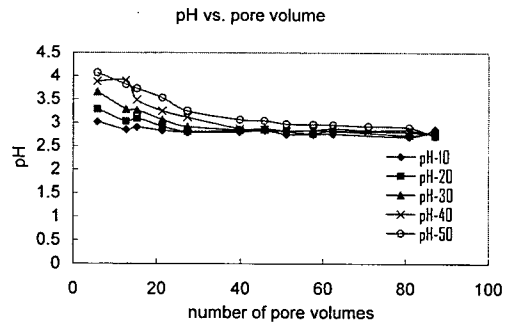
wt soil before filling column	1375.98 g
wt soil after filling column	464.73 g
wt soil in column	911.25 g
Date start	9/30/2002
leachate	ARD max conc/filtered
pore volume	294.0107 ml
flowrate	1.829432 L/day
	1.365656 m/day

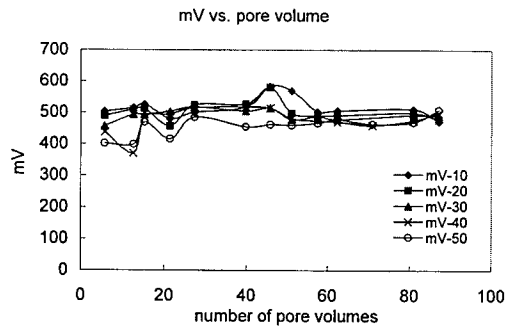
initial concentration of metals, Co	
[Cu]o	116.08
[Fe]o	29.21
[Mn]o	9.317
[Zn]o	50.038
[Al]o	83.1
pH	2.68
mV	534.6
EC	3.24

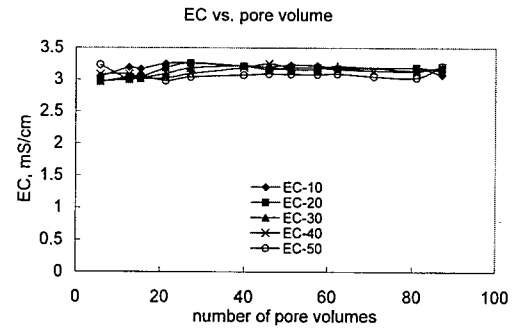
☑ 1 M NaCl pretreated ☐ No pretreatment
ARD concentration:
☐ Natural ☑ Maximum design
☑ Filtered ☐ Non-filtered

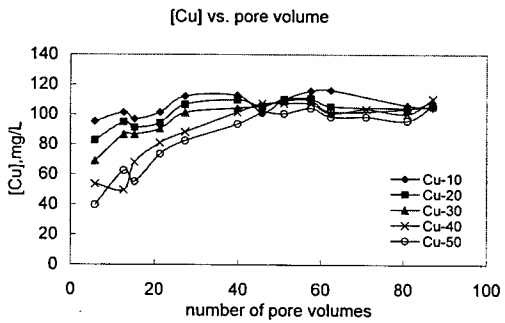
SampleID (Conc)	vol effl (ml	time used hh:mm:ss	(min)	Flowrate L/day	pv/day	#pore vol	10cm Cu-10	Fe-10	Mn-10	Zn-10	Al-10	pH-10	mV-10	mmhos EC-10	20cm Cu-20	Fe-20	Mn-20	Zn-20	Al-20	pH-20	mV-20	mmhos EC-20	30cm Cu-30	Fe-30
1	1700	26:34:00	1594.00	1.535759	5.22348	5.782102	95.43	3.425	8.928	45.669	74.1	3.02	503	3.05	82.86	1.004	8.728	43.821	75.3	3.29	488.7	2.96	69.2	1.041
2	2000	24:05:50	1445.83	1.991931	6.775028	12.58457	101.4	8.212	8.796	47.471	80.8	2.85	514.5	3.19	95	3.845	8.66	46.026	81.8	3.03	510	3.04	86.76	1.643
3	780	22:01:00	1321.00	0.850265	2.891952	15.23754	96.83	7.886	8.737	47.4	77.9	2.9	526.5	3.17	91.39	3.93	8.651	45.232	82.2	3.09	512.5	3.04	86.74	2.504
4	1790	20:22:48	1222.80	2.107949	7.169633	21.32575	101.52	14.966	8.761	48.188	72.2	2.83	479.7	3.25	94.4	10.088	8.674	47.41	75	2.92	456.7	3.18	90.46	3.691
5	1760	22:48:00	1368.00	1.852632	6.301238	27.31193	112.22	18.936	8.979	52.538	73.5	2.79	500.4	3.26	106.64	14.441	8.959	51.334	74.4	2.81	524.1	3.26	101.13	9.638
6	3670	44:46:26	2686.43	1.967218	6.690974	39.79447	112.71	19.94	8.84	52.918	71.8	2.8	517.4	3.21	109.83	17.022	8.981	51.7	70.4	2.84	526.9	3.21	104.32	15.196
7	1770	21:04:34	1264.57	2.015552	6.855369	45.81465	101.42	21.256	9.12	49.424	68.2	2.83	583.4	3.2	105.52	19.227	9.54	47.979	69	2.86	579.7	3.16	105.69	16.848
8	1560	18:49:30	1129.50	1.988845	6.764531	51.12058	110.19	21.137	9.191	48.427	70.3	2.75	569.7	3.23	110.33	17.833	9.406	48.98	70.1	2.8	497.9	3.19	109.19	16.123
9	1890	23:10:00	1390.00	1.957986	6.659572	57.54892	115.74	19.832	8.352	49.63	70.5	2.75	502.6	3.22	110.8	16.919	8.627	49.216	70.6	2.77	490	3.19	109.48	15.539
10	1400	21:20:00	1280.00	1.575	5.356947	62.31065	116.34	19.577	8.775	49.125	63.1	2.76	505.8	3.19	105.45	17.306	9.111	47.04	65.5	2.81	490.6	3.17	101.75	15.977
11	2510	30:40:00	1840.00	1.964348	6.681211	70.84776																		
12	2960	36:00:00	2160.00	1.973333	6.711773	80.91541	106.1	16.683	4.578	46.261	87.2	2.7	510.4	3.18	104.32	16.523	4.844	45.029	86.9	2.73	498.6	3.19	103.75	15.389
13	1825	22:50:43	1370.72	1.917245	6.521004	87.12267	104.69	11.853	4.888	42.806	94.8	2.85	471.7	3.07	105.34	12.599	4.936	43.322	94.3	2.78	476.6	3.13	108.73	16.552
14	1960	24:34:37	1474.62	1.913989	6.509929	93.78909	111.8	19.473	4.785	50.095	87.8	2.71	508.8	3.18	109.24	17.342	4.564	49.061	83.9	2.73	497.9	3.21	108.77	17.038

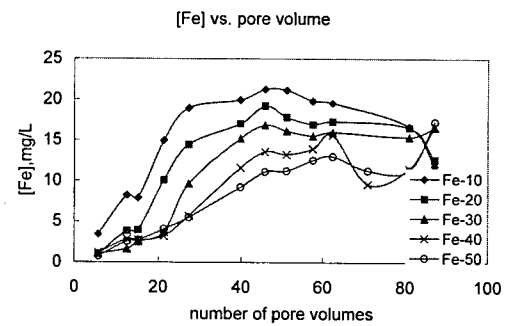
Mn-30	Zn-30	Al-30	pH-30	mV-30	mmhos EC-30	40cm Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-40	mV-40	mmhos EC-40	50cm Cu-50	Fe-50	Mn-50	Zn-50	Al-50	pH-50	mV-50	mmhos EC-50	Eh-50	pe-50	pe+pH-50
8.804	39.75	68.9	3.66	457	2.97	53.74	1.154	8.953	33.513	58.8	3.88	437.9	3.08	39.63	0.741	9.181	28.507	43.3	4.07	401.5	3.23	603.5	10.22881	14.29881
8.778	44.219	82.8	3.29	493.7	3	49.65	2.815	7.768	31.523	68.9	3.9	370.7	3.09	62.58	2.556	8.411	36.905	75.3	3.82	398.7	3	600.7	10.18136	14.00136
8.656	41.949	74.3	3.27	494.3	3.02	68.29	2.687	8.493	37.551	69.3	3.49	484.4	3.02	55.19	2.713	8.475	32.26	63.1	3.73	468.9	3.06	670.9	11.37119	15.10119
8.501	45.752	76.4	3.06	503.1	3.09	81.03	3.218	8.315	42.903	73.3	3.25	494.6	3.02	73.58	4.061	8.174	39.837	71.9	3.53	415.9	2.98	617.9	10.47288	14.00288
8.719	48.712	72.2	2.91	517.7	3.18	88.27	5.669	8.489	45.284	71.2	3.11	515.3	3.09	82.48	5.505	8.563	43.595	71.6	3.25	485.5	3.04	687.5	11.65254	14.90254
8.892	50.578	80	2.85	504.5	3.22	101.53	11.593	8.769	48.711	78.8	2.87	517.7	3.19	93.57	9.215	8.485	47.099	69.4	3.06	454.5	3.07	656.5	11.12712	14.18712
9.659	48.513	72.3	2.87	514	3.19	107.18	13.57	9.031	48.802	71.3	2.85	513.5	3.25	101.1	11.099	8.741	45.979	68.7	3.04	461.8	3.09	663.8	11.25085	14.29085
9.202	48.3	69.5	2.82	477.2	3.16	107.65	13.226	9.401	47.665	69.6	2.82	481	3.19	100.52	11.211	8.875	44.843	68.7	2.97	459.6	3.082	661.6	11.21356	14.18356
8.639	47.296	69.4	2.83	487.7	3.16	107.15	13.958	8.762	47.134	68.1	2.83	473.3	3.19	104.25	12.531	8.365	45.996	69.1	2.96	466.2	3.077	668.2	11.32542	14.28542
8.981	44.717	63.9	2.82	477.9	3.21	100.66	15.631	9.028	43.953	62.6	2.87	470.8	3.16	98.44	13.011	9.077	42.722	62.5	2.95	477.4	3.09	679.4	11.51525	14.46525
						103.55	9.576	5.014	46.208	89	2.83	459.5	3.14	98.39	11.252	5.076	42.354	84.1	2.92	463.1	3.05	665.1	11.27288	14.19288
4.77	43.969	96.8	2.79	492.1	3.14	100.35	11.507	4.861	43.117	93.1	2.83	474.7	3.13	95.86	11.264	4.711	41.951	87.8	2.89	469.1	3.03	671.1	11.37458	14.26458
4.83	43.535	92.7	2.75	489.4	3.19	110.61	16.676	4.745	44.294	91.9	2.73	498.2	3.2	106.12	17.223	4.479	45.854	86.1	2.71	508.5	3.21	710.5	12.04237	14.75237
4.717	47.941	84.8	2.76	498.2	3.19	106.8	10.1	4.591	47.579	87.4	2.77	479	3.19	104.88	11.969	4.714	46.383	88.2	2.84	472.9	3.13	674.9	11.43898	14.27898

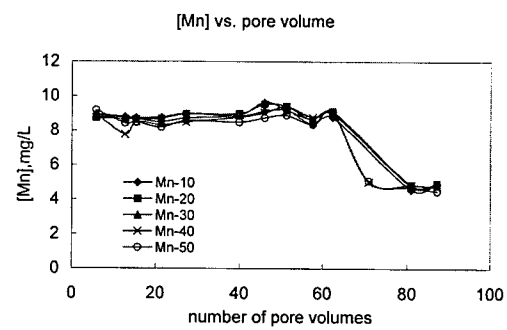

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

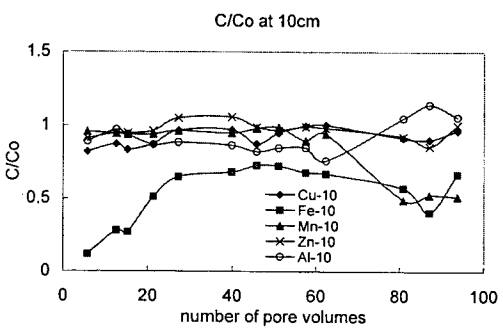

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

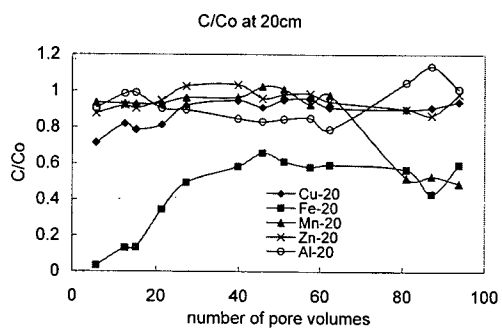

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

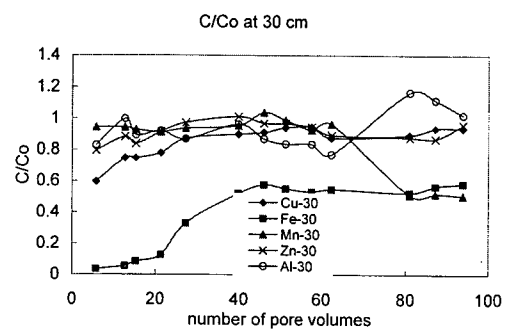

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

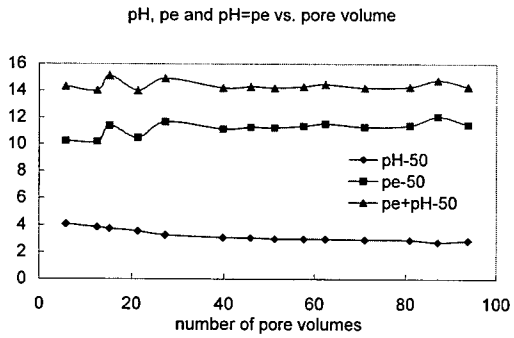

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

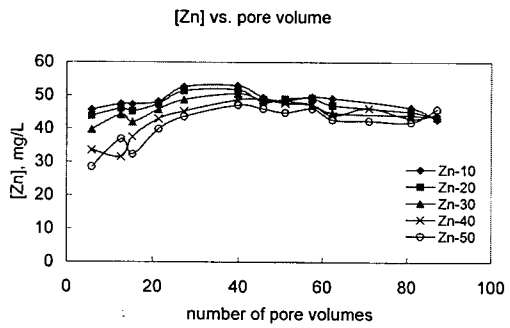

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

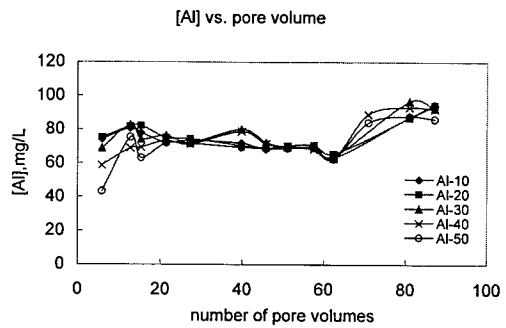

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

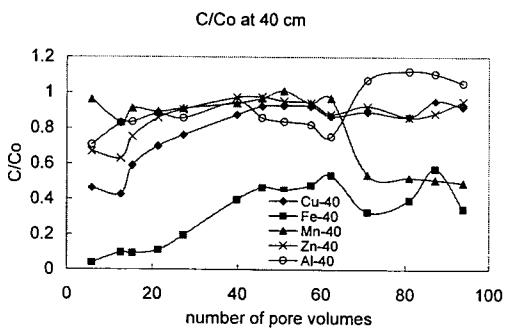

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

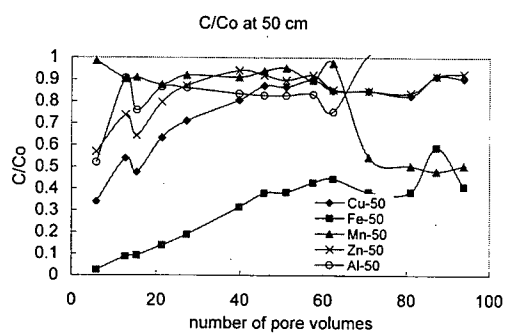

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
number of pore volumes
pH-50
pe-50
pe+pH-50


[Zn] vs. pore volume
[Zn], mg/L
60
50
40
30
20
10
0
0
20
40
60
80
100
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
120
100
80
60
40
20
0
0
20
40
60
80
100
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
100
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID PTB5

wt soil before filling column	1289.79	g
wt soil after filling column	375.86	g
wt soil in column	913.93	g
Date start	9/30/2002	
leachate	ARD natural/filtered	
pore volume	292.7085	ml
flowrate	1.914333	L/day
	1.429033	m/day

initial concentration of metals, Co		
[Cu]o	37.27	mg/L
[Fe]o	0.537	mg/L
[Mn]o	2.686	mg/L
[Zn]o	23.91	mg/L
[Al]o	30.71	mg/L
pH	3.09	
mV	475.75	
EC	2.05	

☑ 1 M NaCl pretreated ☐ No pretreatment

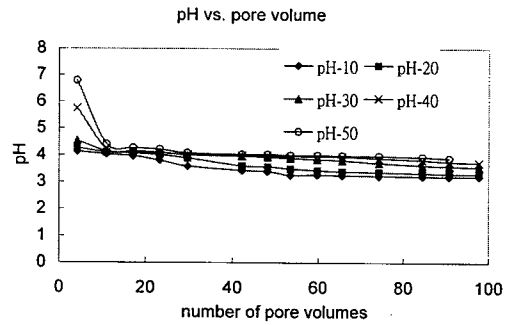
ARD concentration:

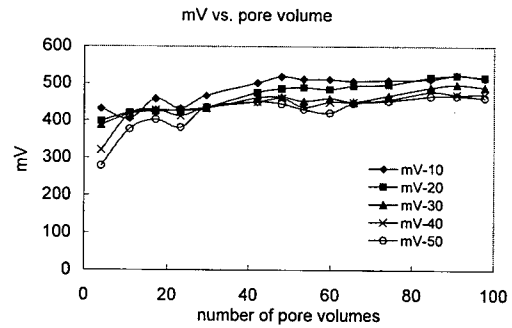
☑ Natural ☐ Maximum design

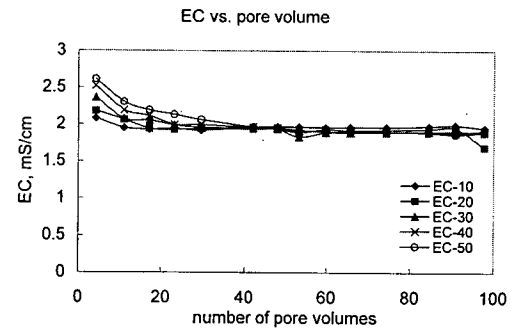
☑ Filtered ☐ Non-filtered

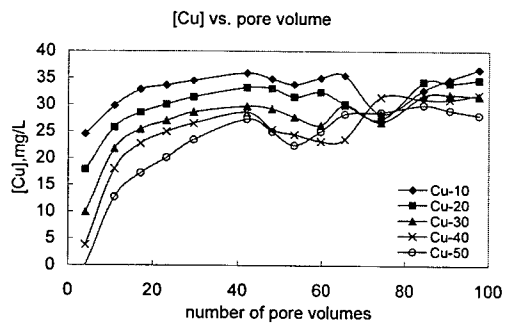
SampleID (Conc)	vol effl (ml	hh:mm:ss	(min)	time used L/day	pv/day	Flowrate #pore vol	Cu-10	Fe-10	10cm Mn-10	Zn-10	Al-10	pH-10	mV-10	EC-10	Cu-20	mmhos Fe-20	20cm Mn-20	Zn-20	Al-20	pH-20	mV-20	EC-20	Cu-30	mmhos Fe-30
1	1210	26:34:00	1594.00	1.093099	3.73443	4.133806	24.531	0.092	4.219	18.9648	33.8	4.13	432	2.08	17.859	0.064	4.798	16.7565	28.74	4.27	398.2	2.18	9.92	0.043
2	1990	24:05:50	1445.83	1.981971	6.771144	10.93238	29.803	0.171	4.084	21.1508	33.08	4.03	405.1	1.951	25.769	0.136	4.1	19.4956	31.39	4.1	420.9	2.06	21.762	0.091
3	1810	22:01:00	1321.00	1.973051	6.740669	17.11601	32.834	0.18	3.897	21.5849	32.86	3.97	458.5	1.928	28.548	0.143	3.949	20.0681	31.75	4.06	424.1	1.94	25.41	0.118
4	1780	20:22:48	1222.80	2.096173	7.161299	23.19714	33.661	0.311	3.861	21.9696	20.76	3.8	432.5	1.941	30.077	0.153	3.748	20.271	13.51	4.01	428.6	1.925	27.043	0.138
5	1860	22:48:00	1368.00	1.957895	6.68889	29.55159	34.519	0.503	3.745	22.4026	23.72	3.59	467.7	1.917	31.443	0.195	3.792	20.7442	19.7	3.89	436.1	1.937	28.633	0.19
6	3670	44:46:26	2686.43	1.967218	6.720742	42.08966	35.965	0.97	3.688	22.6198	49.49	3.43	501	1.961	33.252	0.367	3.773	21.7126	42.95	3.6	475.4	1.934	29.763	0.173
7	1740	21:04:34	1264.57	1.98139	6.769159	48.03414	34.836	0.971	3.732	22.7849	30.26	3.39	518.5	1.968	33.063	0.621	3.821	22.0705	31.18	3.57	486.3	1.937	29.237	0.181
8	1560	18:49:30	1129.50	1.988845	6.794626	53.36368	33.837	0.927	3.551	22.0478	34.11	3.26	511.4	1.964	31.503	0.701	3.7	21.5894	32.82	3.49	489.3	1.892	27.713	0.294
9	1860	23:10:00	1390.00	1.926906	6.583023	59.71812	35.008	0.946	3.556	23.0691	28.93	3.27	511.2	1.957	32.409	0.584	3.686	21.1221	30.61	3.43	484.6	1.928	26.206	0.206
10	1720	21:20:00	1280.00	1.935	6.610673	65.59428	35.474	0.896	3.49	23.4294	30.51	3.25	506.6	1.963	30.138	0.796	3.652	21.0576	29.67	3.39	494.2	1.917	30.015	0.253
11	2525	30:40:00	1840.00	1.976087	6.751041	74.22061	28.32	0.869	3.597	22.8334	30.86	3.23	508.7	1.959	27.321	0.788	3.571	21.7121	30.98	3.36	497.5	1.922	26.805	0.25
12	2980	36:00:00	2160.00	1.986667	6.787186	84.40139	32.772	0.811	3.467	23.2447	29.81	3.21	511.7	1.972	34.307	0.864	3.59	22.4949	29.8	3.33	516.6	1.933	31.732	0.337
13	1860	22:50:43	1370.72	1.954014	6.675633	90.75583	34.79	0.907	3.62	22.5726	29.4	3.2	523	1.986	34.033	0.958	3.565	21.6236	29.12	3.3	522.1	1.943	31.925	0.4
14	2030	24:34:37	1474.62	1.982346	6.772424	97.69106	36.634	0.867	3.566	23.1781	30.49	3.2	514.3	1.948	34.646	0.883	3.674	22.2369	31.67	3.3	516.6	1.689	31.572	0.528

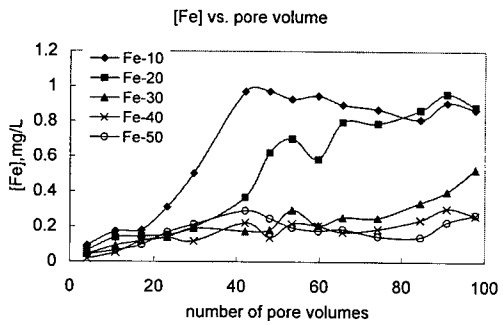
30cm Mn-30	Zn-30	Al-30	pH-30	mV-30	EC-30	Cu-40	mmhos Fe-40	40cm Mn-40	Zn-40	Al-40	pH-40	mV-40	EC-40	Cu-50	mmhos Fe-50	50cm Mn-50	Zn-50	Al-50	pH-50	mV-50	EC-50	Eh	mmhos pe	pH+pe
4.856	12.1469	25.84	4.54	387.9	2.36	3.843	0.016	3.43	6.7978	23.64	5.75	321.1	2.52	-0.042	0.04	2.482	2.1029	23.28	6.79	278.6	2.61	480.6	8.145763	14.93576
4.187	17.353	27.98	4.14	417.5	2.07	17.987	0.052	3.911	15.3349	28.19	4.23	417	2.19	12.707	0.064	4.156	12.688	23.93	4.41	377	2.3	579	9.813559	14.22356
3.9	18.3766	29.44	4.11	428.3	2.05	22.742	0.116	4.073	17.6586	27.91	4.16	428.6	2.11	17.22	0.096	3.841	14.7242	27.97	4.27	402	2.19	604	10.23729	14.50729
3.78	19.0158	3.96	4.08	426.7	1.987	24.933	0.137	3.766	18.0142	0.49	4.1	412.5	1.993	20.106	0.167	3.74	15.8352	26.7177	4.21	381.1	2.13	583.1	9.883051	14.09305
3.774	19.4695	16.19	4	432.6	1.957	26.542	0.117	3.844	18.7308	12.03	4.02	434.2	1.992	23.456	0.212	3.883	17.3574	27.9461	4.08	435	2.06	637	10.79661	14.87661
3.817	19.9227	39.66	3.96	461.4	1.95	28.597	0.221	3.695	19.0415	36.01	4	450.4	1.961	27.332	0.29	3.853	18.931	26.73	4.03	450.1	1.963	652.1	11.05254	15.08254
3.75	20.2731	28.03	3.93	463.4	1.936	25.334	0.137	3.832	19.7429	29.74	4	459.9	1.952	24.957	0.246	3.725	18.8592	28.67	4.03	444.7	1.939	646.7	10.96102	14.99102
3.772	20.0264	30.76	3.89	452.5	1.829	24.456	0.216	3.639	19.2374	31.82	3.95	436.2	1.92	22.436	0.195	3.694	18.9826	32.71	4	429.9	1.912	631.9	10.71017	14.71017
3.706	19.4334	26.87	3.85	460	1.888	23.194	0.203	3.583	18.2465	28.26	3.94	450.3	1.899	25.058	0.176	3.615	18.7168	25.61	4	420.5	1.905	622.5	10.55085	14.55085
3.732	19.5815	30.19	3.8	451.1	1.887	23.603	0.169	3.614	19.2023	28.53	3.94	449.8	1.899	28.284	0.184	3.782	19.7583	29.21	3.98	446.2	1.895	648.2	10.98644	14.96644
3.595	20.5051	27.86	3.71	467.2	1.893	31.5	0.185	3.657	20.0884	28.73	3.88	456.9	1.897	28.639	0.144	3.571	19.0608	25.13	3.97	452.5	1.897	654.5	11.09322	15.06322
3.65	21.1232	27.89	3.62	489.5	1.901	31.006	0.239	3.526	20.3578	27.48	3.82	477.5	1.896	29.956	0.141	3.562	19.7086	28.29	3.93	465.9	1.887	667.9	11.32034	15.25034
3.575	20.3127	29.18	3.59	497.4	1.886	31.019	0.304	3.666	19.5715	27.23	3.75	470.5	1.901	28.984	0.226	3.639	19.253	27.13	3.88	466.5	1.864	668.5	11.33051	15.21051
3.648	21.0689	28.71	3.56	490.3	1.911	31.874	0.264	3.578	19.8557	28.18	3.72	471.8	1.887	28.047	0.268	3.523	19.0898	27.58	3.84	461.7	1.889	663.7	11.24915	15.08915

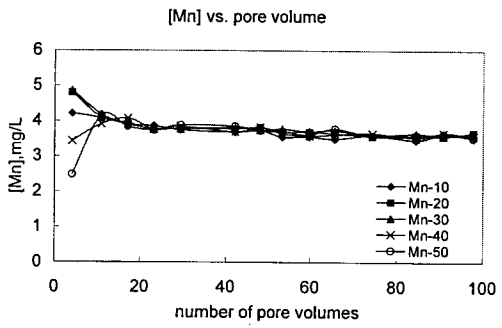

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

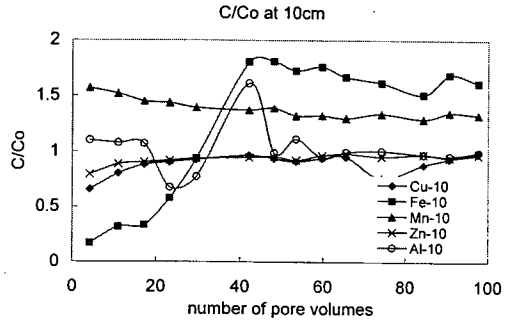

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

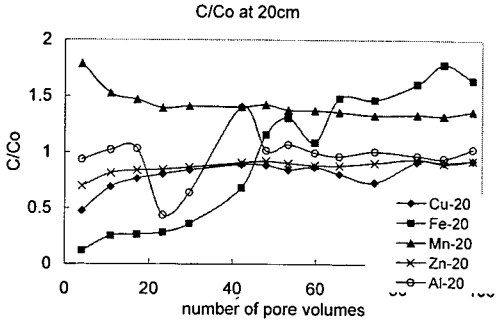

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

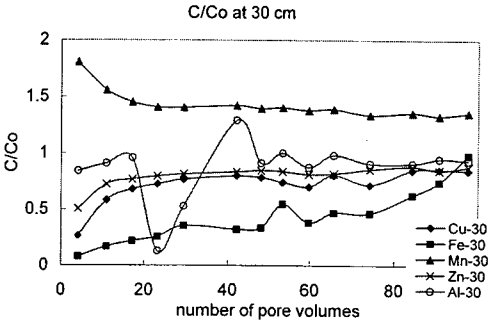

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

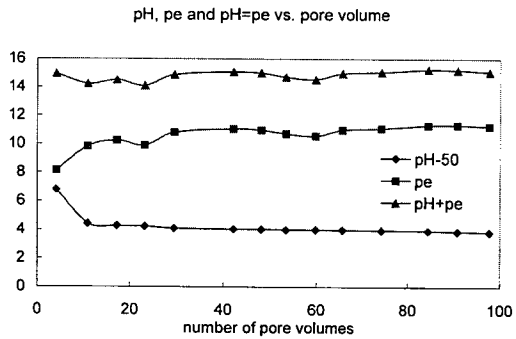

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

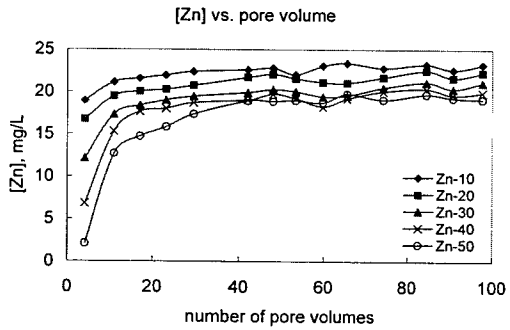

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

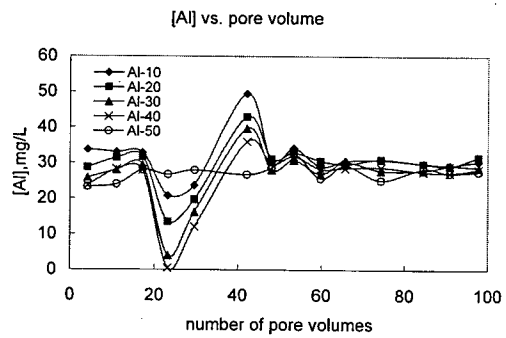

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

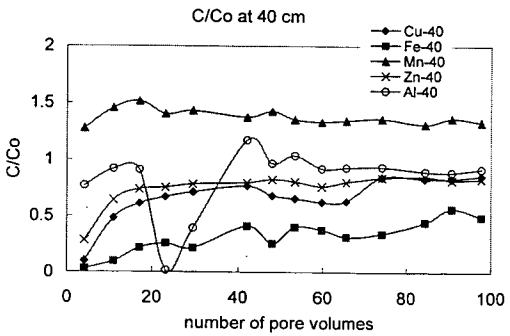

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

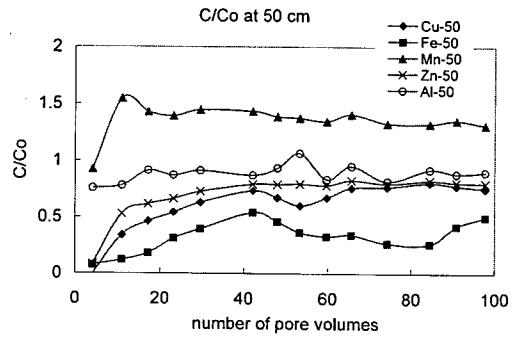

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
number of pore volumes
pH-50
pe
pH+pe


[Zn] vs. pore volume
[Zn], mg/L
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
60
50
40
30
20
10
0
0
20
40
60
80
100
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
2
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
2
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID PTB6

wt soil before filling column	1318.59	g
wt soil after filling column	454.75	g
wt soil in column	863.84	g
Date start	9/30/2002	
leachate	ARD natural/filtered	
pore volume	317.0482	ml
flowrate	2.089967	L/day
	1.560142	m/day

initial concentration of metals, Co		
[Cu]o	37.27	mg/L
[Fe]o	0.537	mg/L
[Mn]o	2.686	mg/L
[Zn]o	23.91	mg/L
[Al]o	30.71	mg/L
pH	3.09	
mV	475.75	
EC	2.05	

☑ 1 M NaCl pretreated ☐ No pretreatment

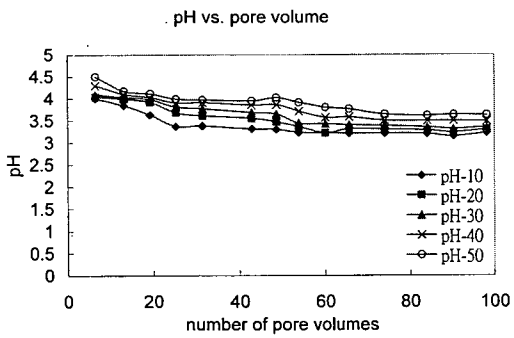
ARD concentration:

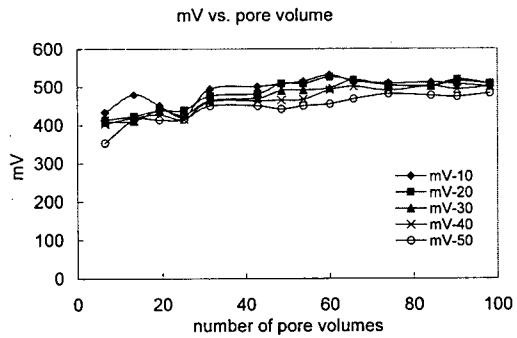
☑ Natural ☐ Maximum design

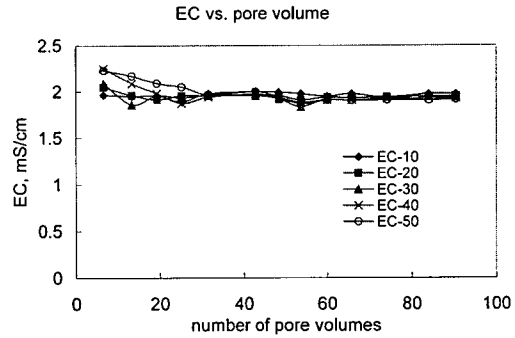
☑ Filtered ☐ Non-filtered

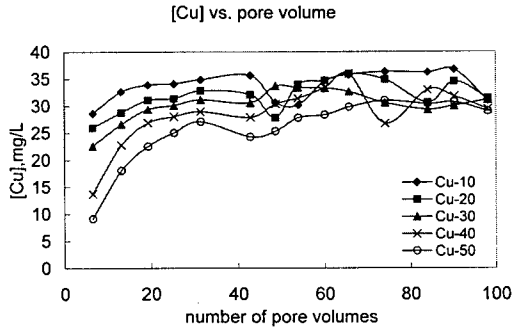
SampleID (Conc)	vol effl (ml	hh:mm:ss (min)	time used L/day	pv/day	Flowrate #pore vol	Cu-10	Fe-10	10cm Mn-10	Zn-10	Al-10	pH-10	mV-10	EC-10	Cu-20	mmhos Fe-20	20cm Mn-20	Zn-20	Al-20	pH-20	mV-20	EC-20	Cu-30	mmhos Fe-30
1	2080	26:34:00	1594.00	1.879046	5.92669	6.560517	28.596	0.174	3.831	19.9788	33.67	4	433.6	1.966	25.96	0.154	4.055	19.5454	33.24	4.04	413.4	2.05	22.576	0.147
2	2125	24:05:50	1445.83	2.116427	6.67541	13.26297	32.636	0.194	3.837	21.347	32.48	3.84	480	1.95	28.781	0.16	3.791	19.9109	32.69	3.99	423.2	1.961	26.622	0.129
3	1920	22:01:00	1321.00	2.09296	6.601394	19.31883	33.868	0.375	3.797	21.9114	31.79	3.63	451.1	1.956	31.029	0.195	3.813	20.5589	27.93	3.92	438.4	1.912	29.35	0.172
4	1870	20:22:48	1222.80	2.202159	6.945818	25.21699	34.1	0.806	3.663	22.061	27.09	3.37	422	1.891	31.367	0.223	3.752	20.8974	26.49	3.68	438.8	1.955	30.08	0.201
5	1960	22:48:00	1368.00	2.063158	6.507395	31.39901	34.862	0.903	3.722	22.5754	21.78	3.38	494.6	1.977	32.784	0.326	3.823	21.3852	19.66	3.61	476.3	1.955	31.089	0.252
6	3620	44:46:26	2686.43	1.940417	6.120258	42.81684	35.637	0.877	3.669	22.4698	49.03	3.31	501.3	1.999	32.07	0.544	3.712	20.566	45.02	3.55	482.7	1.957	30.553	0.294
7	1820	21:04:34	1264.57	2.072489	6.536825	48.55729	30.603	0.818	3.609	22.5165	33.83	3.3	508	1.992	27.8	0.822	3.557	21.6488	32.38	3.47	508.8	1.954	33.638	0.35
8	1650	18:49:30	1129.50	2.103586	6.634908	53.76154	30.176	0.771	3.611	23.4233	35.83	3.23	514.9	1.976	33.94	0.776	3.649	22.6246	35.37	3.36	508.5	1.909	33.36	0.9
9	1990	23:10:00	1390.00	2.061583	6.502427	60.03819	34.611	0.737	3.505	23.2375	31.96	3.22	531	1.948	34.659	0.73	3.661	22.5305	30.85	3.22	526	1.939	33.263	0.736
10	1800	21:20:00	1280.00	2.025	6.387042	65.71556	35.748	0.769	3.501	23.593	32.24	3.21	514.8	1.976	35.945	0.751	3.537	22.6647	31.17	3.31	516.9	1.93	32.603	0.714
11	2650	30:40:00	1840.00	2.073913	6.541318	74.07391	36.305	0.708	3.499	22.5493	29.28	3.21	508.7	1.936	34.857	0.702	3.639	22.6516	30.45	3.3	504.4	1.944	30.537	0.688
12	3160	36:00:00	2160.00	2.106667	6.644626	84.04085	36.173	0.693	3.451	23.0504	28.85	3.2	511.7	1.975	30.553	0.719	3.569	22.5353	28.88	3.28	502.7	1.946	29.304	0.734
13	1990	22:50:43	1370.72	2.090585	6.593904	90.3175	36.678	0.778	3.472	22.363	29.47	3.14	507.3	1.973	34.53	0.762	3.539	21.3848	30.29	3.23	518.8	1.952	30.01	0.763
14	2490	24:34:37	1474.62	2.431547	7.66933	98.1712	30.985	0.809	3.51	21.6085	29.99	3.22	500.9	1.974	31.412	0.779	3.654	19.9457	28.95	3.3	508.6	1.969	31.137	0.71

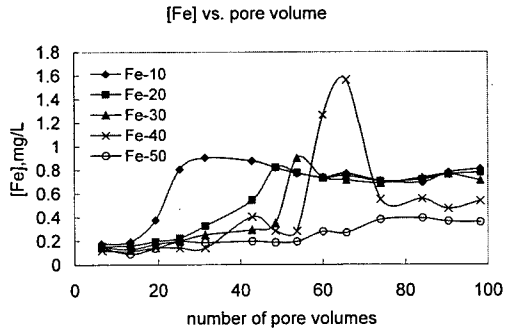
30cm							mmhos	40cm							mmhos	50cm							mmhos		
Mn-30	Zn-30	Al-30	pH-30	mV-30	EC-30	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-40	mV-40	EC-40	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	pH-50	mV-50	EC-50	Eh	pe-50	pH+pe
3.932	17.6158	30.26	4.09	408.5	2.09	13.755	0.118	4.295	13.4145	30.51	4.3	403.1	2.25	9.125	0.141	4.035	10.4139	26.76	4.5	353.1	2.23	555.1	9.408475	13.90847
3.832	19.0737	31.86	4.03	410.5	1.86	22.76	0.112	3.844	17.3618	27.78	4.1	418.9	2.09	18.057	0.089	3.725	14.9441	28.83	4.17	413.4	2.17	615.4	10.43051	14.60051
3.777	19.5964	29.04	3.98	439.1	1.955	26.84	0.142	3.799	18.4649	26.06	4.03	427.1	1.98	22.497	0.136	3.654	16.3283	23.67	4.11	413.5	2.09	615.5	10.4322	14.5422
3.674	20.1278	21.57	3.81	426.4	1.933	28.005	0.14	3.744	19.4233	10.96	3.9	415.5	1.873	25.028	0.194	3.659	17.921	5.36	3.99	414.9	2.05	616.9	10.45593	14.44593
3.79	20.6771	19.13	3.77	464.7	1.958	28.91	0.139	3.706	19.2008	16.78	3.91	461.3	1.941	27.086	0.186	3.656	18.4507	12.4	3.97	450.4	1.969	652.4	11.05763	15.02763
3.75	19.9202	45.77	3.68	470	1.956	27.859	0.403	3.629	18.5258	40.58	3.85	463.3	1.976	24.271	0.196	3.624	16.6303	37.32	3.95	449.8	1.999	651.8	11.04746	14.99746
3.805	21.5174	32.95	3.65	490.4	1.923	30.335	0.283	3.812	20.0487	32.31	3.86	465.4	1.936	25.29	0.186	3.546	17.6324	27.25	4.02	441.7	1.937	643.7	10.91017	14.93017
3.906	22.7578	37.45	3.44	491.5	1.834	31.4	0.283	3.624	21.492	36.91	3.71	466.9	1.884	27.788	0.193	3.59	18.6315	31.18	3.91	449.9	1.868	651.9	11.04915	14.95915
3.64	22.2194	29.27	3.43	496.4	1.928	33.329	1.267	3.818	21.0278	30.4	3.57	492	1.907	28.32	0.277	3.676	19.6848	28.15	3.8	454.9	1.907	656.9	11.1339	14.9339
3.694	22.2745	32.32	3.4	518.1	1.931	35.886	1.564	3.675	20.7445	32.28	3.58	500.7	1.907	29.736	0.268	3.651	19.1462	26.22	3.76	467.8	1.904	669.8	11.35254	15.11254
3.801	21.9791	28.98	3.38	504.2	1.937	26.742	0.55	3.668	21.0577	29.27	3.5	490.3	1.923	30.962	0.378	3.524	20.106	26.49	3.64	481.1	1.907	683.1	11.57797	15.21797
3.517	22.0744	28.76	3.35	501.2	1.947	32.974	0.556	3.596	21.9777	27.69	3.49	501.8	1.928	30.337	0.391	3.583	20.8516	27.02	3.61	477.2	1.906	679.2	11.51186	15.12186
3.486	21.1061	29.56	3.31	514.4	1.942	31.743	0.471	3.613	20.3215	28.02	3.49	493.5	1.927	30.681	0.364	3.624	19.77	27.24	3.63	473.7	1.914	675.7	11.45254	15.08254
3.536	19.9159	27.56	3.35	508.2	1.972	29.368	0.537	3.606	19.07	26.99	3.48	500.7	1.953	29.011	0.359	3.653	17.8643	27.35	3.62	483	1.926	685	11.61017	15.23017

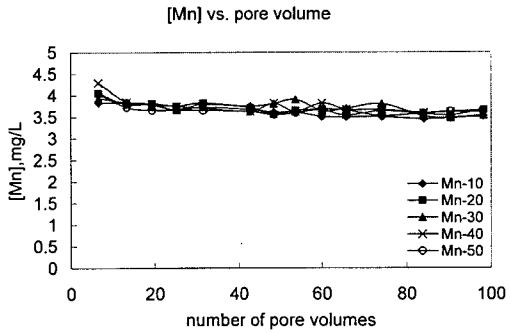

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

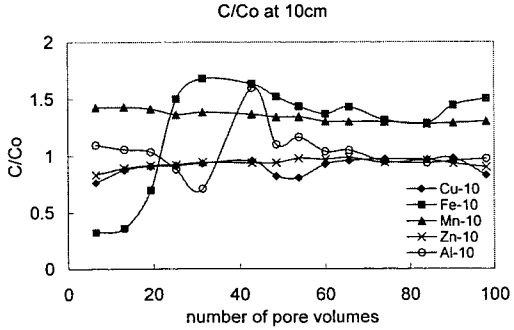

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

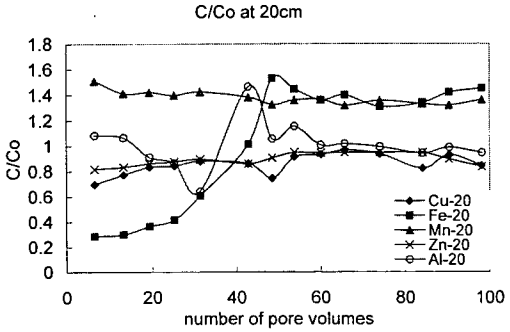

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

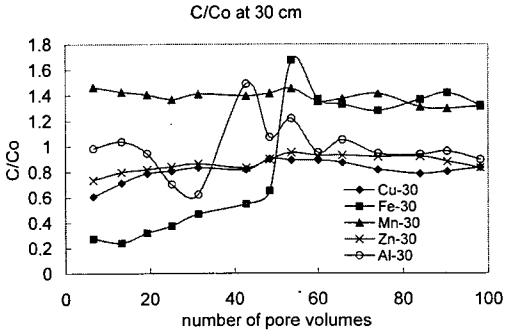

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

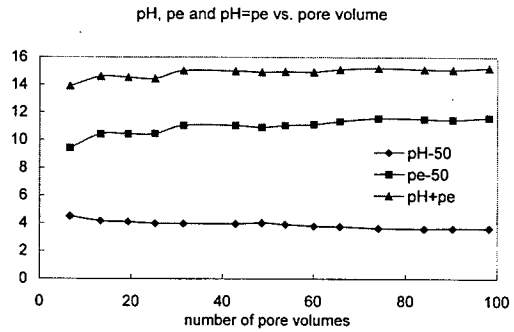

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

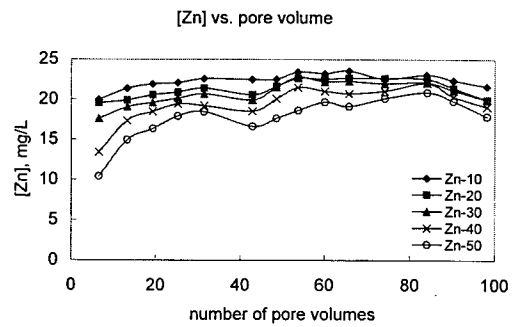

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

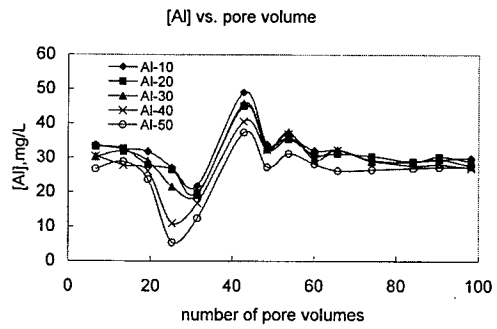

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

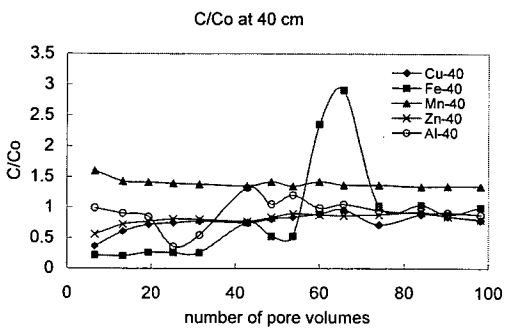

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

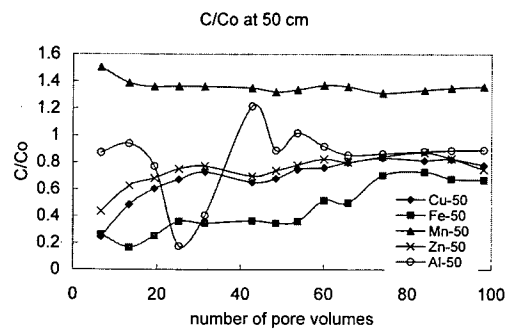

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
pH-50
pe-50
pH+pe
number of pore volumes


[Zn] vs. pore volume
[Zn], mg/L
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50
number of pore volumes


[Al] vs. pore volume
[Al],mg/L
Al-10
Al-20
Al-30
Al-40
Al-50
number of pore volumes


C/Co at 40 cm
C/Co
Cu-40
Fe-40
Mn-40
Zn-40
Al-40
number of pore volumes


C/Co at 50 cm
C/Co
Cu-50
Fe-50
Mn-50
Zn-50
Al-50
number of pore volumes

Cell ID PTB8

wt soil before filling columr	3314 g
wt soil after filling columr	2439.89 g
wt soil in columr	874.11 g
Date start	9/30/2002
leachate	ARD natural/filtered
pore volume	312.0578 ml
flowrate	0.667948 L/day
	0.498617 m/day

initial concentration of metals, Cc	
[Cu]o	37.27 mg/L
[Fe]o	0.537 mg/L
[Mn]o	2.686 mg/L
[Zn]o	23.91 mg/L
[Al]o	30.71 mg/L
pH	3.09
mV	475.75
EC	2.05

☑ 1 M NaCl pretreated ☐ No pretreatment

ARD concentration:

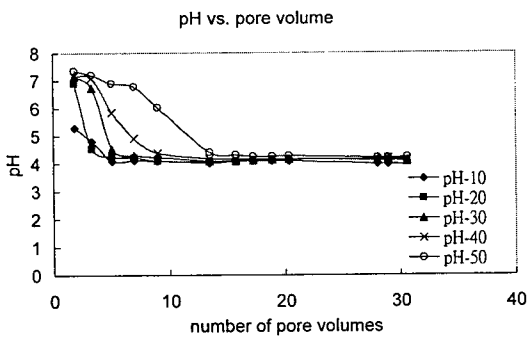
☑ Natural ☐ Maximum design

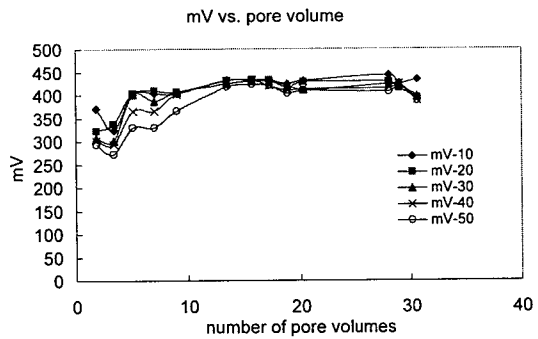
☑ Filtered ☐ Non-filtered

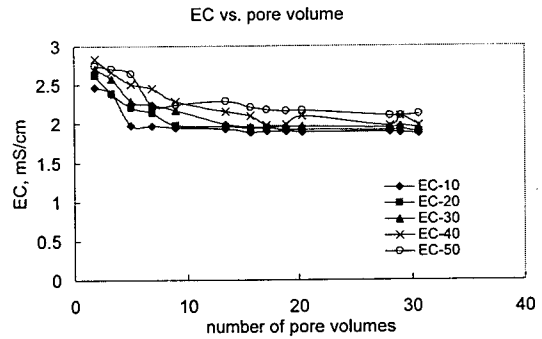
Linear flow rate: 0.5 m/day

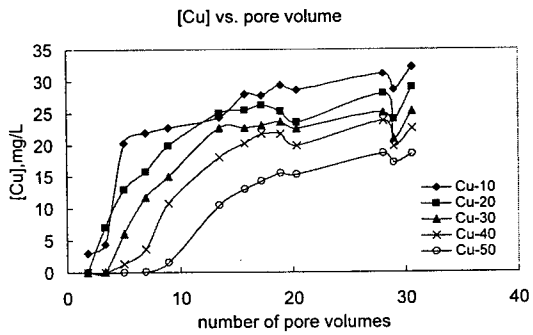
SampleID			time used		Flowrate		10cm								20cm									30cm		
(Conc)	vol effl (m	hh:mm:ss	(min)	L/day	pv/day	#pore vol	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	pH-10	mV-10	EC-10	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	pH-20	mV-20	EC-20	Cu-30	Fe-30	Mn-30
1	570	26:34:00	1594.00	0.514931	1.650114	1.826585	3.034	0.048	3.655	6.2448	0.86	5.3	370.4	2.47	-0.035	-0.012	1.009	0.2276	0.26	6.92	322.2	2.62	-0.045	0.06	0.117
2	470	21:31:30	1291.50	0.524042	1.67931	3.332716	4.454	0.001	4.512	7.679	1.99	4.81	324.3	2.38	7.012	0.019	3.897	8.5069	4.61	4.53	336.7	2.39	0.067	0.015	1.515
3	530	17:08:00	1028.00	0.742412	2.379086	5.031119	20.216	0.107	3.852	17.7646	23.7	4.1	401.3	1.978	12.994	0.049	3.87	12.7643	14.99	4.24	403.5	2.21	6.089	0.056	3.751
4	600	19:28:00	1168.00	0.739726	2.370478	6.95384	21.907	0.081	3.76	17.6252	26.29	4.12	404	1.971	15.803	0.103	3.563	14.3759	21.32	4.22	409.8	2.14	11.782	0.035	4.019
5	640	17:36:00	1056.00	0.872727	2.796685	9.004742	22.646	0.211	3.576	17.5476	25.43	4.09	402.8	1.948	19.875	0.151	3.667	16.7907	24	4.1	406.7	1.977	15.017	0.087	3.755
6	1390	41:50:00	2510.00	0.79745	2.555457	13.45905	24.275	0.129	3.635	19.3037	29.85	4.02	431.4	1.929	25.01	0.123	3.6	18.47	27.73	4.07	430.6	1.961	22.618	0.128	3.711
7	700	21:04:34	1264.57	0.797111	2.55437	15.70222	27.944	0.146	3.665	21.234	26.65	4.08	431.2	1.886	25.472	0.148	3.593	19.6586	26.17	4.1	433.9	1.941	22.657	0.116	3.678
8	468	16:22:00	982.00	0.686273	2.199185	17.20194	27.794	0.164	3.645	21.114	31.18	4.09	431.5	1.898	26.2	0.142	3.671	19.2771	28.26	4.12	432.1	1.939	23.08	0.108	3.631
9	530	19:54:53	1194.88	0.638723	2.046811	18.90035	29.454	0.212	3.663	20.5671	31.13	4.09	423.5	1.902	25.295	0.158	3.595	18.7526	26.17	4.13	415	1.927	23.592	0.15	3.66
10	440	16:43:00	1003.00	0.631705	2.02432	20.31034	28.657	0.205	3.621	19.8159	29.82	4.08	431.2	1.888	23.564	0.135	3.526	17.5226	24.95	4.15	427.7	1.923	22.53	0.112	3.557
13	2420	93:19:00	5599.00	0.622397	1.994492	28.06531	31.136	0.271	3.544	21.0557	29.11	3.97	442.1	1.894	28.034	0.11	3.509	19.8195	26.86	4.12	428.5	1.916	25.059	0.09	3.516
14	285	17:15:00	1035.00	0.396522	1.270668	28.97861	28.624	0.195	3.645	20.3859	41.36	3.97	425.3	1.884	23.976	0.095	3.522	17.8069	36.11	4.12	414.6	1.935	20.93	0.077	3.422
15	515	17:11:00	1031.00	0.719302	2.305027	30.62894	32.21	0.233	3.673	20.6835	33.33	3.95	433.9	1.879	29.032	0.132	3.562	18.7003	32.43	4.1	393.3	1.894	25.214	0.113	3.424

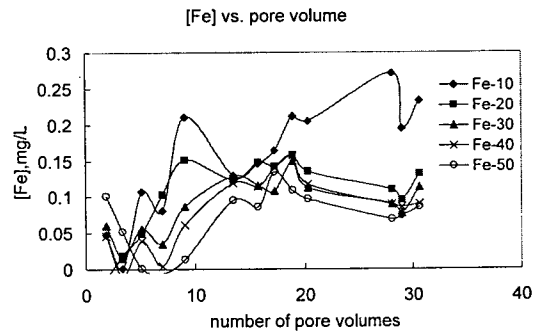
					40cm								50cm											
Zn-30	Al-30	pH-30	mV-30	EC-30	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-40	mV-40	EC-40	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	pH-50	mV-50	EC-50	Eh	pe-50	pH+pe
-0.0201	0.25	7.15	306.8	2.71	-0.038	0.046	0.024	-0.0152	0.16	7.15	301.8	2.83	-0.058	0.101	0.025	-0.0162	0.19	7.35	293.3	2.75	495.3	8.394915	15.74492
1.1386	0.13	6.74	301.9	2.58	-0.048	-0.011	0.302	-0.0188	0.09	7.1	293.5	2.67	-0.057	0.052	-0.075	-0.0464	0.13	7.19	272.4	2.71	474.4	8.040678	15.23068
8.3493	4.45	4.54	401.2	2.29	1.335	0.039	2.538	3.4456	0.41	5.85	365.8	2.51	-0.009	0.001	0.524	0.0802	0.1	6.9	328.9	2.64	530.9	8.998305	15.89831
12.2834	14.06	4.28	386.9	2.24	3.694	0.004	3.179	6.3555	1.76	4.92	365	2.45	0.084	-0.006	2.003	1.6477	0.01	6.78	330	2.23	532	9.016949	15.79695
14.2781	17.25	4.22	405.8	2.17	10.802	0.061	3.892	11.7179	10.54	4.37	401.7	2.29	1.534	0.014	3.143	5.2433	0.51	6.02	365.4	2.24	567.4	9.616949	15.63695
17.7458	27.75	4.09	424	1.989	18.015	0.119	3.618	15.447	25.29	4.17	430.9	2.15	10.526	0.095	3.713	11.6796	12.83	4.39	417.5	2.29	619.5	10.5	14.89
18.1476	23.97	4.1	429.6	1.957	20.22	0.114	3.656	16.8831	23.41	4.15	432.2	2.1	12.99	0.086	3.679	13.2855	16.41	4.32	422.9	2.21	624.9	10.59153	14.91153
18.4073	27.03	4.11	430	1.945	21.671	0.14	3.651	17.1329	25.56	4.16	420.3	1.979	14.242	0.134	3.592	13.7684	19.27	4.25	420.6	2.18	622.6	10.55254	14.80254
17.9717	25.12	4.13	420	1.962	21.691	0.157	3.601	17.0168	25.18	4.16	409.7	1.984	15.524	0.109	3.533	13.9845	19.63	4.24	403	2.16	605	10.25424	14.49424
16.5474	23.94	4.15	410.6	1.96	19.87	0.117	3.507	15.9294	19.34	4.16	413.9	2.1	15.37	0.097	3.526	13.632	16.86	4.26	409.6	2.17	611.6	10.3661	14.6261
18.7209	25.55	4.13	422.2	1.945	23.685	0.089	3.46	17.8294	25.05	4.14	415.3	1.968	18.605	0.069	3.342	15.399	21.08	4.21	406.8	2.1	608.8	10.31864	14.52864
15.8732	35.22	4.16	420.1	1.969	19.741	0.086	3.336	15.0707	33.65	4.17	423.4	2.1	17.176	0.074	3.297	14.308	31.27	4.21	421.9	2.1	623.9	10.57458	14.78458
16.9468	29.54	4.14	396.9	1.951	22.6	0.09	3.597	15.1322	26.75	4.16	388.6	1.982	18.53	0.086	3.462	13.7254	23.2	4.23	386.8	2.12	588.8	9.979661	14.20966

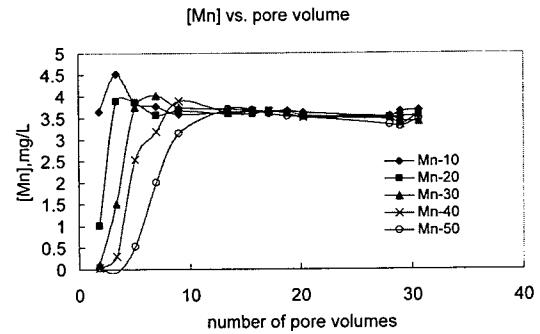

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

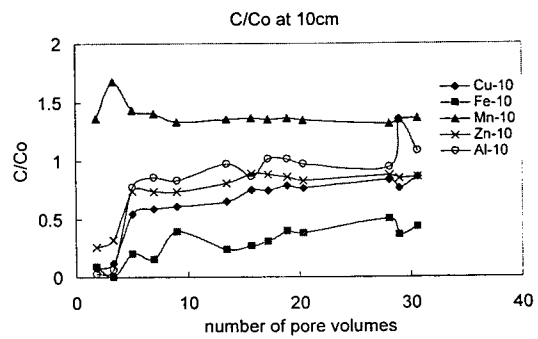

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

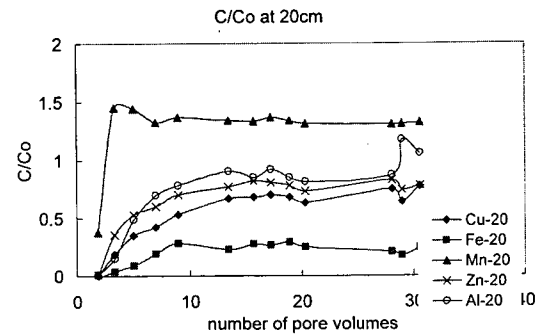

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

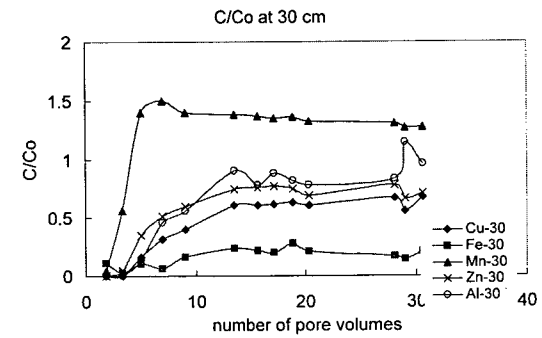

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

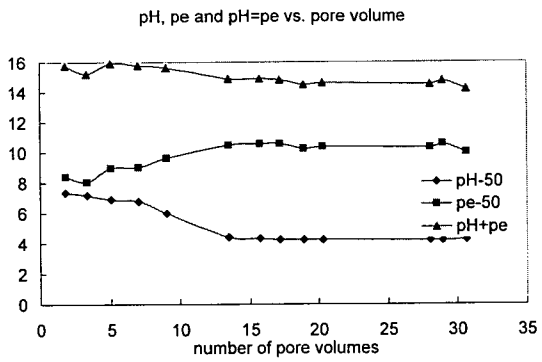

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

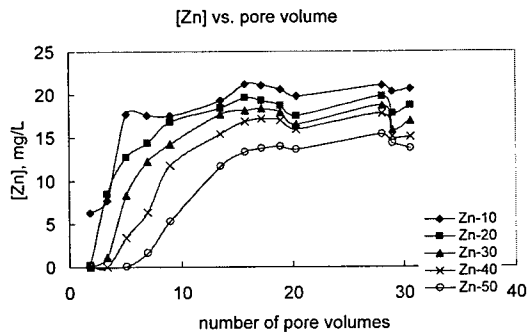

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

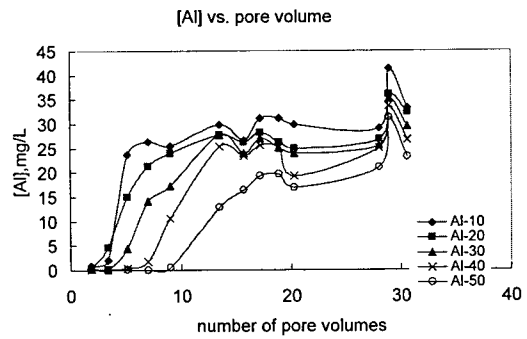

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

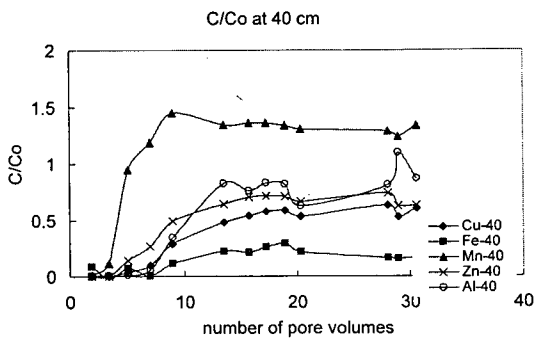

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

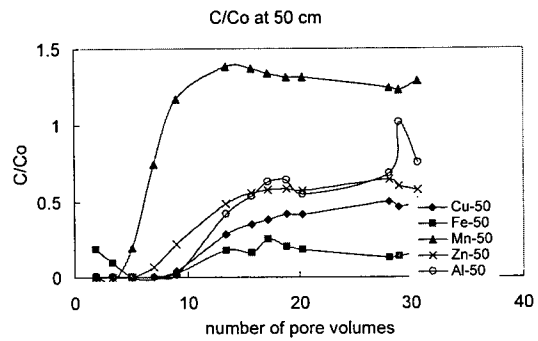

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
5
10
15
20
25
30
35
number of pore volumes
pH-50
pe-50
pH+pe


[Zn] vs. pore volume
[Zn], mg/L
25
20
15
10
5
0
0
10
20
30
40
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
2
1.5
1
0.5
0
0
10
20
30
40
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1.5
1
0.5
0
0
10
20
30
40
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID PTB9

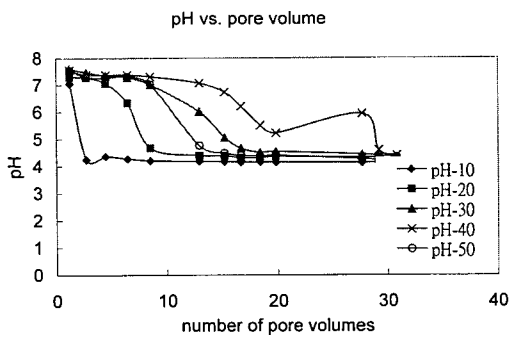
wt soil before filling column	2439.89 g
wt soil after filling column	1563.65 g
wt soil in column	876.24 g
Date start	9/30/2002
leachate	ARD natural/filtered
pore volume	311.0228 ml
flowrate	0.674688 L/day
	0.503649 m/day

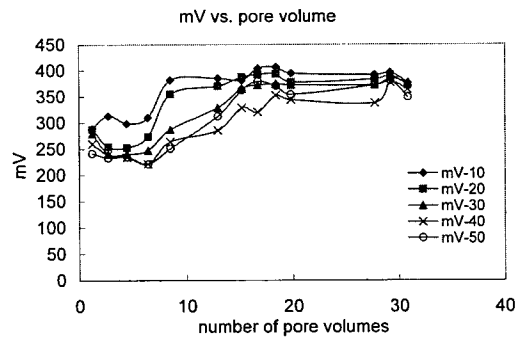
initial concentration of metals, Co		
[Cu]o	37.27	mg/L
[Fe]o	0.537	mg/L
[Mn]o	2.686	mg/L
[Zn]o	23.91	mg/L
[Al]o	30.71	mg/L
pH	3.09	
Redox pot	475.75	mV
EC	2.05	mS/cm

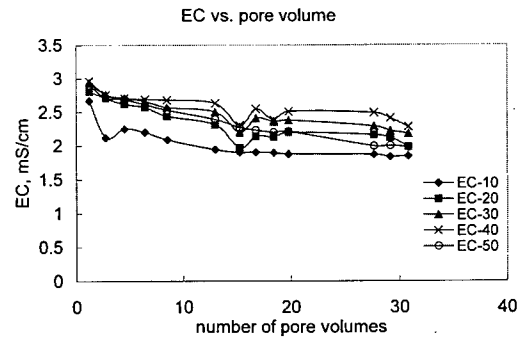
☑ 1 M NaCl pretreated ☐ No pretreatment
ARD concentration:
☑ Natural ☐ Maximum design
☑ Filtered ☐ Non-filtered
Linear flow rate: 0.5 m/day

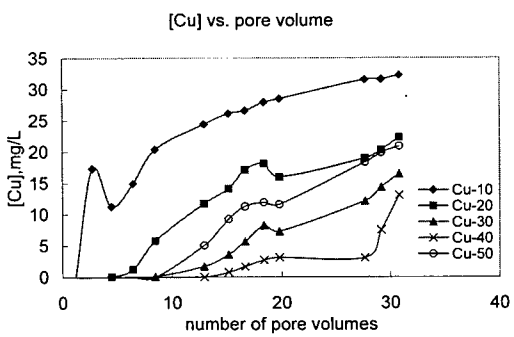
SampleID		time used		Flowrate			10cm									20cm								30cm	
(Conc)	vol effl (ml	hh:mm:ss	(min)	L/day	pv/day	#pore vol	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	pH-10	mV-10	EC-10	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	pH-20	mV-20	EC-20	Cu-30	Fe-30
1	380	26:34:00	1594.00	0.343287	1.103737	1.221775	-0.06	0.024	0.165	-0.0336	0.14	7.06	288.1	2.67	-0.051	0.125	-0.017	-0.0289	0.19	7.3	287.4	2.81	-0.054	0.114
2	470	21:31:30	1291.50	0.524042	1.684898	2.732919	17.358	0.047	3.917	14.1982	21.5	4.24	312.9	2.12	-0.033	0.047	-0.014	-0.0411	0.13	7.28	254.2	2.71	-0.052	0.069
3	540	17:08:00	1028.00	0.75642	2.432041	4.469126	11.248	0.095	4.563	13.8139	10.51	4.36	298.5	2.25	0.046	0.138	0.971	1.1065	0.17	7.06	252.1	2.62	-0.014	0.065
4	608	19:28:00	1168.00	0.749589	2.410078	6.423967	14.894	0.028	4.388	15.512	16.08	4.28	309.7	2.2	1.229	-0.014	1.632	3.2392	0.03	6.34	273.3	2.57	-0.015	0.002
5	640	17:57:00	1077.00	0.85571	2.751279	8.481694	20.411	0.079	4.05	18.1736	23.68	4.2	381.5	2.09	5.776	0.035	2.837	7.462	3.88	4.67	354.7	2.44	0.078	0.056
6	1380	41:50:00	2510.00	0.791713	2.545515	12.91867	24.385	0.116	3.808	19.1998	28.79	4.17	384.7	1.94	11.69	0.084	3.326	11.4937	13.02	4.39	369.9	2.31	1.661	0.015
7	700	21:04:34	1264.57	0.797111	2.56287	15.16931	26.102	0.108	3.799	20.9506	29.25	4.16	381.1	1.903	14.077	0.067	3.539	12.8589	14.24	4.38	387	1.969	3.566	-0.002
8	468	16:22:00	982.00	0.686273	2.206504	16.67402	26.577	0.154	3.842	21.7728	30.74	4.15	404.2	1.904	17.108	0.101	3.649	14.8115	19.85	4.3	392.2	2.14	5.664	0
9	530	19:54:53	1194.88	0.638723	2.053623	18.37808	27.948	0.188	3.739	20.1616	29.66	4.15	406.3	1.895	18.121	0.114	3.595	15.6242	19.26	4.3	393.4	2.13	8.222	0.047
10	440	16:43:00	1003.00	0.631705	2.031057	19.79276	28.508	0.169	3.656	20.3181	25.65	4.15	394.5	1.877	15.96	0.087	3.357	13.7509	13.78	4.36	377.5	2.2	7.268	0.027
13	2450	93:19:00	5599.00	0.630113	2.025937	27.67	31.572	0.116	3.593	21.6114	31.94	4.13	391.5	1.871	18.957	0.056	3.232	15.0784	17.92	4.32	383	2.16	12.135	0.034
14	465	17:15:00	1035.00	0.646957	2.080094	29.16507	31.632	0.097	3.627	21.8204	29.12	4.13	395.7	1.835	20.294	0.064	3.24	15.8651	21.96	4.31	390.8	2.12	14.362	0.033
15	515	17:11:00	1031.00	0.719302	2.312698	30.82089	32.273	0.134	3.602	21.1274	36.34	4.13	376.5	1.85	22.29	0.1	3.291	15.7826	26.23	4.27	371	1.982	16.471	0.07

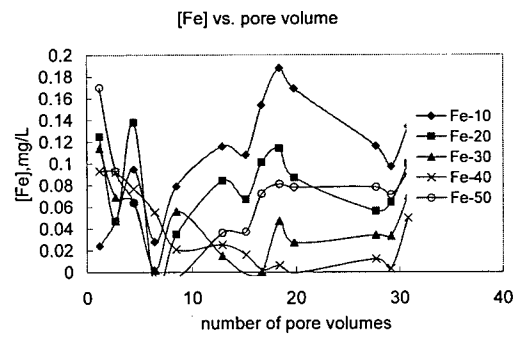
Mn-30	Zn-30	Al-30	pH-30	mV-30	EC-30	40cm Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-40	mV-40	EC-40	50cm Cu-50	Fe-50	Mn-50	Zn-50	Al-50	pH-50	mV-50	EC-50	Eh	pe-50	pH+pe
-0.014	-0.0264	0.19	7.6	279.7	2.94	-0.047	0.093	-0.025	-0.0309	0.21	7.56	259.6	2.96	-0.04	0.17	0.004	-0.0328	0.24	7.55	241	2.9	443	7.508475	15.05847
-0.034	-0.0596	0.13	7.47	240.4	2.76	-0.057	0.092	-0.026	-0.0632	0.1	7.38	238.4	2.76	-0.048	0.093	-0.034	-0.0625	0.12	7.3	232.7	2.72	434.7	7.367797	14.6678
0.066	-0.0041	0.1	7.36	240	2.71	-0.028	0.077	0.05	-0.0001	0.1	7.38	233.4	2.71	-0.018	0.064	0.039	-0.0059	0.05	7.27	234.6	2.69	436.6	7.4	14.67
0.298	0.0142	-0.04	7.29	247	2.66	-0.027	0.055	0.046	-0.0072	-0.01	7.38	221.6	2.69	-0.02	-0.002	0.265	0.0237	-0.06	7.32	220.9	2.61	422.9	7.167797	14.4878
1.54	1.5956	0.23	7.01	286.9	2.57	-0.03	0.021	0.219	0.0159	0.2	7.31	263.4	2.68	-0.025	-0.006	1.843	1.0824	0.19	7.03	250.7	2.53	452.7	7.672881	14.70288
2.427	4.0109	0.38	6.01	328.4	2.5	-0.002	0.025	0.528	0.318	0.12	7.07	285	2.63	5.024	0.036	3.826	8.5228	4.1	4.75	312.1	2.39	514.1	8.713559	13.46356
2.888	5.8695	1.81	5.05	364.9	2.2	0.728	0.016	1.314	1.948	0.3	6.73	328.3	2.3	9.198	0.037	4.283	12.561	10.76	4.47	362.1	2.27	564.1	9.561017	14.03102
3.2	7.7216	4.05	4.66	371.7	2.41	1.661	0.002	1.665	3.1558	0.79	6.21	320	2.55	11.242	0.072	4.131	13.472	14.21	4.39	378.4	2.23	580.4	9.837288	14.22729
3.436	9.5659	7.01	4.5	374.4	2.36	2.707	0.006	1.943	4.0912	1.08	5.5	352.3	2.38	11.903	0.081	3.945	12.8947	14.69	4.37	370.1	2.2	572.1	9.69661	14.06661
3.298	8.9116	5.29	4.54	372.3	2.38	3.107	-0.001	2.022	4.2992	1.33	5.22	343.5	2.51	11.592	0.078	3.724	11.9168	12.44	4.4	353.9	2.21	555.9	9.422034	13.82203
3.199	11.1332	11.27	4.43	372.1	2.29	3.052	0.012	1.903	4.1717	1.3	5.94	337.3	2.49	18.315	0.078	3.507	16.0213	21.06	4.26	371.3	1.994	573.3	9.716949	13.97695
3.26	12.8638	16	4.38	386.2	2.22	7.528	0.003	2.458	7.7874	6.03	4.59	376.5	2.41	19.857	0.071	3.553	16.6183	24.73	4.23	379.6	1.998	581.6	9.857627	14.08763
3.313	12.7795	19.32	4.34	374.4	2.18	13.023	0.05	2.964	10.6018	15.08	4.4	363.6	2.28	20.866	0.092	3.4	15.6859	25.43	4.3	348.7	1.979	550.7	9.333898	13.6339

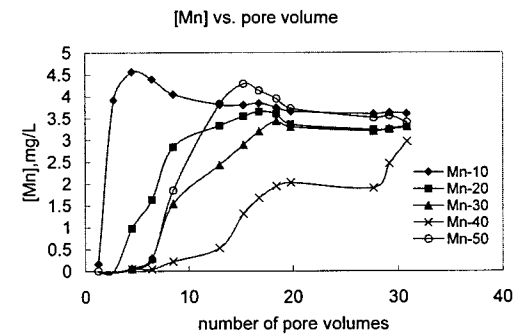

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

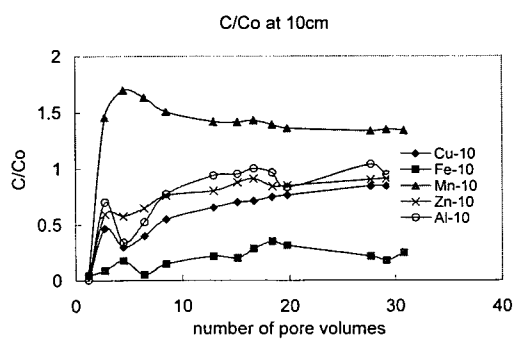

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

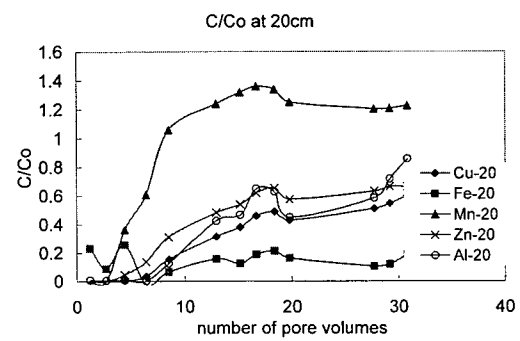

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

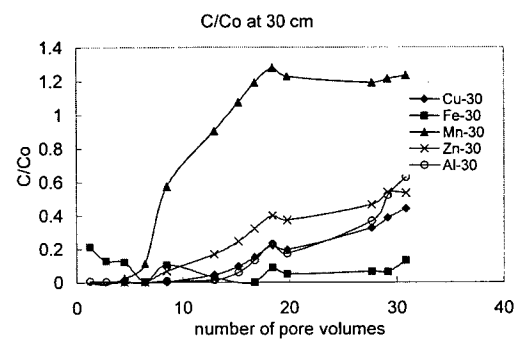

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50


[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

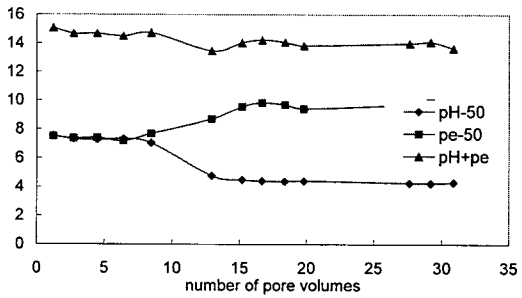

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50


C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

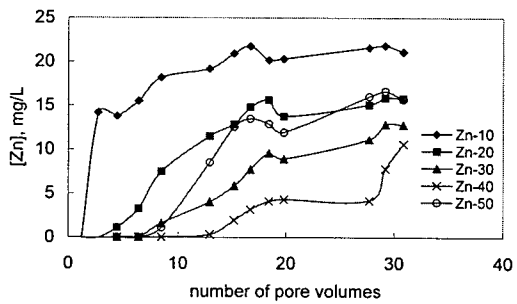

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20


C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30

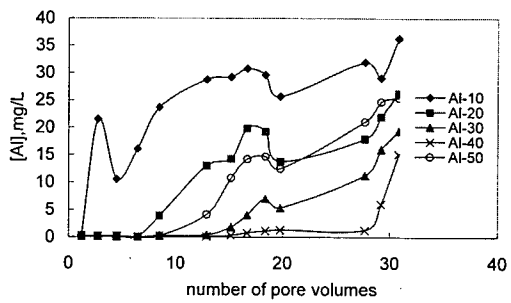
pH, pe and pH=pe vs. pore volume



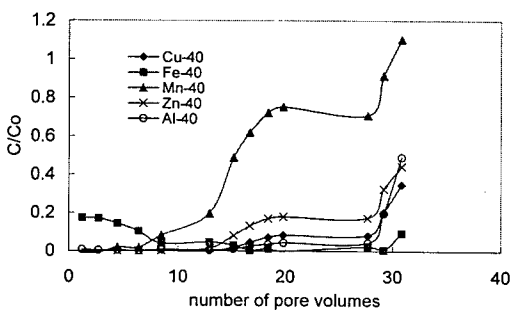
[Zn] vs. pore volume



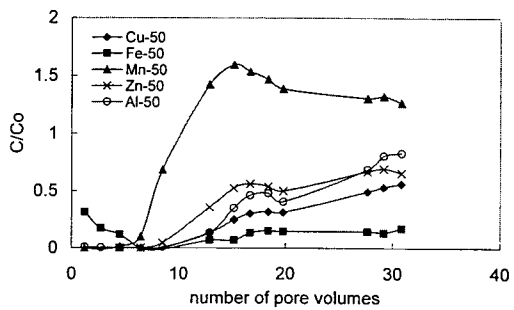
[Al] vs. pore volume



C/Co at 40 cm



C/Co at 50 cm



Cell ID PTB11

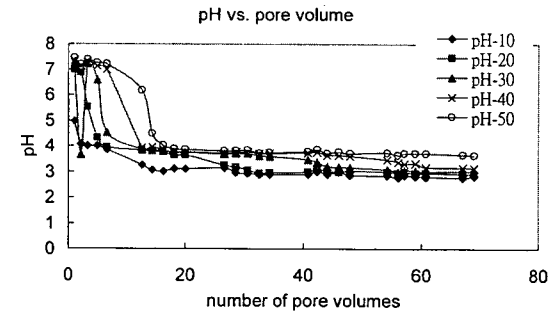
wt soil before filling column	3134 g
wt soil after filling column	2266.42 g
wt soil in column	867.58 g
Date start	Jan 19, 2003
leachate	max conc-filtered
pore volume	315.231 ml
flowrate	0.68975 L/day
	0.51489 m/day

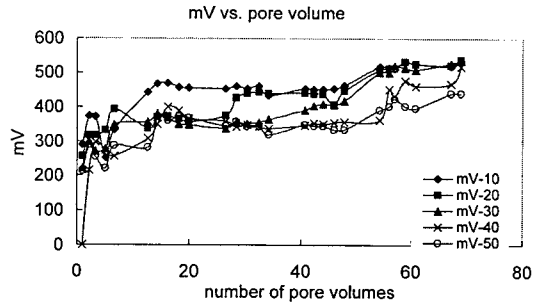
initial concentration of metals, Cc	
[Cu]o	110.075 mg/L
[Fe]o	8.712 mg/L
[Mn]o	8.669 mg/L
[Zn]o	47.654 mg/L
[Al]o	68.3 mg/L
pH	2.96
Redox p	575.1 mV
EC	2.99 mS/cm

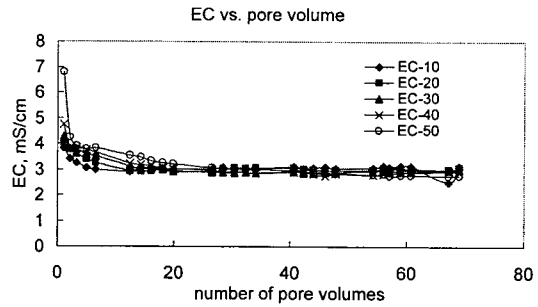
☑ 1 M NaCl pretreated ☐ No pretreatment
ARD concentration:
☐ Natural ☑ Maximum design
☑ Filtered ☐ Non-filtered
Linear flow rate: 0.5 m/day

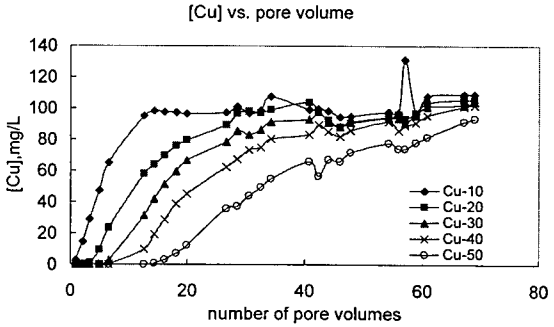
ID	Date	Time	vol effl (n	time used hh:mm:ss	(min)	Flowrate L/day	pv/day	#pore vo	10cm pH-10	mV-10	EC-10	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	20cm pH-20	mV-20	EC-20	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	30cm pH-30
1	Jan 20, 20	10:36a	315.4	15:45:00	945.00	0.48061	1.52463	1.00054	4.96	289.6	3.82	2.712	0.087	4.041	5.4312	3.06	7	255.7	4.06	-0.034	0.142	-0.09	0.0211	1.38	7.22
2	jan 21,200	9:30a	333.98	16:30:00	990.00	0.48579	1.54106	2.06001	4.07	373.9	3.41	14.69	0.216	7.292	14.9592	26.93	6.86	316.8	3.79	0.032	0.103	0.855	0.3648	0.02	3.67
3	jan 22, 20(	9:10a	368.46	17:36:31	1056.52	0.5022	1.59312	3.22887	4.01	370.7	3.25	28.97	0.459	7.842	21.5472	47.75	5.53	317.7	3.59	1.188	0	4.433	4.2061	1.33	7.23
4	jan 23,200	9:00a	533.81	17:53:56	1073.93	0.71577	2.27061	4.92227	4.01	251.8	3.06	47.525	1.505	8.226	30.7635	64.8	4.32	332.2	3.4	9.449	0.117	7.137	12.3072	22.25	6.58
5	jan 24, 20(	9:00a	508.53	18:43:18	1123.30	0.6519	2.06802	6.53546	3.85	332.3	3	64.945	3.052	8.397	35.3	75.85	3.94	391.6	3.25	23.475	0.428	7.872	19.9801	45.31	4.52
6	jan 27,200	9:00a	1885.26	68:48:32	4128.53	0.65756	2.08598	12.516	3.25	442.3	2.91	95.435	10.397	8.592	43.242	81.5	3.84	337	2.94	57.965	3.723	8.328	33.5265	80.45	3.86
7	Jan 28, 20	8:50a	574.93	18:40:45	1120.75	0.7387	2.34337	14.3399	3.05	467.8	3.06	98.55	12.482	8.214	43.5445	73.95	3.8	369.3	2.91	64.025	4.851	8.336	34.729	74.75	3.82
8	Jan 29,20(	8:40a	576.7	18:55:16	1135.27	0.7315	2.32052	16.1693	3.01	468.9	3.05	97.525	12.164	6.539	43.536	73.45	3.76	371.8	2.95	69.785	5.843	6.67	37.6525	73.98	3.8
9	Jan 30,20(	9:30a	611.84	19:58:58	1198.97	0.73484	2.33112	18.1103	3.12	456.5	3.03	97.06	12.215	6.398	41.9805	73.08	3.65	364.9	2.96	75.96	6.825	6.577	38.2785	73.85	3.74
10	Jan 31,20(	8:50a	581.75	18:51:21	1131.35	0.74046	2.34895	19.9557	3.11	454.6	3.01	96.66	12.71	7.598	43.868	73.14	3.64	357	2.9	79.665	7.515	7.58	39.3905	74.02	3.74
11	Feb 3,200	9:10a	2083.49	67:31:44	4051.73	0.74048	2.34901	26.5651	3.13	453.1	3.01	97.135	14.57	7.719	44.401	73.21	3.26	373.8	2.92	89.25	9.968	7.676	41.782	74.31	3.68
12	Feb 4,200	8:10a	578.8	18:22:40	1102.67	0.75587	2.39783	28.4012	2.96	460.8	3.08	101.37	16.179	8.154	43.599	73.35	3.17	425.5	2.96	96.86	12.929	8.209	41.2935	74.8	3.72
13	Feb 5,200	9:05a	632.98	20:32:27	1232.45	0.73958	2.34614	30.4092	2.94	452.4	3	96.91	15.725	8.232	42.981	73.3	3.06	438.5	3.05	98.06	14.288	8.349	42.0345	73.9	3.71
14	Feb 6,200	10:40a	643.23	21:06:20	1266.33	0.73144	2.32034	32.4497	2.89	460.3	3.02	98.83	15.558	8.081	44.843	75.45	2.95	441.6	3.03	97.175	14.801	8.103	44.93	73.3	3.62
15	Feb 7,200	9:10a	541.98	17:38:40	1058.67	0.7372	2.33861	34.1691	2.88	434.1	3.02	107.515	15.521	8.068	43.6015	69.85	2.97	439.2	3.06	99.235	14.054	8.2	40.337	65.2	3.59
16	Feb 10,20(	9:05a	2065.77	67:05:49	4025.82	0.73891	2.34402	40.7223	2.89	454	3.1	99.205	14.841	7.844	44.1075	67.3	3	440.3	3.06	104.055	14.6	8.038	44.786	71.6	3.47
17	Feb 11,20(	9:10a	514.84	19:52:40	1192.67	0.62161	1.97191	42.3555	3.01	451.9	3.02	99.615	13.856	7.765	45.0935	75.3	3.1	436.2	3.01	97.425	13.663	7.86	42.633	71.15	3.37
18	Feb 12,20(	7:30a	521.63	17:38:41	1058.68	0.70951	2.25077	44.0102	2.9	451.6	3.05	98.55	12.774	8.172	42.0025	64.3	3.01	436.8	2.99	92.425	12.609	8.198	39.128	61.95	3.2
19	Feb 13,20(	9:30a	620.37	20:50:31	1250.52	0.71437	2.26618	45.9782	3	452.6	3.08	94.445	12.968	8.122	42.7605	67.85	3	406.6	2.97	87.795	11.32	7.977	39.432	64.6	3.17
20	Feb 14,20(	9:40a	590.36	19:43:22	1183.37	0.71839	2.27893	47.851	2.87	462.5	3.04	94.85	12.572	8.286	41.8505	62.9	3.03	446.7	2.97	90.585	9.942	8.343	39.688	63.7	3.15
21	Feb 17,20(	9:00a	2008.22	67:11:50	4031.83	0.71725	2.27532	54.2216	2.85	517.7	3.07	97.51	10.806	8.141	43.6565	62.55	3	508	2.98	94	6.372	8.191	42.138	64.9	3.09
22	Feb 18,20(	900a	554.78	19:50:26	1190.43	0.67109	2.12887	55.9815	2.78	514.2	3.13	97.44	10.306	9.059	41.429	70.3	2.94	512.2	3.04	95.92	6.555	9.021	41.0245	65.8	2.99
23	Feb 19,20(	9:00a	322.87	10:50:30	650.5	0.71473	2.26733	57.0058	2.85	511.9	3.08	131.395	9.63	8.751	41.1196	103.9	2.98	513.1	3.02	93.32	6.548	8.927	41.0805	78.9	3.06
24	Feb 20,20(	8:45a	596.51	19:17:01	1157.02	0.7424	2.35511	58.8981	2.81	532.5	3.13	96.595	10.202	8.845	43.9765	76.9	2.95	532.8	3.03	96.68	6.473	8.947	43.823	79.05	3.04
25	Feb 21,20(	9:00a	585.04	19:49:08	1189.13	0.70846	2.24744	60.754	2.79	525.4	3.14	107.975	10.37	7.889	41.5755	82	2.95	525.3	3.02	103.41	6.769	7.993	38.765	82.15	3.02
26	Feb 24,20(	9:20a	2000.71	67:32:27	4052.45	0.71093	2.25528	67.1008	2.78	519.1	2.5	109.19	9.685	7.634	41.9355	85.15	2.92	522	2.99	105.565	7.025	7.583	39.793	88.5	3.01
27	Feb 25,20(	9:10a	572.85	19:19:11	1159.18	0.71163	2.25747	68.918	2.81	532.9	3.14	109.005	9.903	7.874	42.141	82.85	2.91	536.9	3.07	105.095	7.171	7.938	40.2555	83.2	2.99

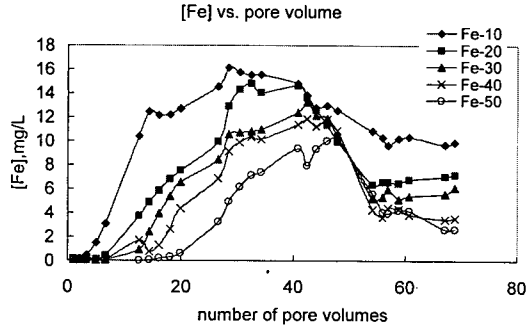
mV-30	EC-30	Cu-30	Fe-30	Mn-30	Zn-30	Al-30	40cm pH-40	mV-40	EC-40	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	50cm pH-50	mV-50	EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	Eh-50	pe-50	pH+pe-5
221.2	4.28	-0.069	0.089	-0.076	0.0116	1.47	7.34	216.3	4.74	-0.074	0.032	-0.087	0.0048	1.16	7.45	213.3	6.8	-0.098	0.113	-0.011	0.2818	1.02	415.3	7.03898	14.489
299.2	3.81	-0.043	0.096	0.018	-0.0085	-0.1	7.13	298	3.84	-0.037	0.085	0.04	0.0077	-0.41	7.17	288.4	4.25	-0.043	0.075	0.032	0.0218	-0.62	490.4	8.31186	15.4819
270.9	3.78	0.021	0.243	0.074	-0.0004	-0.03	7.3	273.8	3.83	-0.012	-0.037	-0.06	-0.0111	0.17	7.37	254.6	3.9	0.023	0.053	0.006	0.0137	-0.18	456.6	7.73898	15.109
276.8	3.6	0.038	0.043	2.842	1.0343	0.45	7.14	256.1	3.75	0.007	0.032	0.029	0.0067	0.21	7.26	220	3.79	-0.032	0.122	-0.014	-0.0095	0.27	422	7.15254	14.4125
347.7	3.52	2.653	0.054	7.327	8.2853	7.73	6.98	307.4	3.67	0.025	0.037	0.883	-0.012	-0.18	7.2	285.8	3.82	0.045	0.017	-0.039	-0.026	-0.17	487.8	8.2678	15.4678
356.6	3.11	31.39	0.93	8.104	23.9204	70.5	3.92	349.5	3.22	9.673	1.676	7.263	13.5109	54.98	6.16	281.7	3.54	0.036	0.003	4.444	1.0177	1.65	483.7	8.19831	14.3583
379	3.02	41.765	2.392	8.241	29.271	73.4	3.96	400.1	3.17	19.28	0.751	7.622	19.0391	66.95	4.49	371.1	3.48	0.752	0.063	7.661	6.7305	11.67	573.1	9.71356	14.2036
369.2	3.03	51.29	3.945	6.87	32.607	73.2	3.83	389.4	3.14	28.555	1.298	6.787	22.5505	69.45	4.02	360.1	3.33	3.209	0.191	6.324	8.9654	23.84	562.1	9.52712	13.5471
350.1	2.98	59.47	5.369	6.633	33.9295	73.61	3.77	364.5	3.04	38.957	2.639	6.498	28.551	72.34	3.89	371.6	3.26	6.982	0.305	5.987	11.9431	38.42	573.6	9.72203	13.612
347.6	2.93	66.645	6.565	7.568	36.953	73.07	3.77	358.5	3.02	45.205	4.339	6.992	31.2545	73.89	3.86	367.3	3.2	12.316	0.6	5.97	14.9247	52.74	569.3	9.64915	13.5092
337.5	2.88	78.45	8.476	7.895	39.9885	73.68	3.73	341.5	2.96	62.195	6.882	7.681	35.8705	77.68	3.81	343.2	3.07	35.52	3.246	7.184	23.3967	67.69	545.2	9.24068	13.0507
354.4	2.9	85.46	10.564	8.424	38.21	77.55	3.75	347.5	2.9	67.64	9.108	8.244	34.7475	76.85	3.8	356.9	3.03	37.235	4.909	7.894	25.007	71.3	558.9	9.47288	13.2729
350.6	2.86	83.215	10.705	8.262	38.774	76.5	3.76	342.5	2.88	73.375	9.875	8.208	36.3115	77.75	3.82	342.2	2.98	43.975	6.179	7.749	28.0385	74.85	544.2	9.22373	13.0437
355.5	2.88	86.31	10.834	8.012	41.7675	77.15	3.7	337.4	2.87	74.825	10.342	7.949	38.677	76.8	3.72	341.8	2.98	49.485	7.109	7.671	31.092	73.4	543.8	9.21695	12.9369
363.8	2.86	91.535	10.952	8.21	38.7355	70.9	3.7	345.3	2.85	80.42	10.174	7.953	36.5165	69.2	3.73	319.6	2.99	54.905	7.359	7.728	28.7765	66.3	521.6	8.84068	12.5707
391.1	2.91	92.845	12.434	7.895	41.951	72.8	3.73	353.2	2.88	83.2	11.385	8.027	39.429	74.1	3.78	347.5	2.97	66.07	9.388	7.674	33.9885	70.8	549.5	9.31356	13.0936
402.8	2.87	98.01	13.26	8.189	42.895	77.7	3.75	350	2.93	89.51	11.86	8.073	41.344	78.85	3.85	344.1	2.95	56.455	7.939	7.408	31.11	71.05	546.1	9.25593	13.1059
408.5	2.87	90.965	12.173	8.328	38.3675	65.4	3.65	355.4	2.81	85.185	11.249	8.192	36.8585	67.4	3.71	344.7	2.84	66.875	9.33	7.839	31.939	65.45	546.7	9.2661	12.9761
405.9	2.9	88.06	11.886	8.403	39.0475	65.85	3.65	356.5	2.75	81.98	11.804	8.346	37.3035	67.75	3.75	334	2.84	65.97	9.993	7.81	33.02	67.75	536	9.08475	12.8347
418	2.9	91.42	10.423	8.329	40.362	65.8	3.61	361.9	2.85	86.045	10.849	8.651	38.845	68.2	3.72	333.8	2.83	71.81	10.181	8.064	34.7645	68.05	535.8	9.08136	12.8014
501.4	2.94	94.305	5.243	8.384	41.5115	65.95	3.48	451.6	2.8	91.185	4.24	8.591	40.967	68.2	3.74	389.7	2.8	77.5	5.584	8.25	36.501	66.8	591.7	10.0288	13.7688
500.2	2.99	93.56	5.316	9.326	37.8675	66.75	3.38	432.5	2.83	85.75	3.641	9.18	36.7715	71.05	3.65	401.5	2.81	74.01	4.07	8.913	33.1365	69.7	603.5	10.2288	13.8788
520.1	2.93	90.78	5.947	9.377	39.7475	80.8	3.31	475.8	2.84	88.97	4.405	9.238	39.1505	84.05	3.72	421.8	2.75	74.095	3.944	8.624	34.837	83.1	623.8	10.5729	14.2929
514.4	2.94	95.71	5.138	8.912	41.918	79.25	3.32	460.9	2.86	90.855	4.332	8.998	41.2115	98.85	3.71	400.3	2.78	78.135	4.218	8.779	37.09	103.35	602.3	10.2085	13.9185
508.3	2.97	101.21	5.378	7.969	38.166	85.35	3.19	467	2.88	95.425	3.835	7.937	36.877	90.2	3.7	396	2.77	81.63	4.167	7.775	32.8295	91.6	598	10.1356	13.8356
526.3	2.96	101.94	5.583	7.91	39.2795	89.2	3.15	517.7	2.91	101.155	3.425	7.839	38.053	91	3.67	438.3	2.74	91.235	2.63	7.597	36.1245	93.05	640.3	10.8525	14.5225
536.2	3	104.265	6.121	7.926	40.4895	84.25	3.13	520	2.9	102.07	3.53	7.894	39.902	86.45	3.65	439.3	2.74	93.33	2.604	7.668	36.9045	88.25	641.3	10.8695	14.5195

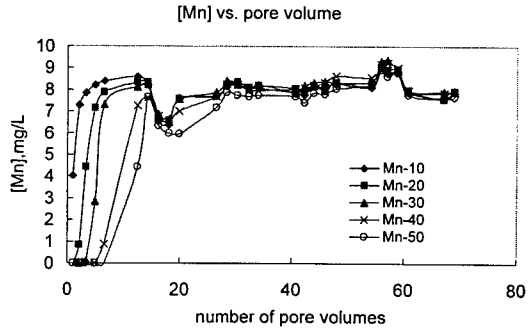

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

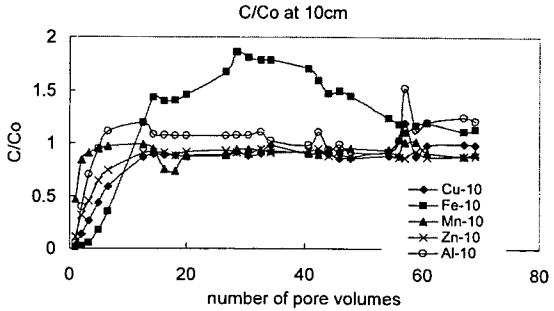

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

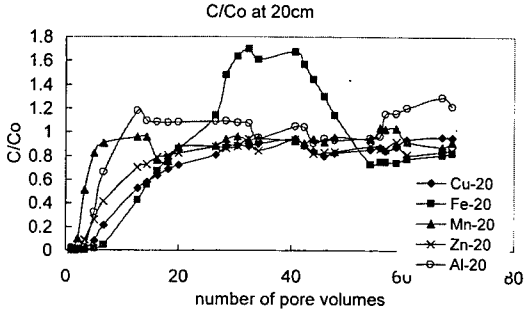

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

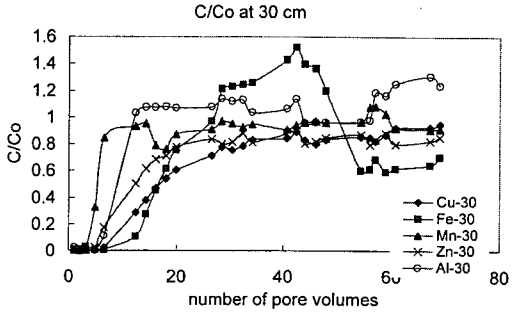

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

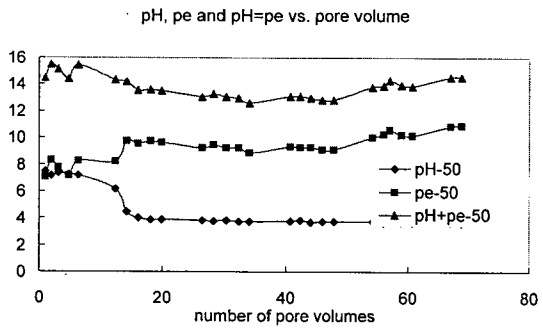

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

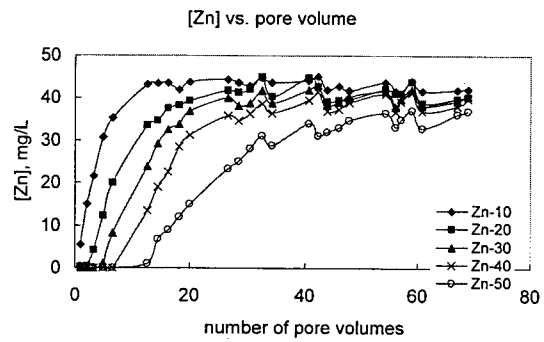

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

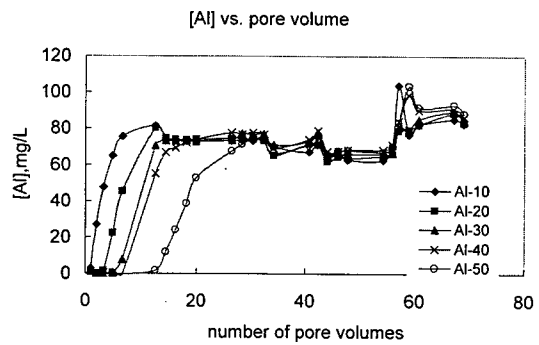

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

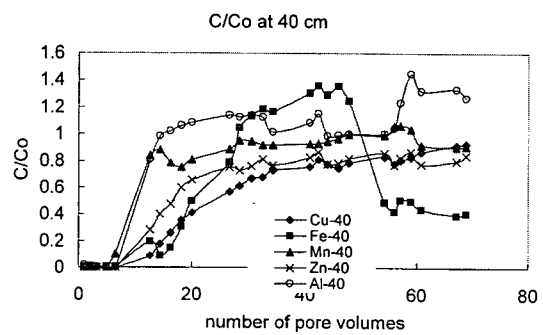

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

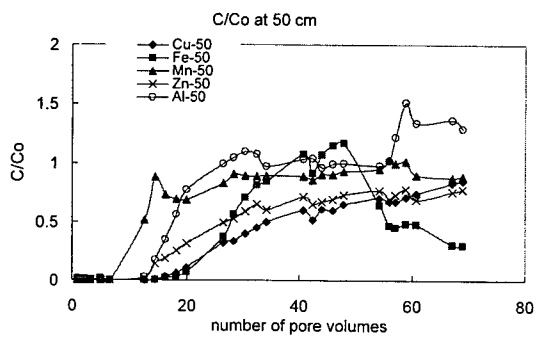

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
20
40
60
80
number of pore volumes
pH-50
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
50
40
30
20
10
0
0
20
40
60
80
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
120
100
80
60
40
20
0
0
20
40
60
80
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
2
1.5
1
0.5
0
0
20
40
60
80
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID PTB12

wt soil before filling column	2266.42 g
wt soil after filling column	1393.73 g
wt soil in column	872.69 g
Date start	Jan 19,2003 04:00
leachate	max conc -filtered (design flowrate 0.5m/day)
pore volume	312.748 ml
flowrate	0.71285 L/day
	0.53214 m/day

initial concentration of metals, Co		
[Cu]o	110.075	mg/L
[Fe]o	8.712	mg/L
[Mn]o	8.669	mg/L
[Zn]o	47.654	mg/L
[Al]o	68.3	mg/L
pH	2.96	
Redox P	575.1	mV
EC	2.99	mS/cm

☑ 1 M NaCl pretreated ☐ No pretreatment

ARD concentration:

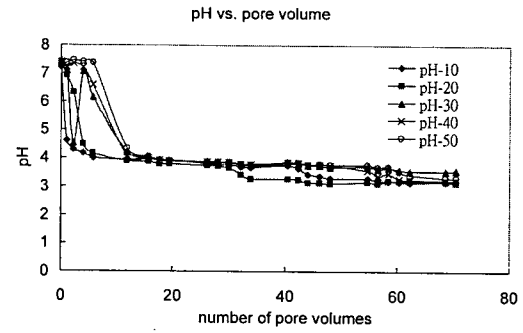
☐ Natural ☑ Maximum design

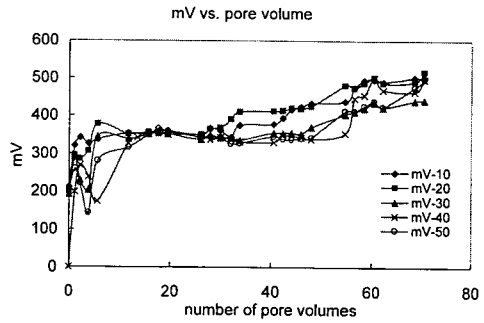
☑ Filtered ☐ Non-filtered

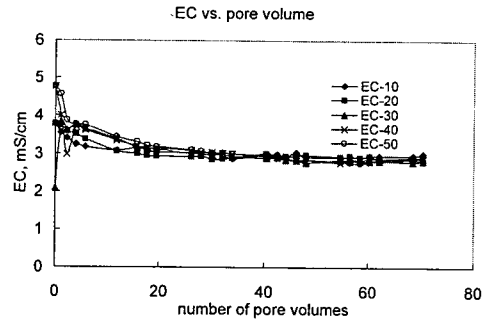
Linear flow rate: 0.5 m/day

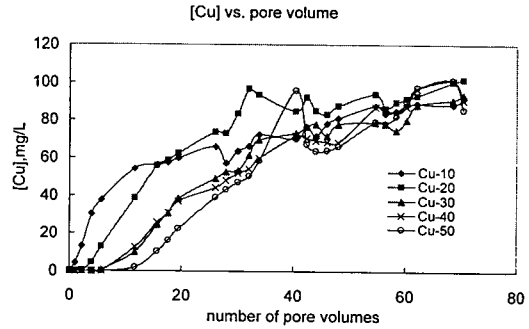
			time used		Flowrate			10cm								20cm								30cm	
ID	Date	Time	vol effl (n	hh:mm:ss	(min)	L/day	pv/day	#pore vo	pH-10	mV-10	EC-10	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	pH-20	mV-20	EC-20	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	pH-30	mV-30
1	Jan 20, 200	10:36a	0	15:45:00	945.00	0	0	0	7.21	211.4	3.78	0.068	0.07	1.185	0.7668	1.33	7.37	203	3.77	-0.014	0.313	-0.178	0.0039	1.65	7.45	192
2	jan 21,2003	9:30a	326.24	16:30:00	990.00	0.47453	1.5173	1.04314	4.61	320.7	3.54	4.242	-0.002	5.36	8.1328	8.09	6.9	294.5	3.75	0.007	0.031	0.06	-0.0029	-0.61	7.1	288.7
3	jan 22, 2003	9:10a	368.55	17:36:31	1056.52	0.50232	1.60616	2.22157	4.28	341.8	3.4	13.335	0.13	6.243	13.6428	25.92	6.32	284.7	3.58	0.344	0.044	2.284	1.7915	0.35	4.52	229
4	jan 23,2003	9:00a	540.23	17:53:56	1073.93	0.72438	2.31617	3.94893	4.18	325	3.24	30.253	0.782	7.245	21.7908	43.69	4.49	305.2	3.52	4.661	0.059	5.12	7.7216	12.01	7.06	203.1
5	jan 24, 2003	9:00a	565.13	18:43:18	1123.30	0.72446	2.31644	5.75592	4	336.7	3.17	37.648	1.561	7.055	23.8094	40.94	4.15	377	3.36	12.838	0.315	5.956	12.392	25.02	6.15	345.1
6	jan 27,2003	9:00a	1887.06	68:48:32	4128.53	0.65819	2.10454	11.7897	3.94	353.2	3.07	54.11	4.11	7.657	29.6055	68.15	3.89	351.7	3.05	38.64	2.582	8.112	27.87	76.1	4.2	338.3
7	Jan 28, 200	8:50a	561.29	18:40:45	1120.75	0.72118	2.30593	13.5844																		
8	Jan 29,2003	8:40a	669.23	18:55:16	1135.27	0.84887	2.71422	15.7243	4	349.5	3.16	56.105	4.707	6.04	29.897	66.57	3.86	357	2.99	55.775	4.619	6.586	34.15	66.87	4.02	351.9
9	Jan 30,2003	9:30a	609.83	19:58:58	1198.97	0.73243	2.34191	17.6742	3.93	359.1	3.09	57.26	5.323	6.002	29.78	67.56	3.78	352	2.95	58.82	5.486	6.522	33.633	67.25	3.9	358.5
10	Jan 31,2003	8:50a	558.33	18:51:21	1131.35	0.71065	2.27228	19.4594	3.91	359	3.03	59.54	5.745	6.536	31.529	66.34	3.78	352	2.93	62.245	6.471	7.288	35.793	69.3	3.88	351.9
11	Feb 3,2003	9:10a	2067.17	67:31:44	4051.73	0.73468	2.34911	26.0691	3.81	348.9	3.02	65.975	7.508	7.265	34.071	65.21	3.73	349.5	2.91	73.585	8.235	7.769	38.744	72.69	3.83	337.4
12	Feb 4,2003	8:10a	584.66	18:22:40	1102.67	0.76352	2.44133	27.9386	3.76	367	2.98	57.23	8.425	7.32	28.82	64.6	3.71	365.1	2.93	73.02	9.712	8.066	35.988	79.25	3.83	347.6
13	Feb 5,2003	9:05a	639.29	20:32:27	1232.45	0.74695	2.38834	29.9827	3.77	361.7	2.98	63.675	9.292	7.777	29.1515	65.4	3.65	368.5	2.85	83.37	10.605	8.279	39.651	77.35	3.82	341.6
14	Feb 6,2003	10:40a	647.47	21:06:20	1266.3333	0.73626	2.35418	32.0529	3.7	343.2	2.96	66.27	9.076	7.438	32.2915	64.8	3.41	390.9	2.86	96.7	12.451	7.816	44.952	78.1	3.76	341.3
15	Feb 7,2003	9:10a	550.71	17:38:40	1058.6667	0.74908	2.39515	33.8138	3.67	373.8	2.86	72.285	8.629	7.362	30.7765	62.05	3.25	410.8	2.88	93.295	13.07	8.281	39.594	70.95	3.74	334.6
16	Feb 10,2003	9:05a	2071.89	67:05:49	4025.82	0.7411	2.36963	40.4386	3.73	377.2	2.98	69.99	8.409	7.251	34.859	72.5	3.26	412.2	2.99	84.71	14.424	8.349	33.357	70.45	3.81	354.5
17	Feb 11,2003	9:10a	594.37	19:52:40	1192.6667	0.71763	2.29459	42.3391	3.63	394.8	2.97	76.68	9.172	7.283	34.952	68.55	3.23	413.6	2.95	92.17	14.248	8.442	42.089	74.55	3.8	352.7
18	Feb 12,2003	7:30a	527.18	17:38:41	1058.6833	0.71706	2.29277	44.0247	3.44	417	2.91	71.7	9.203	7.497	32.177	58.75	3.13	420.3	2.92	85.07	12.875	8.277	36.397	64.05	3.73	355.5
19	Feb 13,2003	9:30a	625.06	20:50:31	1250.5167	0.71977	2.30144	46.0233	3.36	423.6	3.02	78.045	9.915	7.553	35.4245	63.35	3.13	417.8	2.95	82.975	12.304	8.329	38.046	66.25	3.73	352.1
20	Feb 14,2003	9:40a	594.23	19:43:22	1183.3667	0.7231	2.31208	47.9233	3.28	433.7	2.91	81.145	10.246	8.018	36.3805	62.35	3.1	425	2.96	87.7	10.497	8.544	38.826	67.3	3.68	370
21	Feb 17,2003	9:00a	2087.38	67:11:50	4031.83	0.74552	2.38379	54.5977	3.28	437.8	2.9	87.67	6.778	7.737	38.349	64.85	3.14	481.2	2.91	93.635	4.402	8.64	40.964	69.85	3.69	404.5
22	Feb 18,2003	900a	580.14	19:50:26	1190.4333	0.70176	2.24386	56.4526	3.19	474.2	2.93	83.82	5.819	8.296	34.6645	66.95	3.11	473.5	2.92	86.215	3.105	9.043	37.467	70.95	3.6	410.6
23	Feb 19,2003	9:00a	603.78	19:50:30	1190.5	0.73032	2.33516	58.3832	3.2	496.1	2.89	85.09	5.64	8.193	37.6245	79.75	3.2	486.6	2.89	89.605	2.404	8.705	40.836	86.6	3.65	419.6
24	Feb 20,2003	8:45a	601.77	19:17:01	1157.0167	0.74895	2.39474	60.3073	3.16	497.5	2.93	88.16	6.137	8.317	39.3195	94.1	3.2	501.6	2.92	91.45	2.085	8.858	41.016	101.6	3.58	434.4
25	Feb 21,2003	9:00a	588.06	19:49:08	1189.1333	0.71212	2.27698	62.1876	3.15	490.5	2.94	88.735	6.19	7.346	36.2435	88.15	3.19	488	2.86	93.215	2.228	7.968	34.378	93.1	3.54	421.7
26	Feb 24,2003	9:20a	1998.91	67:32:27	4052.45	0.71029	2.27114	68.5791	3.18	502.7	2.94	88.26	5.323	7.482	34.768	81.7	3.18	490.8	2.9	100.24	2.319	7.732	40.194	89.7	3.55	440.3
27	Feb 25,2003	9:10a	594.94	19:19:11	1159.1833	0.73907	2.36314	70.4814	3.19	501.6	2.99	91.79	6.159	7.474	35.981	84.2	3.13	515.9	2.9	101.44	2.835	7.691	39.997	86.4	3.57	442.2

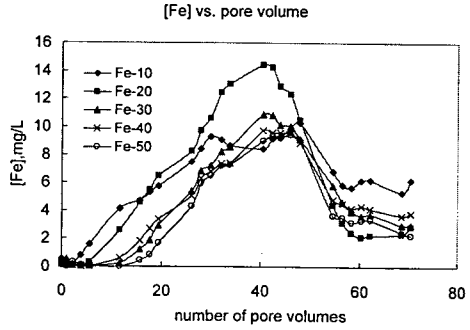
						40cm								50cm											
EC-30	Cu-30	Fe-30	Mn-30	Zn-30	Al-30	pH-40	mV-40	EC-40	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-50	mV-50	EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	Eh-50	pe-50	pH+pe-5
2.07	0.002	0.574	-0.122	-0.0017	1.44	7.42	197.1	4.77	-0.001	0.13	0.076	0.0156	1.63	7.31	198.6	4.77	0.212	0.476	2.426	0.494	1.65	400.6	6.7898	14.1
3.84	-0.007	0.506	-0.049	0.0003	0.25	7.21	268	4.01	-0.005	0.092	-0.033	0.0003	-0.48	7.37	258	4.56	-0.024	0.247	-0.08	0.0266	-0.58	460	7.7966	15.167
3.61	0.003	0.157	-0.042	-0.0056	-0.22	7.34	237.2	2.97	-0.005	0.07	-0.038	-0.0144	-0.53	7.46	219.9	3.88	0.004	0.291	-0.026	-0.0154	-0.27	421.9	7.1508	14.611
3.76	-0.016	0.022	0.444	0.1689	0.23	7.21	174	3.7	-0.034	0.002	0.122	-0.0302	0.36	7.41	143	3.76	-0.037	0.071	-0.118	-0.0243	0.38	345	5.8475	13.257
3.65	0.536	0.048	1.429	1.6034	0.59	6.59	327.3	3.62	0.097	-0.01	3.645	1.5941	0.1	7.36	279.9	3.75	0.023	0.063	-0.087	-0.0181	-0.01	481.9	8.1678	15.528
3.39	10.185	0.213	7.404	12.754	28.18	4.06	341.9	3.34	12.675	0.6	6.377	12.681	41.3	4.32	315.3	3.44	2.015	0.01	6.098	6.3349	19.88	517.3	8.7678	13.088
																						202		
3.14	24.45	1.221	5.916	19.146	46.64	3.97	358.3	3.18	25.714	1.862	5.861	18.437	45.83	4.04	349.5	3.31	10.244	0.45	6.073	12.478	33.47	551.5	9.3475	13.387
3.13	30.645	1.882	5.942	21.177	51.69	3.92	349.2	3.14	30.961	2.707	5.575	19.712	49.72	3.92	365	3.21	16.225	0.828	5.957	15.776	47.65	567	9.6102	13.53
3.11	38.216	2.935	6.4	23.869	58.4	3.9	347.5	3.14	37.101	3.364	5.95	22.342	56.86	3.89	358.4	3.17	22.323	1.663	5.837	17.883	54.78	560.4	9.4983	13.388
3	48.985	5.413	7.208	29.948	63.71	3.87	337.5	3.08	44	5.02	6.734	27.584	59.76	3.87	342.1	3.09	39.04	4.301	6.98	23.425	63.7	544.1	9.222	13.092
2.99	52.625	6.819	7.406	28.398	67.9	3.87	342.1	3.02	48.075	6.323	7.262	25.86	62.3	3.85	343.1	3.05	43.03	5.914	7.215	24.777	67.2	545.1	9.239	13.089
2.96	53.235	7.244	7.669	29.354	71.05	3.85	336.7	3.03	51.74	6.781	7.445	27.51	65.2	3.85	341.6	3.01	46.87	6.478	7.41	27.851	65.55	543.6	9.2136	13.064
3	61.245	8.187	7.175	34.213	70.35	3.79	329.9	3.01	54.045	7.355	7.214	31.377	64	3.79	326	3.01	50.4	7.188	7.242	30.739	67.95	528	8.9492	12.739
2.93	69.54	8.543	7.611	32.353	68.4	3.79	330.8	2.99	59.735	7.384	7.627	28.667	62.35	3.77	327.5	2.99	58.445	7.278	7.446	28.897	63.8	529.5	8.9746	12.745
2.88	73.078	10.885	7.704	36.453	72.54	3.83	347.5	2.93	71.635	9.716	7.618	30.338	61.25	3.84	344.8	2.95	95.55	8.971	7.528	42.6	74.65	546.8	9.2678	13.108
2.9	76.615	10.823	7.807	38.362	79.15	3.83	347.1	2.9	70.425	9.548	7.66	35.638	77.65	3.83	338.4	2.92	67.25	9.348	7.565	34.297	73.65	540.4	9.1593	12.989
2.83	77.69	10.115	8.09	34.457	68	3.75	341.3	2.85	68.955	9.565	8.005	31.982	67.65	3.77	336.9	2.87	63.65	9.218	7.785	30.437	64.95	538.9	9.1339	12.904
2.83	71.68	10.027	8.261	35.489	67.85	3.76	338	2.82	68.31	9.517	7.786	33.945	71.75	3.78	340.4	2.82	63.895	9.404	7.788	32.248	67.25	542.4	9.1932	12.973
2.76	77.81	9.126	8.271	36.842	70.85	3.74	352.6	2.83	68.095	8.839	8.016	33.687	70.35	3.76	340.9	2.84	66.245	9.014	7.823	33.934	69.5	542.9	9.2017	12.962
2.83	78.825	5.807	8.469	34.86	71.75	3.56	447	2.76	86.875	4.79	8.358	39.677	72.75	3.75	412.1	2.78	79.09	3.66	7.919	36.873	71.5	614.1	10.408	14.158
2.82	78.255	4.598	8.886	32.424	77.5	3.36	454	2.86	85.845	4.521	9.11	35.328	79.8	3.67	411.4	2.76	78.015	3.485	8.92	34.19	81.35	613.4	10.397	14.067
2.79	74.65	3.96	8.216	34.795	86.15	3.46	500.4	2.83	83.685	4.168	8.89	39.109	89.15	3.7	425.6	2.74	82.01	3.167	8.837	39.116	93.75	627.6	10.637	14.337
2.8	80.075	3.642	8.718	36.647	104.2	3.26	468.4	2.87	87.3	4.276	8.939	40.317	108.25	3.51	438.7	2.79	89.61	3.304	9.126	39.762	110.3	640.7	10.859	14.369
2.81	88.135	3.74	7.8	32.29	97.45	3.24	463.5	2.86	96.62	4.125	8.012	35.432	98.8	3.41	423.4	2.79	97.17	3.332	7.721	35.43	98	625.4	10.6	14.01
2.78	90.955	2.963	7.624	35.536	89.65	3.22	497.6	2.88	100.9	3.632	7.79	38.867	90.4	3.31	476.1	2.84	101.33	2.414	7.816	38.693	90.5	678.1	11.493	14.803
2.82	93.39	2.972	7.607	36.024	90.05	3.21	507.1	2.87	90.92	3.796	7.787	38.766	88.85	3.31	497.6	2.82	85.545	2.245	7.75	37.904	88.95	699.6	11.858	15.168

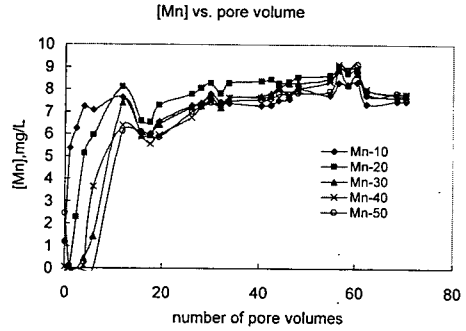

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

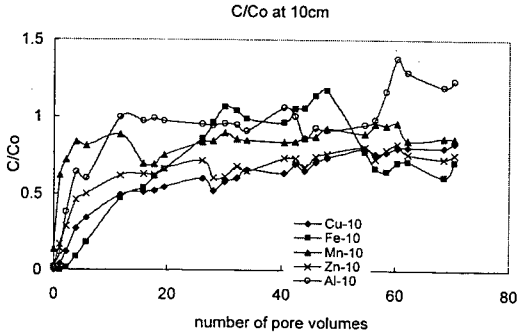

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

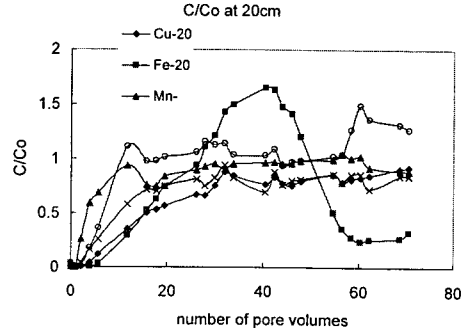

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

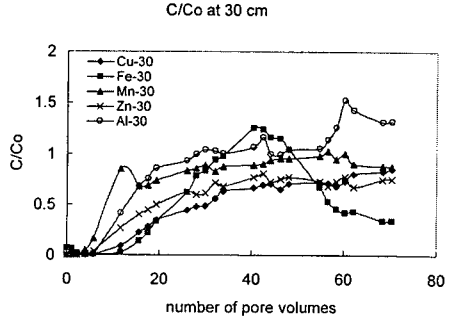

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50


[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

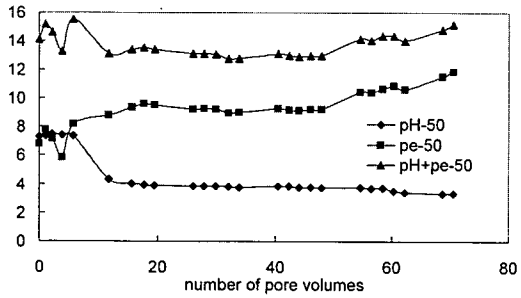

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50


C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

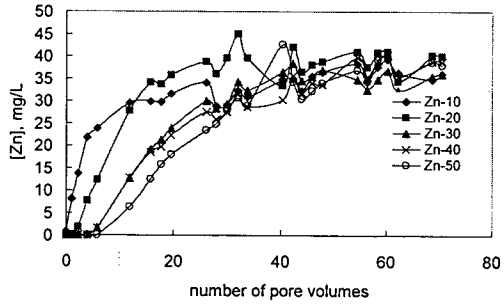

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-


C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30

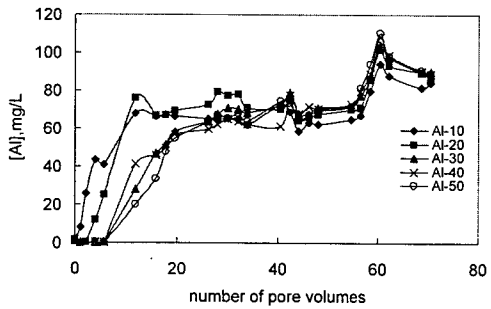
pH, pe and pH=pe vs. pore volume



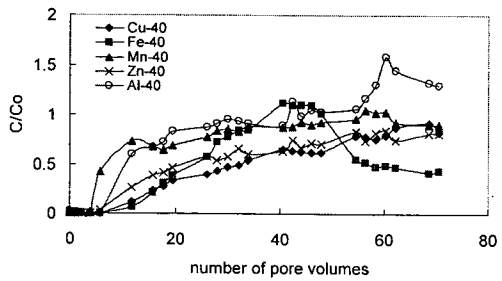
[Zn] vs. pore volume



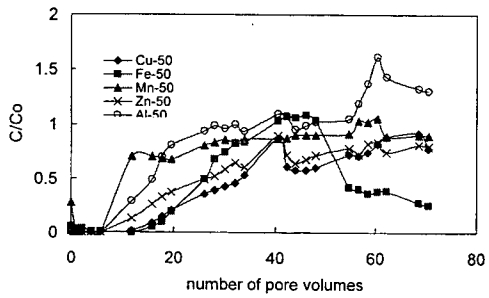
[Al] vs. pore volume



C/Co at 40 cm



C/Co at 50 cm



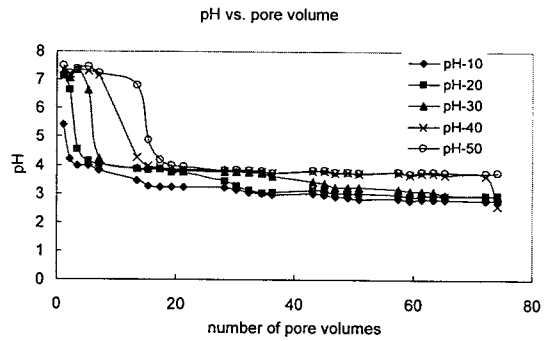
Cell ID PTB13

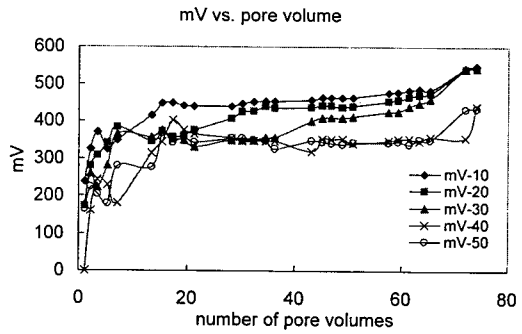
wt soil before filling column	1393.73 g	initial concentration of metals, Cc	
wt soil after filling column	510.71 g	[Cu]o	109.87 mg/L
wt soil in column	883.02 g	[Fe]o	49.46 mg/L
Date start	Jan 19,2003 04:0(	[Mn]o	8.763 mg/L
leachate	max conc -non-filtered (design flowrate 0.5m/da	[Zn]o	44.4735 mg/L
pore volume	307.728 ml	[Al]o	68.8 mg/L
flowrate	0.71845 L/day	pH	2.93
	0.53632 m/day	redox po	589.1 mV
		EC	3.06 mS/cm

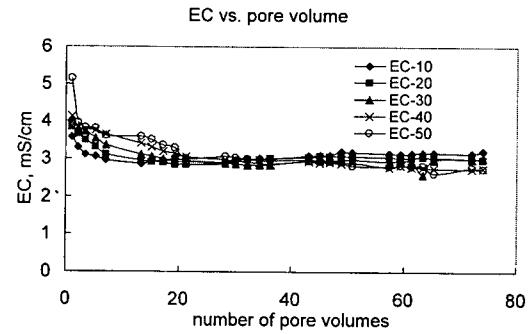
☑ 1 M NaCl pretreated ☐ No pretreatment
ARD concentration:
☐ Natural ☑ Maximum design
☐ Filtered ☑ Non-filtered
Linear flow rate: 0.5 m/day

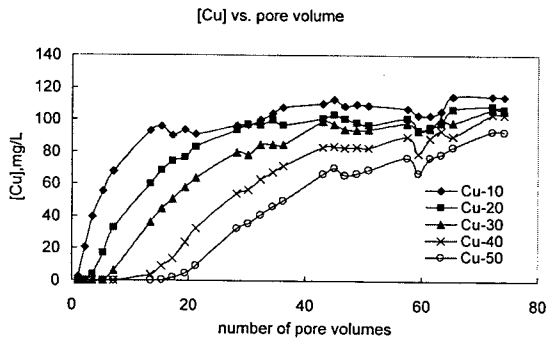
ID	Date	Time	vol effl (n	time used hh:mm:s	(min)	Flowrate L/day	pv/day	#pore vo	10cm pH-10	mV-10	EC-10	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	20cm pH-20	mV-20	mmhos EC-20	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	30cm pH-30
1	Jan 20, 2	10:36a	342.95	15:45:00	945.00	0.52259	1.69822	1.11446	5.42	238.5	3.58	2.33	0.059	4.462	6.2971	2.48	7.14	172	3.84	-0.101	0.118	-0.226	0.0037	1.84	7.28
2	jan 21,2(	9:30a	338.53	16:30:00	990.00	0.49241	1.60014	2.21455	4.2	324.7	3.32	20.372	0.238	7.606	18.6151	38.7	6.64	279.9	3.66	0.026	-0.034	1.874	0.8696	-0.29	7.06
3	jan 22, 2	9:10a	383.85	17:36:31	1056.52	0.52318	1.70012	3.46192	3.99	370.2	3.11	39.705	0.726	7.864	5.7301	55.88	4.56	307.4	3.49	3.693	0.076	6.482	8.7509	7.92	7.37
4	jan 23,2(	9:00a	555.2	17:53:56	1073.93	0.74445	2.41917	5.26611	3.99	324.2	3.06	55.65	2.194	7.849	32.2575	69.9	4.15	341.3	3.31	17.077	0.224	7.188	17.2864	44.68	6.64
5	jan 24, 2	9:00a	566.02	18:43:18	1123.30	0.7256	2.35793	7.10546	3.82	349.5	2.96	67.665	3.63	8.802	36.7935	78.85	4.03	383.1	3.12	32.717	0.691	7.633	24.1007	46.81	4.22
6	jan 27,2(	9:00a	1937.97	68:48:32	4128.53	0.67595	2.19658	13.4031	3.47	414.4	2.87	93.365	8.596	8.87	43.05	77	3.85	345.6	2.95	60.08	4.111	8.424	33.939	74.8	3.9
7	Jan 28, 2	8:50a	589.7	18:40:45	1120.75	0.75768	2.46217	15.3194	3.28	447.4	2.93	95.955	10.373	8.9	43.7225	78.95	3.84	371.3	2.91	68.405	5.051	8.245	36.1515	77.6	3.88
8	Jan 29,2	8:40a	594.89	18:55:16	1135.27	0.75457	2.45208	17.2526	3.22	448	2.93	89.985	10.485	8.695	42.916	77.65	3.85	356.4	2.9	74.325	6.153	8.112	39.0435	74.68	3.87
9	Jan 30,2	9:30a	633.01	19:58:58	1198.97	0.76027	2.47058	19.3096	3.24	441.9	3	93.755	10.936	8.537	42.723	78.3	3.76	360.7	2.85	76.405	7.297	8.264	38.644	76.87	3.82
10	Jan 31,2	8:50a	599.89	18:51:21	1131.35	0.76355	2.48125	21.259	3.24	439.1	2.95	91.065	11.278	8.739	43.1535	78.96	3.74	374.4	2.85	82.96	8.237	8.206	41.1875	78.24	3.8
11	Feb 3,20	9:10a	2148.76	67:31:44	4051.73	0.76368	2.48166	28.2417	3.23	438.9	2.9	96.37	12.108	8.787	44.278	78.23	3.44	406.2	2.87	93.615	10.857	8.574	43.9395	77.67	3.78
12	Feb 4,20	8:10a	596.21	18:22:40	1102.67	0.77861	2.53017	30.1792	3.14	446.7	2.97	96.63	14.469	8.824	41.184	77.35	3.28	424.4	2.97	97.13	13.842	8.739	40.2255	83.85	3.78
13	Feb 5,20	9:05a	655.97	20:32:27	1232.45	0.76644	2.49063	32.3108	3.05	451.4	2.98	99.68	15.707	9.062	43.3745	78.05	3.13	427	2.99	96.78	14.858	8.929	43.1745	74.35	3.75
14	Feb 6,20	10:40a	662.53	21:06:20	1266.333	0.75339	2.44823	34.4638	3.01	452.9	3.01	104.005	16.706	9.255	47.8965	71.7	3.04	438.9	2.99	99.515	15.286	9.123	46.253	71.05	3.72
15	Feb 7,20	9:10a	558.35	17:38:40	1058.667	0.75947	2.46798	36.2782	2.96	452.6	3	107.555	15.779	8.785	42.875	72.75	3.05	435	3.02	96.58	14.295	8.996	39.571	70.15	3.61
16	Feb 10,2	9:05a	2105.32	67:05:49	4025.82	0.75305	2.44714	43.1197	3.01	456.8	3.08	110	17.531	8.93	47.7	75.55	3.13	436.5	3.04	100.66	14.753	8.836	43.281	71.25	3.42
17	Feb 11,2	9:10a	606.32	19:52:40	1192.667	0.73206	2.37891	45.09	2.97	463.6	3.1	112.78	18.128	8.641	47.926	74.45	3.09	441	3.08	103.07	15.212	8.649	45.009	71.2	3.35
18	Feb 12,2	7:30a	537.11	17:38:41	1058.683	0.73057	2.37406	46.8354	2.9	462.1	3.1	108.48	17.154	8.773	42.8695	66.5	3.01	441.8	3.06	100.32	14.324	8.629	39.6395	66.1	3.24
19	Feb 13,2	9:30a	637.64	20:50:31	1250.517	0.73426	2.38606	48.9075	2.89	463.4	3.19	109.525	17.895	8.494	46.7215	70.05	3.02	436.6	3.09	97.995	15.207	8.763	42.546	69.8	3.24
20	Feb 14,2	9:40a	602.73	19:43:22	1183.367	0.73344	2.38341	50.8661	2.82	463.3	3.18	108.96	18.676	9.036	46.987	67.85	3.01	440.3	3.07	96.62	14.932	8.799	43.3155	67.85	3.23
21	Feb 17,2	9:00a	2019.51	67:11:50	4031.83	0.72128	2.3439	57.4288	2.84	475.4	3.15	106.815	17.026	8.194	45.5035	63.65	2.98	453.7	3.05	100.725	15.846	8.75	43.0405	64.95	3.17
22	Feb 18,2	900a	594.31	19:50:26	1190.433	0.7189	2.33616	59.3601	2.78	478.3	3.14	102.635	15.901	9.388	40.84	76.7	2.91	456.8	3.04	93.62	14.136	9.506	38.5975	77.5	3.11
23	Feb 19,2	9:00a	618.84	19:50:30	1190.5	0.74853	2.43245	61.3711	2.82	482.8	3.15	102.605	15.583	8.91	45.1735	89.05	2.93	465.1	3.04	95.6	13.808	9.469	42.7775	86.6	3.1
24	Feb 20,2	8:45a	614.14	19:17:01	1157.017	0.76435	2.48384	63.3668	2.81	486	3.17	105.2	15.586	9.444	46.3875	102.5	2.94	470.1	3.05	97.92	12.441	9.696	44.05	105.8	3.07
25	Feb 21,2	9:00a	600.37	19:49:08	1189.133	0.72703	2.36256	65.3178	2.79	482.7	3.17	114.365	14.205	8.033	40.972	92.15	2.93	474.8	3.03	106.54	9.719	8.124	38.095	95	2.98
26	Feb 24,2	9:20a	2067.48	67:32:27	4052.45	0.73466	2.38736	72.0363	2.78	541.5	3.15	114.335	14.213	7.967	43.02	80.15	2.95	538.7	3.02	108.355	8.214	7.872	41.661	85.3	2.93
27	Feb 25,2	9:10a	610.3	19:19:11	1159.183	0.75815	2.46369	74.0195	2.79	549.4	3.22	114.15	14.196	7.848	44.6005	83.3	2.95	542.6	2.98	106.465	8.27	7.978	42.124	85.4	2.94

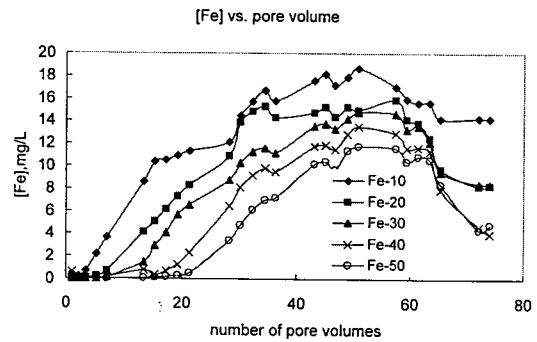
mV-30	mmhos EC-30	Cu-30	Fe-30	Mn-30	Zn-30	Al-30	40cm pH-40	mV-40	mmhos EC-40	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	50cm pH-50	mV-50	mmhos EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	Eh-50	pe-50	pH+pe-5(
176.5	4.05	-0.106	0.048	-0.155	0.0072	1	7.36	160.7	4.13	-0.071	0.576	-0.207	-0.0156	1.28	7.5	163	5.15	-0.107	0.245	-0.179	0.0398	0.93	365	6.18644	13.6864
259.2	3.81	-0.022	0.05	-0.012	-0.0098	-0.59	7.2	243.6	3.82	-0.017	0.043	-0.074	0.0108	-0.58	7.22	223.5	3.95	-0.004	0.107	-0.05	0.0651	-0.54	425.5	7.21186	14.4319
222.6	3.73	-0.005	0.059	0.066	0.0165	-0.72	7.34	227.5	3.77	-0.018	0.031	-0.045	0.0122	-0.66	7.4	203.6	3.82	0.011	0.054	-0.007	0.0464	-0.44	405.6	6.87458	14.2746
281.5	3.54	0.051	0	4.991	2.6294	0.5	7.31	180.7	3.76	-0.014	-0.011	-0.173	-0.0514	0.23	7.45	178.5	3.8	-0.037	0.059	-0.143	0.0187	0.24	380.5	6.44915	13.8992
364.8	3.37	6.256	0.177	7.537	12.6046	24.67	7.16	314.4	3.65	0.039	0.179	0.273	-0.0298	0.16	7.24	279.9	3.61	0.038	-0.016	-0.107	0.0188	-0.03	481.9	8.1678	15.4078
356.8	3.11	36.317	1.447	7.908	24.4212	62.9	4.27	343.3	3.42	3.772	0.746	7.206	7.9776	28.14	6.81	276.3	3.59	-0.037	0.029	3.428	0.1146	-1.92	478.3	8.10678	14.9168
374.9	3.06	44.54	2.927	7.965	29.4465	70.3	3.97	401.4	3.31	9.034	0.336	7.322	13.4176	51.15	4.88	367.7	3.51	0.202	0.094	7.453	4.9679	4.11	569.7	9.65593	14.5359
352	3	50.69	4.063	7.81	31.9665	73.57	3.92	375.5	3.2	13.69	0.659	6.927	16.0492	63.14	4.18	342.9	3.36	1.735	0.158	6.614	7.8522	14.59	544.9	9.23559	13.4156
349.4	2.94	57.85	5.655	8.274	33.588	75.92	3.86	364.7	3.15	23.476	1.238	7.428	20.8086	69.87	3.98	355.8	3.29	4.69	0.279	6.556	10.6959	28.54	557.8	9.45424	13.4342
330.6	2.91	63.465	6.509	8.099	36.276	77.69	3.85	354.5	3.05	32.254	2.301	7.8	24.4189	75.96	3.94	342.5	3.02	9.194	0.48	6.714	13.7311	47.86	544.5	9.22881	13.1688
348.9	2.88	79.56	8.761	8.477	40.5725	78.87	3.8	344.9	2.99	53.92	6.397	8.216	34.9815	77.47	3.82	353.6	3.06	32.342	3.343	7.741	22.9484	68.97	555.6	9.41695	13.2369
349.3	2.86	78.095	10.278	8.741	35.771	84.5	3.8	346.4	2.95	56.445	8.084	8.645	31.584	83.9	3.83	353	3.03	35.45	4.711	8.059	23.6145	78.75	555	9.40678	13.2368
349	2.83	84.475	11.233	8.848	39.504	79.1	3.8	345.5	2.92	62.59	9.129	8.736	34.1345	77.85	3.82	349.4	3	40.68	6.073	8.227	27.078	76.25	551.4	9.34576	13.1658
354.8	2.84	84.335	11.587	8.606	42.885	75.95	3.78	347	2.89	67.185	9.781	8.697	37.987	77.75	3.8	347.8	2.97	46.105	6.974	8.119	31.26	74.4	549.8	9.31864	13.1186
355.3	2.83	84.46	11.149	8.811	35.866	74.1	3.72	318.4	2.87	71	9.459	8.511	33.94	77.75	3.73	326.4	2.95	49.415	7.198	7.846	28.337	73.85	528.4	8.95593	12.6859
400.4	2.96	98.855	13.525	8.748	43.3715	78	3.8	351.9	2.93	82.985	11.715	8.914	39.0135	80.15	3.82	347.6	2.98	66.235	10.141	8.728	34.9495	78	549.6	9.31525	13.1353
408.5	2.97	96.84	13.735	8.466	42.3775	72.05	3.79	349.6	2.9	83.36	11.831	8.679	40.363	77.6	3.81	343.6	2.94	70.175	10.361	8.422	35.479	75.5	545.6	9.24746	13.0575
409.9	2.96	93.92	13.326	8.757	38.5735	68.3	3.72	351.7	2.91	82.715	11.488	8.838	35.5115	71.4	3.74	339.8	2.93	65.42	9.669	8.38	31.4235	71.3	541.8	9.18305	12.9231
407.5	2.96	93.7	14.21	8.626	41.16	72.45	3.74	339.7	2.88	82.945	12.846	8.753	39.33	75.6	3.76	336.6	2.91	66.675	11.366	8.703	34.371	73.25	538.6	9.12881	12.8888
411.7	2.98	94.005	14.777	9.064	42.141	69.5	3.7	347.9	2.9	82.38	13.463	9.369	39.7815	73.45	3.73	342.2	2.82	68.955	11.74	8.92	35.8535	73.35	544.2	9.22373	12.9537
425.1	2.93	97.655	14.646	8.894	42.2845	66.5	3.74	351.3	2.78	89.435	12.876	8.81	39.637	69.85	3.77	342.6	2.81	76.575	11.588	8.619	36.673	69.65	544.6	9.23051	13.0005
425.6	2.96	93.02	13.255	9.383	36.6805	83.15	3.67	351.3	2.83	79.1	11.56	9.524	33.8255	87.35	3.71	345.7	2.84	66.92	10.401	9.041	32.675	84.2	547.7	9.28305	12.9931
440.4	2.93	94.87	13.551	9.458	42.0225	88.65	3.72	347.8	2.78	88.82	11.642	9.291	40.424	95.85	3.78	337.8	2.81	76.34	10.824	8.962	36.694	92.15	539.8	9.14915	12.9292
447.3	2.58	100.28	12.129	9.546	43.0585	112.3	3.73	357.4	2.78	93.09	11.305	9.678	41.6375	120.9	3.77	350	2.82	78.48	10.553	9.251	37.6555	121.8	552	9.35593	13.1259
458.7	2.99	98.255	9.476	8.25	36.555	98	3.67	354.6	2.75	89.845	7.888	8.116	34.139	104.2	3.74	349.4	2.62	82.995	8.353	8.05	32.169	105.45	551.4	9.34576	13.0858
540.2	3	106.56	8.399	7.999	40.6885	83.5	3.65	439.6	2.74	103.58	4.611	8.085	39.3725	93.65	3.72	430.7	2.77	92.9	4.366	7.885	36.3735	92.95	632.7	10.7237	14.4437
542.4	3.03	105.77	8.356	8.218	41.564	85.55	2.58	443.4	2.75	102.975	3.989	8.118	40.94	94.25	3.76	432.5	2.74	92.29	4.777	8.008	38.0725	94.9	634.5	10.7542	14.5142

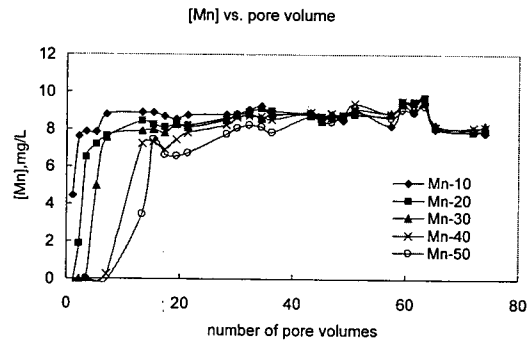

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30
pH-40
pH-50

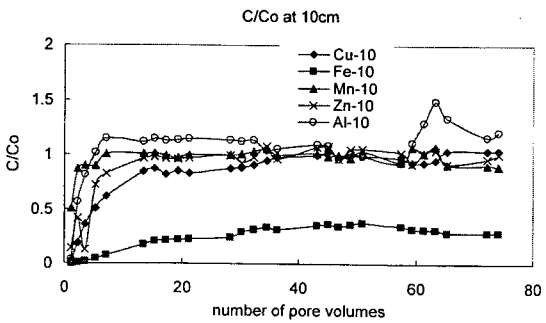

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

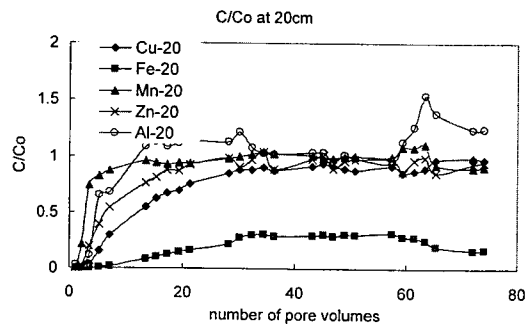

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

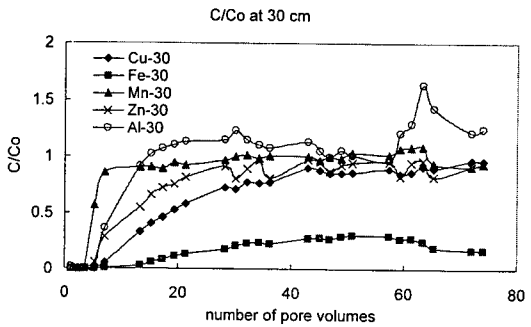

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

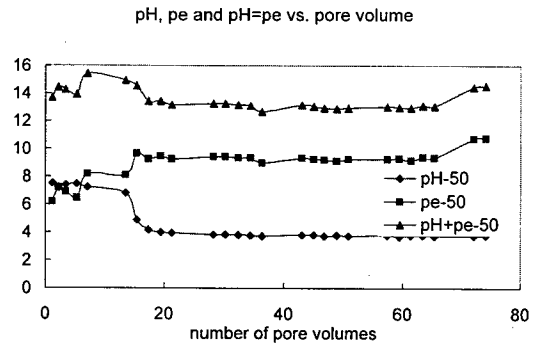

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

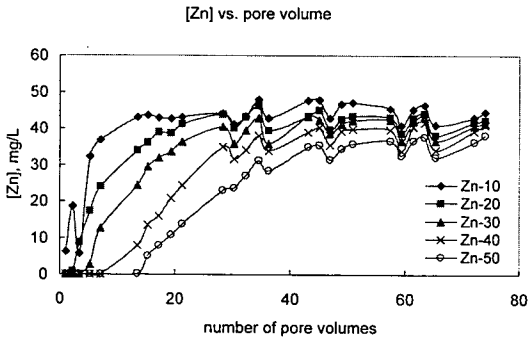

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

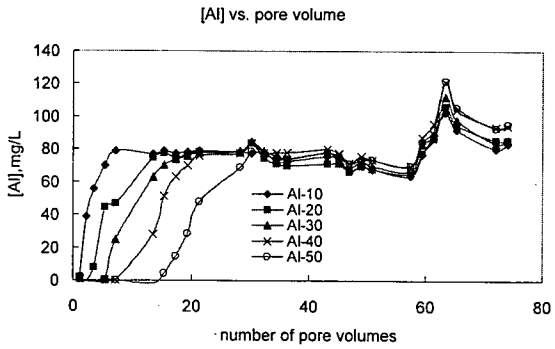

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

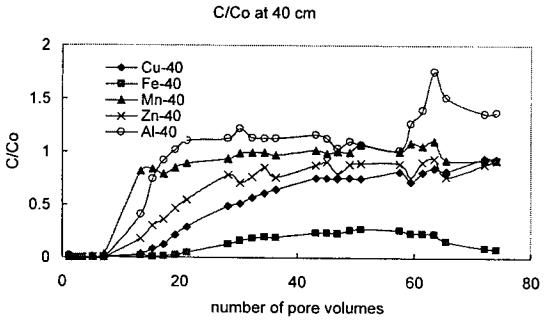

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

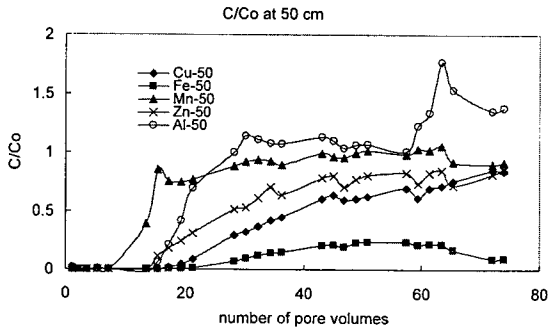

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
20
40
60
80
number of pore volumes
pH-50
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
60
50
40
30
20
10
0
0
20
40
60
80
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
140
120
100
80
60
40
20
0
0
20
40
60
80
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
2
1.5
1
0.5
0
0
20
40
60
80
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
2
1.5
1
0.5
0
0
20
40
60
80
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID PTB14

wt soil before filling column	2016.95 g
wt soil after filling column	1135.45 g
wt soil in column	881.5 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	308.467 ml
flowrate	0.72911 L/day
	0.54427 m/day

initial concentration of metals, Co	
[Cu]o	109.87 mg/L
[Fe]o	49.46 mg/L
[Mn]o	8.763 mg/L
[Zn]o	44.4735 mg/L
[Al]o	68.8 mg/L
pH	2.93
Redox p(	589.1 mV
EC	3.06 mS/cm

☑ 1 M NaCl pretreated ☐ No pretreatment

ARD concentration:

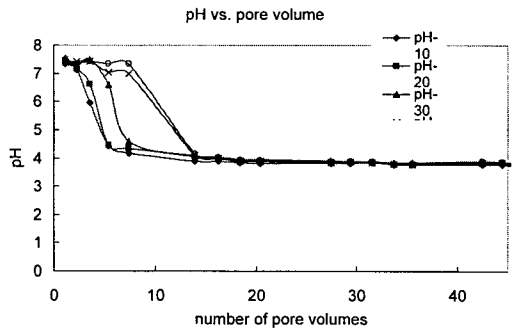
☐ Natural ☑ Maximum design

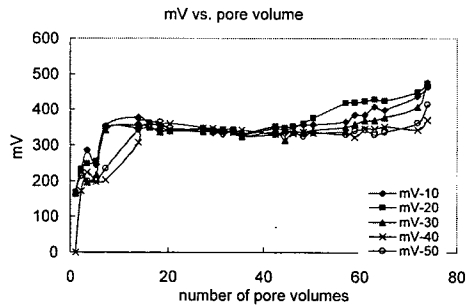
☐ Filtered ☑ Non-filtered

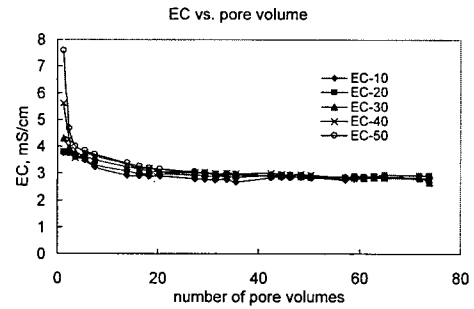
Linear flow rate: 0.5 m/day

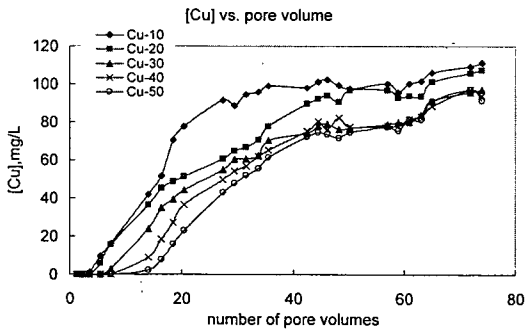
ID	Date	Time	vol effl (n	time used hh:mm:ss	(min)	Flowrate L/day	pv/day	#pore vo	10cm pH-10	mV-10	mmhos EC-10	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	20cm pH-20	mV-20	mmhos EC-20	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	30cm pH-30	mV-30
1	Jan 20, 2003	10:36a	360.81	15:45:00	945.00	0.54981	1.78238	1.16969	7.34	163.7	3.77	-0.011	0.239	-0.287	0.0054	0.89	7.47	164.6	3.8	0.018	0.184	-0.264	-0.0054	1.22	7.54	165.4
2	jan 21,2003	9:30a	347.64	16:30:00	990.00	0.50566	1.63926	2.29668	7.12	231.1	3.76	0.026	0.111	0.391	0.3024	-0.68	7.17	232.5	3.75	-0.027	0.084	0.044	-0.0051	-0.43	7.29	228.6
3	jan 22, 2003	9:10a	382.98	17:36:31	1056.52	0.52199	1.69221	3.53824	5.96	286.1	3.63	1.281	0.037	2.075	3.3094	0.67	6.62	248.6	3.64	0.139	0.034	2.095	1.7782	-0.31	7.5	196.6
4	jan 23,2003	9:00a	573.12	17:53:56	1073.93	0.76848	2.49128	5.3962	4.43	244.2	3.5	9.79	0.032	4.583	10.8373	14.28	4.46	254.5	3.53	5.894	0.045	4.732	9.4292	18.38	6.6	217.5
5	jan 24, 2003	9:00a	599.34	18:43:18	1123.30	0.76832	2.49076	7.33917	4.16	354.6	3.23	16.193	0.193	5.899	14.2862	20.86	4.33	350.4	3.3	15.363	0.158	6.284	15.038	31.03	4.57	340.9
6	jan 27,2003	9:00a	2034.41	68:48:32	4128.53	0.70959	2.30036	13.9344	3.87	377.2	2.92	42.06	1.618	8.399	32.977	83.65	4.03	347.6	3.08	36.373	1.799	7.626	24.511	56.7	4.07	355.2
7	Jan 28, 2003	8:50a	19.56	0:38:45	38.75	0.72687	2.35641	13.9978																		
8	Jan 29,2003	8:40a	706.21	22:55:16	1375.27	0.73945	2.39718	16.2872	3.89	358.3	2.91	51.715	3.004	8.216	35.5945	84.62	3.97	348	2.99	45.285	3.323	7.401	28.882	65.32	4.03	350.4
9	Jan 30,2003	9:30a	652.48	19:58:58	1198.97	0.78365	2.54047	18.4025	3.84	356.3	2.88	70.585	5.695	8.219	41.286	85.36	3.9	339.5	2.99	48.6	4.141	7.504	30.729	67.8	3.95	335.8
10	Jan 31,2003	8:50a	616.03	18:51:21	1131.35	0.78409	2.5419	20.3995	3.82	340.1	2.88	77.635	7.514	8.542	43.5675	86.2	3.87	340.5	2.97	51.235	4.989	7.752	32.14	72.85	3.94	340.5
11	Feb 3,2003	9:10a	2173.36	67:31:44	4051.73	0.77242	2.50406	27.4452	3.81	346.1	2.79	91.515	9.453	8.781	45.163	87.6	3.85	342.5	2.94	60.615	6.302	8.006	35.117	77.6	3.9	338.1
12	Feb 4,2003	8:10a	605.72	18:22:40	1102.67	0.79102	2.56438	29.4089	3.82	335.4	2.78	88.69	11.364	9	40.8185	88.7	3.86	339.3	2.89	64.785	7.963	8.21	33.356	82.1	3.89	339.4
13	Feb 5,2003	9:05a	659.74	20:32:27	1232.45	0.77084	2.49895	31.5476	3.83	338.9	2.76	94.535	11.744	9.17	45.5315	81.3	3.85	342.8	2.88	66.735	8.215	8.296	37.342	77.2	3.89	340.3
14	Feb 6,2003	10:40a	666.37	21:06:20	1266.3333	0.75776	2.45653	33.7079	3.77	339.2	2.77	95.935	12.548	9.539	47.0605	79.9	3.78	343.3	2.87	70.575	8.785	8.42	39.574	76.05	3.83	338.1
15	Feb 7,2003	9:10a	560.78	17:38:40	1058.6667	0.76277	2.47279	35.5259	3.76	328.2	2.69	98.91	12.794	9.353	40.46	85.15	3.78	330.7	2.87	77.655	8.414	8.567	34.894	77.15	3.83	324.2
16	Feb 10,2003	9:05a	2143.23	67:05:49	4025.82	0.76661	2.48524	42.4739	3.77	347.5	2.84	97.975	16.034	9.534	44.7265	79.2	3.82	351.9	2.88	89.82	11.377	8.711	43.342	82.35	3.88	337.2
17	Feb 11,2003	9:10a	611.54	19:52:40	1192.6667	0.73836	2.39365	44.4564	3.78	340.1	2.86	101.13	16.063	9.374	45.666	79.05	3.81	348.4	2.87	92.185	11.981	8.739	43.033	78.3	3.86	314.1
18	Feb 12,2003	7:30a	539.15	17:38:41	1058.6833	0.73334	2.37737	46.2042	3.68	350.6	2.85	102.37	15.11	9.244	39.775	73.8	3.72	351.8	2.86	93.72	12.114	8.988	39.151	73.25	3.82	336.1
19	Feb 13,2003	9:30a	648.79	20:50:31	1250.5167	0.7471	2.42197	48.3075	3.68	356.8	2.86	99.425	16.291	9.457	43.3765	74.7	3.66	361.3	2.84	90.72	13.84	9.227	41.184	74.5	3.79	336.6
20	Feb 14,2003	9:40a	606.23	19:43:22	1183.3667	0.7377	2.39151	50.2728	3.61	358	2.84	97.575	17.086	9.782	44.1675	73.85	3.64	376.2	2.83	96.91	14.06	9.005	44.722	74.45	3.78	341.6
21	Feb 17,2003	9:00a	2100.99	67:11:50	4031.83	0.75038	2.43263	57.0839	3.6	366.5	2.76	100.355	16.19	8.921	42.9275	67.65	3.33	417.3	2.85	96.935	16.164	8.66	42.969	66.85	3.81	350.5
22	Feb 18,2003	900a	568.35	19:50:26	1190.4333	0.6875	2.22877	58.9264	3.42	385.1	2.79	95.92	14.633	9.604	38.0895	87.7	3.16	419.3	2.88	92.965	16.517	10.119	38.529	88.65	3.74	359.7
23	Feb 19,2003	9:00a	629.1	19:50:30	1190.5	0.76094	2.46686	60.9658	3.43	384.6	2.81	100.31	15.114	9.356	43.4675	85.5	3.19	423.3	2.86	93.755	16.68	9.581	42.06	83.7	3.73	369.1
24	Feb 20,2003	8:45a	628.25	19:17:01	1157.0167	0.78191	2.53482	63.0025	3.36	407	2.88	101.7	15.376	9.678	43.9505	122.35	3.15	427.5	2.9	93.495	17.499	10.163	41.9	124.7	3.73	370.2
25	Feb 21,2003	9:00a	609.32	19:49:08	1189.1333	0.73787	2.39204	64.9778	3.3	398.4	2.87	106.24	13.72	8.49	37.2205	102.4	3.12	424.9	2.93	101.345	15.522	8.837	35.889	107.6	3.71	377.5
26	Feb 24,2003	9:20a	2124.21	67:32:27	4052.45	0.75482	2.447	71.8642	3.26	437.7	2.83	109.505	9.954	8.088	41.576	88.7	3.14	448.8	2.92	105.935	9.464	8.146	39.904	86.25	3.59	406.7
27	Feb 25,2003	9:10a	625.17	19:19:11	1159.1833	0.77662	2.51768	73.8909	3.24	462.4	2.85	111.15	9.216	8.334	43.3305	85.85	3.1	473	2.91	107.265	8.943	8.287	41.296	88.95	3.43	477.1

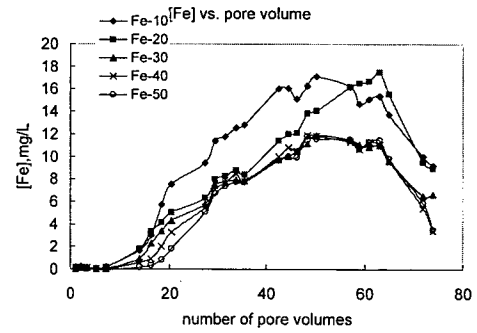
mmhos						40cm		mmhos						50cm		mmhos								
EC-30	Cu-30	Fe-30	Mn-30	Zn-30	Al-30	pH-40	mV-40	EC-40	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-50	mV-50	EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	Eh-50	pe-50	pH+pe-5
4.3	-0.004	0.074	-0.216	-0.005	0.62	7.38	172.1	5.61	-0.004	0.103	-0.201	0.0097	1.05	7.34	168.8	7.59	-0.001	0.04	-0.124	0.0622	1.01	370.8	6.2847	13.625
3.96	-0.012	0.267	0.033	-0.0001	0.09	7.4	223.8	4.25	-0.013	0.11	-0.018	0.0106	-0.33	7.35	213.2	4.66	-0.031	0.083	0.061	0.0052	-0.09	415.2	7.0373	14.387
3.76	0.005	0.154	0.032	0.0123	-0.67	7.44	198.1	3.56	-0.015	0.16	0.014	0.0179	-0.57	7.42	200.1	4.01	0.014	0.121	0.066	0.0246	-0.22	402.1	6.8153	14.235
3.65	0.039	0.054	2.468	1.5091	0.62	7.04	202.3	3.77	-0.023	0.012	-0.207	-0.0243	0.17	7.34	200	3.84	0.006	0.034	-0.241	-0.0071	0.2	402	6.8136	14.154
3.5	2.839	0.078	5.588	7.8777	14.55	6.99	306.6	3.64	0.036	-0.042	1.6	0.3416	0.56	7.34	234	3.71	0.021	-0.036	0.075	0.0367	0.72	436	7.3898	14.73
3.23	23.866	0.907	7.088	19.217	50.2	4.09	368.2	3.32	9.043	0.621	6.73	12.454	51.47	4.14	342.6	3.37	2.182	0.188	6.062	8.3412	47.14	544.6	9.2305	13.371
3.14	34.692	2.312	6.739	22.831	63.5	3.99	358.3	3.18	18.276	0.916	6.703	17.351	60.4	4.02	362	3.25	7.686	0.327	5.855	12.382	57.63	202 564	9.5593	13.579
3.09	39.228	3.372	7.122	26.435	66.1	3.88	361.1	3.19	27.143	1.99	7	21.188	64.58	3.93	364.3	3.2	15.668	0.82	6.827	16.894	60.7	566.3	9.5983	13.528
3.03	44.07	4.31	7.361	29.785	70.69	3.88	347.7	3.08	36.604	3.244	7.426	24.343	68.9	3.9	346.7	3.14	22.869	1.783	7.125	19.686	63.84	548.7	9.3	13.2
3.01	54.755	5.773	7.575	32.27	73.8	3.84	346.6	3.04	49.53	5.48	7.747	31.059	71.65	3.85	343.7	3.06	42.875	5.053	7.676	29.355	70.92	545.7	9.2492	13.099
2.99	60.385	7.47	7.991	30.38	76.9	3.85	342.5	3.03	54.24	7.109	7.932	29.022	78.85	3.87	342.3	3	47.855	6.723	8.121	27.502	79.45	544.3	9.2254	13.095
2.97	60.67	7.764	7.877	33.73	69.4	3.83	334.9	2.99	56.93	7.617	7.995	33.013	71.25	3.86	329	2.97	52.09	7.36	8.103	31.901	70.7	531	9	12.86
2.93	62.235	7.881	7.785	34.457	69.25	3.8	341.6	3.01	61.91	8.439	8.087	34.99	71.75	3.78	343.1	2.98	55.455	7.738	8.203	34.289	69.1	545.1	9.239	13.019
2.94	70.385	7.834	8.12	32.679	73	3.78	331.5	2.99	65.18	7.786	8.05	30.39	71.8	3.79	324.3	2.95	61.32	7.661	8.335	29.278	70.7	526.3	8.9203	12.71
2.94	74.155	9.758	8.044	37.056	71.9	3.84	342.1	3	75.22	9.959	8.374	37.579	75.4	3.87	328.7	2.94	72.205	9.645	8.273	37.078	75.5	530.7	8.9949	12.865
2.94	78.045	10.051	8.122	36.863	70.3	3.84	332.4	2.95	80.195	10.801	8.357	38.707	72.2	3.86	332.1	2.94	74.445	9.967	8.282	37.652	71.2	534.1	9.0525	12.913
2.93	78.95	10.443	8.253	34.914	68.3	3.78	336	2.94	76.09	10.538	8.467	33.907	68.95	3.77	338.5	2.94	73.595	9.894	8.329	33.209	69.7	540.5	9.161	12.931
2.93	76.26	11.174	8.261	36.558	68.8	3.77	333.7	2.97	82.38	11.878	8.62	39.659	72.1	3.78	323.8	2.92	71.625	11.749	9.034	35.604	69.8	525.8	8.9119	12.692
2.9	76.82	11.87	8.397	37.459	68.45	3.81	336.7	2.94	77.325	11.823	8.559	37.396	69.45	3.78	334.9	2.88	74.5	11.542	8.5	37.027	69.8	536.9	9.1	12.88
2.86	78.785	11.48	7.886	37.087	65.75	3.81	323.1	2.83	78.2	11.278	8.151	36.862	65.65	3.81	328.7	2.81	77.44	11.506	8.66	37.142	66.15	530.7	8.9949	12.805
2.87	79.86	11.083	8.986	34.329	81.4	3.73	345	2.83	77.81	10.619	8.775	33.506	81.75	3.75	339.4	2.83	75.495	10.668	9.049	33.46	84.85	541.4	9.1763	12.926
2.82	79.98	10.868	8.356	37.688	77.65	3.79	345.5	2.83	81.53	11.28	8.605	38.083	80.5	3.79	342.7	2.8	81.3	11.277	8.684	37.312	78.55	544.7	9.2322	13.022
2.84	83.985	11.002	9.051	39.232	101.85	3.78	351.5	2.86	82.915	11.054	9.169	39.41	107.65	3.8	330.3	2.84	81.415	11.43	9.099	39.668	103.55	532.3	9.022	12.822
2.87	91.13	9.603	7.691	33.88	95.85	3.77	343.2	2.81	88.23	9.638	7.765	33.112	97.6	3.82	337	2.81	90.965	9.83	7.755	33.682	100.1	539	9.1356	12.956
2.81	95.705	6.476	7.521	38.412	87.35	3.7	370.3	2.82	97.06	5.408	7.57	38.029	90.05	3.76	362.3	2.79	97.185	5.827	7.632	37.783	87.95	564.3	9.5644	13.324
2.66	97.165	6.638	7.781	38.743	90.85	3.67	437.7	2.78	93.73	3.387	7.724	38.441	89.45	3.74	414.7	2.76	91.175	3.483	7.841	38.45	92.55	616.7	10.453	14.193

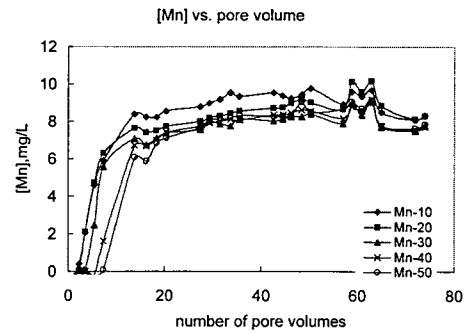

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30

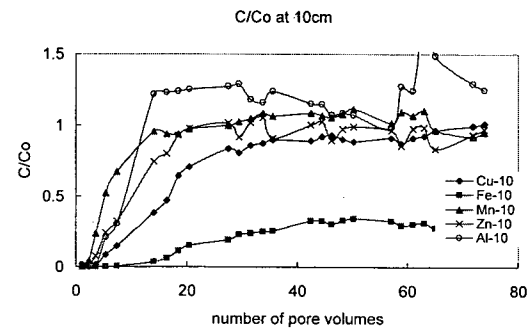

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

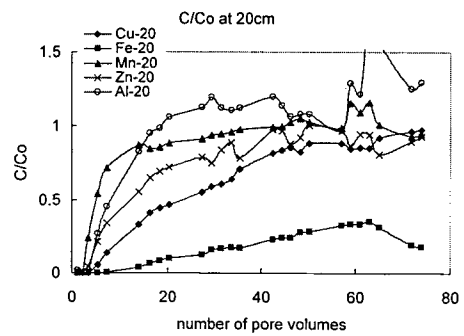

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

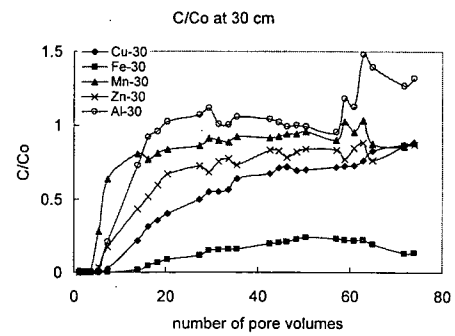

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50

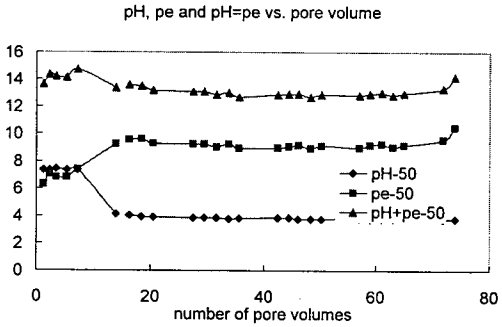

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

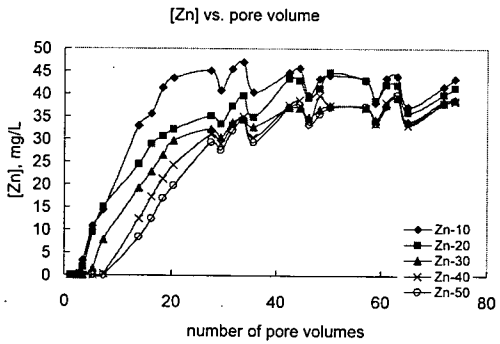

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

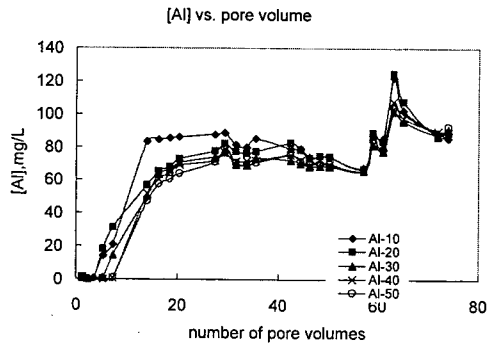

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

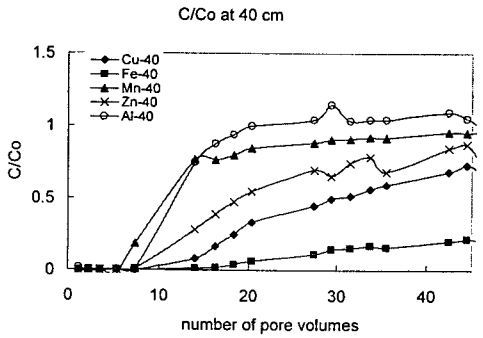

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

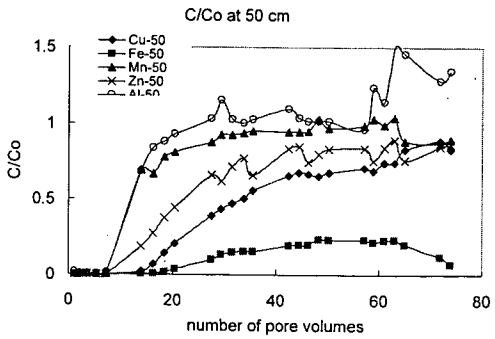

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
20
40
60
80
number of pore volumes
pH-50
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
50
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
140
120
100
80
60
40
20
0
0
20
40
60
80
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.5
1
0.5
0
0
10
20
30
40
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50

Cell ID PTB15

wt soil before filling column	2499.35 g	initial concentration of metals, Co	
wt soil after filling column	1639.29 g	[Cu]o	36.23 mg/L
wt soil in column	860.06 g	[Fe]o	10.74 mg/L
Date start	Jan 19,2003 04:00	[Mn]o	3.62 mg/L
leachate	max conc -non-filtered (design flowrate 0.5m/day)	[Zn]o	23.92 mg/L
pore volume	318.885 ml	[Al]o	34.85 mg/L
flowrate	0.63069 L/day	pH	3.14
	0.4708 m/day	redox pot	504.9 mV
		EC	1.99 mS/cm

☑ 1 M NaCl pretreated ☐ No pretreatment

ARD concentration:

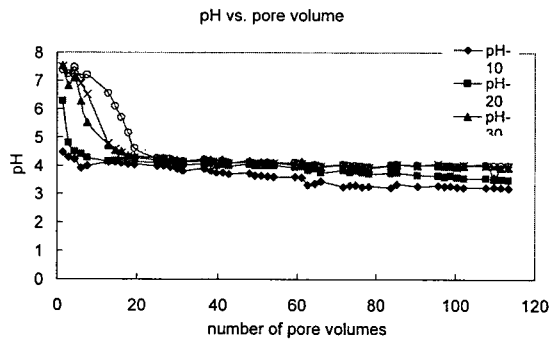
☑ Natural ☐ Maximum design

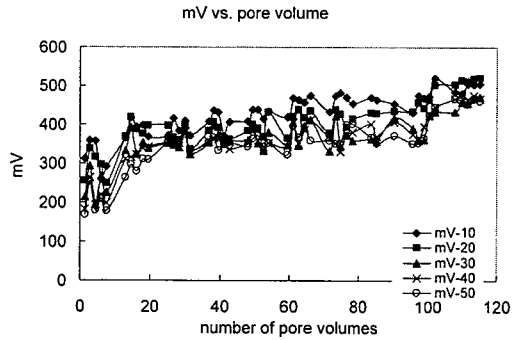
☐ Filtered ☑ Non-filtered

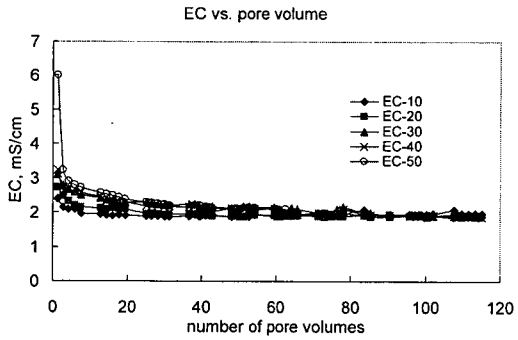
Linear flow rate: 0.5 m/day

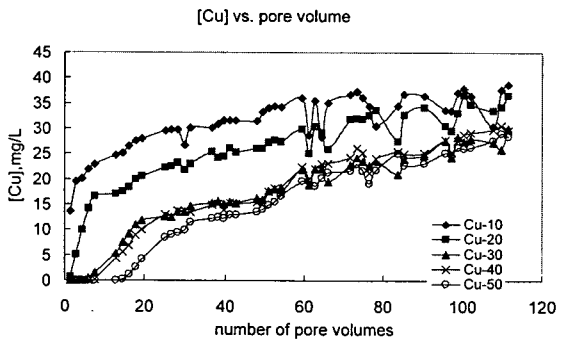
ID	Date	Time	vol effl (m	time used hh:mm:ss	(min)	Flowrate L/day	pv/day	#pore vol	10cm pH-10	mV-10	mmhos EC-10	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	20cm pH-20	mV-20	mmhos EC-20	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	30cm pH-30	mV-30
1	Jan 20, 200	10:36a	433.81	15:45:00	945.00	0.66104	2.07299	1.3604	4.47	312.9	2.4	13.596	0.229	3.062	11.7652	12.76	6.27	255.3	2.72	0.715	0.469	0.875	1.6664	0.09	7.54	213.9
2	jan 21,2003	9:30a	453.93	16:30:00	990.00	0.66026	2.07053	2.78389	4.3	358.2	2.14	19.489	0.115	3.407	16.0403	22.3	4.8	338.4	2.47	5.052	0.079	2.654	6.9377	2.52	6.82	294.1
3	jan 22, 2003	9:10a	492.81	17:36:31	1056.52	0.67169	2.10636	4.3293	4.22	357.3	2.1	20.072	0.175	3.368	16.4736	21.15	4.48	315.1	2.32	9.936	0.369	3.277	10.6219	10.11	7.11	194.7
4	jan 23,2003	9:00a	510.66	17:53:56	1073.93	0.68473	2.14725	5.9307	3.9	259.4	2.09	21.896	0.235	3.463	16.7809	21.55	4.4	296.2	2.2	14.099	0.196	3.586	13.2065	15.67	6.27	265.9
5	jan 24, 2003	9:00a	513.15	18:43:18	1123.30	0.65783	2.06289	7.5399	3.98	291.7	1.969	22.886	0.2	3.586	17.3128	23.98	4.27	248.7	2.14	16.614	0.219	3.566	14.1442	20.29	5.52	225
6	jan 27,2003	9:00a	1694.58	68:48:32	4128.53	0.59106	1.85351	12.854	4.13	364.5	1.946	24.684	0.276	3.595	18.4367	30.86	4.15	368.5	2.12	17.056	0.859	3.457	14.4845	24.97	4.71	332.7
7	Jan 28, 200	8:50a	510.77	18:40:45	1120.75	0.65626	2.058	14.4557	4.11	418	1.922	25.17	0.249	3.555	18.4029	27.04	4.16	419	2.1	17.551	0.255	3.394	14.6264	21.63	4.54	392.4
8	Jan 29,2003	8:40a	514.99	18:55:16	1135.27	0.65323	2.04847	16.0707	4.09	393.3	1.918	26.438	0.295	3.642	18.9607	27.26	4.16	387.1	2.13	18.361	0.162	3.604	15.6171	22.37	4.5	324.5
9	Jan 30,2003	9:30a	538.87	19:58:58	1198.97	0.6472	2.02958	17.7605	4.05	398	1.933	27.595	0.271	3.526	19.4473	27.31	4.09	376	2.09	19.996	0.151	3.318	16.0571	23.82	4.33	353.8
10	Jan 31,2003	8:50a	510.44	18:51:21	1131.35	0.6497	2.0374	19.3612	4.04	369	1.911	27.946	0.21	3.483	19.3626	27.75	4.13	397.6	2.1	20.575	0.112	3.351	16.2574	24.38	4.34	339.4
11	Feb 3,2003	9:10a	1815.45	67:31:44	4051.73	0.64522	2.02335	25.0544	4	371.1	1.892	29.49	0.232	3.619	20.3671	27.86	4.13	396.5	1.954	22.199	0.003	3.36	17.2014	25.71	4.24	351.8
12	Feb 4,2003	8:10a	493.2	18:22:40	1102.67	0.64408	2.01979	26.601	4	415.9	1.893	29.789	0.255	3.635	18.6791	27.94	4.1	366.8	1.97	22.515	0.087	3.602	15.7899	26.35	4.25	347.2
13	Feb 5,2003	9:05a	524.78	20:32:27	1232.45	0.61316	1.92281	28.2467	3.95	384	1.889	29.779	0.284	3.461	20.496	29.2	4.08	360.6	1.94	23.282	0.126	3.426	17.6351	26.32	4.22	341.2
14	Feb 6,2003	10:40a	538.02	21:06:20	1266.333	0.6118	1.91858	29.9339	3.89	409.7	1.885	26.779	0.404	3.666	20.548	27.95	4.03	396.6	1.936	21.718	0.133	3.436	17.7304	24.78	4.18	384.7
15	Feb 7,2003	9:10a	449.68	17:38:40	1058.667	0.61166	1.91811	31.344	3.82	371.9	1.883	30.145	0.314	3.41	20.254	29.22	4.03	336.7	1.948	23.018	0.088	3.291	16.9638	25.75	4.17	324.6
16	Feb 10,2003	9:05a	1692.81	67:05:49	4025.82	0.6055	1.89882	36.6526	3.88	407.8	1.889	30.125	0.419	3.523	20.4854	27.94	4.06	384.5	1.948	25.362	0.094	3.399	18.2741	26.08	4.21	354.7
17	Feb 11,2003	9:10a	489.68	19:52:40	1192.667	0.59123	1.85405	38.1882	3.82	437.3	1.922	30.801	0.356	3.397	21.8368	27.84	4.08	407.1	1.957	24.238	0.072	3.382	17.8353	23.74	4.19	397.8
18	Feb 12,2003	7:30a	441.68	17:38:41	1058.683	0.60076	1.88395	39.5732	3.76	432.4	1.884	31.597	0.443	3.449	19.8933	26.45	4	391.4	1.929	24.444	0.077	3.289	16.8514	24.05	4.12	372.4
19	Feb 13,2003	9:30a	512.32	20:50:31	1250.517	0.58995	1.85004	41.1798	3.74	369.5	1.919	31.572	0.49	3.449	20.7357	26.42	4.04	365.7	1.915	26.118	0.157	3.494	17.8543	23.72	4.21	350.4
20	Feb 14,2003	9:40a	497.05	19:43:22	1183.367	0.60484	1.89675	42.7385	3.71	406.3	1.906	31.518	0.407	3.51	20.4096	24.79	4	361.7	1.89	25.272	0.059	3.475	17.5433	23.23	4.09	358.3
21	Feb 17,2003	9:00a	1660.53	67:11:50	4031.83	0.59307	1.85983	47.9458	3.72	408.4	1.873	31.507	0.511	3.494	20.8974	24.33	4.04	384.2	1.886	26.025	0.15	3.484	18.0127	21.6	4.16	358.6
22	Feb 18,2003	900a	473.49	19:50:26	1190.433	0.57275	1.79612	49.4307	3.63	438.2	1.897	33.241	0.451	3.798	21.3227	32.48	3.98	400.4	1.91	26.017	0.113	3.552	18.1568	28.52	4.08	389.6
23	Feb 19,2003	9:00a	500.85	19:50:30	1190.5	0.60582	1.89979	51.0013	3.64	438.3	1.91	33.997	0.454	3.598	20.5598	32.72	3.99	390.6	1.882	27.227	0.119	3.6	17.8346	30.18	4.13	351.9
24	Feb 20,2003	8:45a	481.92	19:17:01	1157.017	0.59979	1.88089	52.5126	3.61	413.8	1.88	34.393	0.393	3.568	22.0154	34.13	3.99	368.2	1.931	27.756	0.13	3.671	19.1499	32.83	4.13	334
25	Feb 21,2003	9:00a	496.26	19:49:08	1189.133	0.60095	1.88455	54.0688	3.6	434	1.93	34.246	0.629	3.259	21.3141	38.16	3.99	431.3	1.936	27.393	0.155	3.218	18.0494	34.08	4.1	378.7
26	Feb 24,2003	9:20a	1710.51	67:32:27	4052.45	0.60781	1.90606	59.4328	3.59	418.8	1.898	36.012	0.712	3.172	21.5365	36.66	3.95	364.4	1.91	29.931	0.09	3.138	18.8215	34.42	4.09	347.6
27	Feb 25,2003	9:10a	505.42	19:19:11	1159.183	0.62786	1.96892	61.0178	3.57	467.7	1.925	28.614	0.66	3.268	21.147	36.77	3.97	420.7	1.884	25.047	0.002	3.364	18.6283	35.76	4.14	404.3
28	Feb 26,2003	9:30a	523.81	20:01:39	1201.65	0.62771	1.96845	62.6604	3.32	463.5	1.923	35.408	0.805	3.38	23.1805	35.72	3.84	437.4	1.897	30.408	0.251	3.55	19.2952	30.29	3.99	345.5
29	Feb 27,2003	9:15a	522.61	20:22:20	1222.333	0.61567	1.93071	64.2993	3.36	456.7	1.911	28.339	0.681	3.227	19.2102	40.22	3.88	418.2	1.895	29.1	0.193	3.326	18.4413	37.94	4.04	392
30	Feb 28,2003	8:45a	525.13	19:07:10	1147.167	0.65918	2.06713	65.9461	3.44	474	1.917	35.069	0.662	3.246	21.845	38.42	3.75	434.6	1.905	25.88	0.107	3.153	18.2716	34.28	3.95	412.7
31	Mar 3,2003	8:45a	1760.41	67:50:31	4070.52	0.62277	1.95296	71.4666	3.25	433.9	1.944	36.641	0.778	3.372	22.9453	35.45	3.84	378.1	1.892	31.861	0.158	3.506	20.5911	34.75	4.03	332.3
32	Mar 4,2003	9:30a	545.3	20:47:47	1247.783	0.6293	1.97344	73.1766	3.29	474	1.955	37.249	0.794	3.378	23.3916	36.51	3.77	438.8	1.856	31.952	0.178	3.44	20.6207	35.11	3.97	421.7
33	Mar 5,2003	8:45a	494.34	19:12:52	1152.867	0.61746	1.93631	74.7268	3.31	482.6	1.94	36.076	0.719	3.381	22.7547	36.43	3.82	427.2	1.89	31.842	0.131	3.411	20.3087	35.05	3.94	345.2
34	Mar 6,2003	8:50a	536.03	20:03:09	1203.15	0.64155	2.01186	76.4078	3.25	470.6	1.955	34.326	0.785	3.401	22.1968	36.25	3.74	394.3	1.896	32.542	0.18	3.437	20.092	30.67	3.95	372.6
35	Mar 7,2003	9:35a	541.14	20:26:40	1226.667	0.63525	1.9921	78.1047	3.27	453.5	1.957	30.489	0.713	3.344	19.0526	43.69	3.71	414.3	1.898	33.659	0.17	3.442	18.9447	41.92	3.93	358.4
36	Mar 10,2003	9:25a	1775.81	67:33:12	4053.20	0.6309	1.97846	83.6736	3.23	470.6	2.07	34.518	0.782	3.222	21.9346	29.54	3.72	430.9	1.907	27.406	0.268	3.458	19.9432	28.63	4.02	363.9
37	Mar 11,2003	9:15a	500.33	19:17:56	1157.933	0.62221	1.9512	85.2426	3.33	463.2	1.928	36.808	0.752	3.284	22.6883	31.82	3.74	428.7	1.879	32.653	0.295	3.372	21.1079	31.85	4.04	357.1
38	Mar 14,2003	9:30a	1647.07	67:00:40	4020.67	0.5899	1.84988	90.4076	3.27	454	1.95	36.413	0.912	3.475	22.2159	35.16	3.67	435.3	1.884	34.125	0.324	3.627	20.2599	34.64	4.01	417.6
39	Mar 17,2003	9:40a	1688.43	67:43:18	4063.30	0.59837	1.87643	95.7024	3.29	432.4	1.953	33.61	0.97	3.65	19.6061	37.15	3.64	432.7	1.894	30.507	0.34	3.559	18.9173	38.1	4.02	390.1
40	Mar 18,2003	9:00a	483.06	18:50:32	1130.53	0.61529	1.92951	97.2173	3.26	474.9	1.943	33.516	0.847	3.438	20.5971	34.52	3.6	456.9	1.902	29.549	0.339	3.446	18.1965	36.07	3.99	360.4
41	Mar 19,2003	8:45a	501.64	19:07:05	1147.08	0.62974	1.97481	98.7904	3.29	467.8	1.949	37.038	0.956	3.402	23.5666	33.71	3.65	442.1	1.893	32.974	0.383	3.545	22.3464	35.2	3.99	361.9
42	Mar 20,2003	8:45a	497.71	19:24:12	1164.20	0.61562	1.93053	100.351	3.25	473.6	1.95	37.879	1.077	3.495	24.5064	35.18	3.57	464	1.887	36.579	0.473	3.48	22.727	35.47	3.97	423.4
43	Mar 21,2003	9:18a	534.84	20:26:23	1226.38	0.628	1.96936	102.028	3.23	521	1.958	36.378	0.91	3.488	22.5381	35.05	3.56	501.5	1.898	34.742	0.411	3.529	21.4993	35.5	3.98	434.1
44	Mar 24,2003	9:05a	1827.6	67:50:07	4070.12	0.6466	2.0277	107.76	3.22	484.9	2.07	30.412	0.853	3.436	21.1974	32.22	3.55	503	1.89	33.543	0.398	3.435	20.8562	31.89	4.01	434.1
45	Mar 25,2003	1040a	622.08	21:32:48	1292.80	0.69291	2.17292	109.71	3.24	481.5	1.973	37.582	0.915	3.795	24.5601	33.84	3.5	514.7	1.902	34.199	0.467	3.773	20.5624	35.64	3.57	458.9
46	Mar 26,2003	1005a	557.18	19:22:34	1162.57	0.69014	2.16424	111.458	3.23	505.4	1.963	38.757	1.026	3.651	23.3263	32.69	3.5	511.3	1.906	36.475	0.552	3.631	22.3131	33.32	3.93	455.8
47	Mar 27,2003	10a	578.28	19:28:37	1168.617	0.71257	2.23457	113.271	3.21	503.1	1.965						3.48	517.8	1.915						3.95	468
48	Mar 28,2003	9:40a	562.11	19:28:38	1168.633	0.69264	2.17206	115.034	3.2	505.3	1.974						3.47	521.2	1.913						3.92	470.9

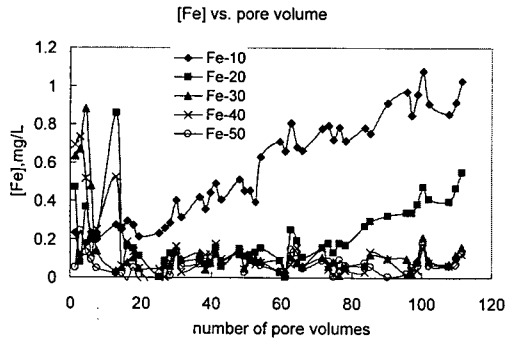
mmhos EC-30	Cu-30	Fe-30	Mn-30	Zn-30	Al-30	40cm pH-40	mV-40	mmhos EC-40	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	50cm pH-50	mV-50	mmhos EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	Eh-50	pe-50	pH+pe-5(
3.13	-0.02	0.633	0.046	-0.0013	0.24	7.5	182.4	3.23	-0.029	0.692	-0.035	-0.0013	0.45	7.37	168.6	6.01	-0.011	0.051	0.19	-0.0028	-0.23	370.6	6.2814	13.651
2.77	-0.005	0.668	0.07	0.0189	-0.62	7.26	263.5	2.62	0.004	0.732	0.03	-0.012	-0.15	7.23	253.7	3.23	-0.046	0.242	-0.039	-0.0079	-0.44	455.7	7.7237	14.954
2.67	0.06	0.879	0.306	0.2397	0.73	7.3	193.5	2.73	0.007	0.515	0.011	0.0052	0.13	7.47	179.4	2.9	0.009	0.131	0.024	0.0096	0.21	381.4	6.4644	13.934
2.59	0.526	0.477	1.143	1.5056	0.46	6.88	219.6	2.68	0.045	0.125	0.541	0.1209	-0.09	7.08	210.3	2.79	0.057	0.094	-0.089	-0.0906	-0.13	412.3	6.9881	14.068
2.51	1.627	0.139	2.015	3.6317	2.43	6.52	199.2	2.58	0.099	0.25	1.416	1.1709	1.69	7.2	177.9	2.72	0.005	0.048	0.011	-0.0041	-0.38	379.9	6.439	13.639
2.42	5.334	0.032	2.871	7.2006	4.04	4.77	311.7	2.45	4.329	0.524	3.096	6.5942	3.22	6.55	263.3	2.57	0.009	0.024	1.66	0.9991	-0.12	465.3	7.8864	14.436
2.37	7.497	0.052	3.123	8.8038	6.22	4.57	315.7	2.42	5.525	0.062	3.318	7.8178	5.04	6.09	296.2	2.53	0.251	0.023	2.313	2.4874	0.45	498.2	8.4441	14.534
2.34	9.226	0.076	3.453	10.055	8.89	4.44	323	2.36	6.892	0.185	3.368	8.8329	8.76	5.68	279.8	2.49	1.225	-0.017	2.915	4.4543	2.68	481.8	8.1661	13.846
2.3	10.986	0.102	3.294	11.241	11.25	4.32	340.1	2.29	8.922	0.136	3.263	9.8741	10.53	5.14	311.3	2.43	2.665	0.05	3.006	6.1709	4.96	513.3	8.7	13.84
2.29	11.887	0.049	3.361	11.409	13.98	4.27	342.7	2.29	10.1	0.048	3.198	10.681	13.52	4.59	309.7	2.38	4.182	-0.011	3.281	7.4516	8.23	511.7	8.6729	13.263
2.3	12.599	-0.084	3.311	11.513	15.65	4.18	355.3	2.19	12.971	0.046	3.305	12.169	14.96	4.25	354.6	2.29	8.423	-0.063	3.33	9.9259	11.63	556.6	9.4339	13.684
2.25	12.495	0.063	3.417	11.043	17.31	4.18	355.5	2.19	12.48	0.002	3.434	11.029	19.11	4.24	363.8	2.28	9.087	0.07	3.443	9.4817	14.37	565.8	9.5898	13.83
2.24	13.501	0.06	3.377	12.472	17.57	4.17	351.9	2.18	13.795	0.081	3.428	12.631	19.53	4.23	350.8	2.26	9.465	0.011	3.339	10.349	14.84	552.8	9.3695	13.599
2.22	13.55	0.14	3.45	12.605	17.22	4.09	381.6	2.18	13.657	0.163	3.392	12.917	18.99	4.14	374.2	2.23	9.876	0.13	3.326	10.926	15.42	576.2	9.7661	13.906
2.21	14.59	0.097	3.305	12.609	18.45	4.13	332.3	2.16	13.394	0.029	3.2	12.484	19.19	4.14	333.7	2.21	11.459	0.062	3.423	10.571	15.52	535.7	9.0797	13.22
2.24	15.243	0.129	3.191	12.65	18.39	4.14	357.2	2.16	14.898	0.074	3.269	13.225	21.16	4.2	354.2	2.14	12.26	0.072	3.213	11.757	18.84	556.2	9.4271	13.627
2.24	15.603	0.042	3.347	12.913	17.7	4.14	364.7	2.17	15.106	0.119	3.225	13.038	18.94	4.16	366.9	2.21	12.408	0.079	3.148	11.492	17.4	568.9	9.6424	13.802
2.16	14.96	0.076	3.149	12.589	17.34	4.07	361.6	2.15	13.888	0.123	3.034	12.5044	18.39	4.08	334	2.21	12.244	0.071	3.108	11.3682	17.39	536	9.0847	13.165
2.14	15.494	0.125	3.311	12.82	16.36	4.14	354.6	2.17	15.225	0.176	3.334	12.962	19.15	4.17	350.5	2.16	12.892	0.155	3.345	11.43	16.87	552.5	9.3644	13.534
2.17	15.21	0.085	3.261	12.677	17.15	4.08	337.2	2.04	15.17	0.097	3.4	12.858	18.18	4.1	354.6	2.13	12.968	0.065	3.357	11.687	17.12	556.6	9.4339	13.534
2.11	16.255	0.124	3.3	13.397	16.74	4.1	351.8	2.11	15.348	0.13	3.312	13.563	18.52	4.12	342.5	2.1	13.51	0.144	3.182	12.348	17.42	544.5	9.2288	13.349
2.11	15.841	0.047	3.262	13.477	22.11	4.02	390.1	2.12	14.906	0.044	3.219	13.006	23.86	4.05	364	2.11	14.08	0.03	3.462	12.086	22.81	566	9.5932	13.643
2.16	17.701	0.093	3.367	14.109	24.24	4.07	358.2	2.09	17.382	0.119	3.31	13.847	25.4	4.07	370.7	2.13	14.829	0.095	3.304	13.109	24.48	572.7	9.7068	13.777
2.16	18.065	0.1	3.477	14.374	24.7	4.08	343.1	2.12	18.132	0.072	3.494	15.055	28.49	4.09	343.1	2.14	15.484	0.079	3.519	13.397	26.18	545.1	9.239	13.329
2.15	18.382	0.087	3.099	12.801	27.18	4.08	352.6	2.1	17.221	0.077	3.106	12.772	28.93	4.06	351.8	2.12	16.711	0.065	3.067	12.106	26.92	553.8	9.3864	13.446
2.14	21.854	0.033	3.102	14.512	28.28	4.04	342.4	2.11	22.322	0.089	3.091	14.917	30.25	4.09	321.5	2.09	19.552	0.031	3.044	13.831	28.16	523.5	8.8729	12.963
2.08	18.88	0.025	3.139	14.235	26.81	4.07	405.4	2.09	20.001	0.046	3.131	14.787	29.56	4.08	394.6	2.08	19.554	0.024	3.168	13.68	28.05	596.6	10.112	14.192
1.983	21.986	0.107	3.349	15.268	28.03	3.98	351.8	1.981	22.061	0.071	3.213	14.708	27.65	4	367.1	2.09	18.639	0.147	3.143	13.366	26.19	569.1	9.6458	13.646
2.12	22.019	0.079	3.216	14.585	30.53	4.02	385	1.978	22.995	0.155	3.184	14.67	34.24	4.02	404.3	1.999	20.229	0.132	3.197	13.653	33.67	606.3	10.276	14.296
2.09	19.511	0.06	3.101	14.084	27.44	3.96	410.5	1.946	23.064	0.059	3.13	15.491	30.18	3.97	359.3	1.957	21.306	0.049	3.207	14.975	30.73	561.3	9.5136	13.484
1.993	22.761	0.105	3.264	16.183	27.74	4.02	364.4	1.976	24.374	0.153	3.25	16.572	31.39	4.03	358.7	1.968	21.628	0.089	3.294	15.786	29.94	560.7	9.5034	13.533
1.987	24.139	0.061	3.282	15.788	28.58	3.97	351.9	1.939	26.123	0.046	3.304	17.007	30.6	4	351.3	1.961	23	0.086	3.287	15.871	30.83	553.3	9.378	13.378
1.906	23.528	0.084	3.254	16.256	29.73	3.96	330.6	1.989	25.13	0.018	3.274	17.05	31.36	3.99	351.3	1.945	21.653	0.005	3.181	15.583	29.35	553.3	9.378	13.368
2.09	22.615	0.013	3.338	15.671	25.53	3.94	375.6	1.951	21.184	0.052	3.356	16.212	29.27	3.97	398.2	1.951	19.157	0.092	3.275	14.81	27.53	600.2	10.173	14.143
2.17	23.629	0.059	3.39	14.667	34.57	3.92	381.4	2.09	24.114	0.037	3.425	15.429	36.79	3.95	401.3	1.968	21.795	0.063	3.3	14.085	35.88	603.3	10.225	14.175
1.976	20.867	0.065	3.266	15.826	22.97	3.98	402.1	1.939	25.457	0.03	3.387	17.631	27.43	4.01	366.3	1.922	25.1	0.078	3.192	16.743	24.46	568.3	9.6322	13.642
1.982	23.972	0.122	3.278	17.163	24.66	4.03	369.9	1.939	24.863	0.135	3.162	17.971	26.72	4.04	350.5	1.928	22.698	0.057	3.185	16.924	25.96	552.5	9.3644	13.404
1.926	24.653	0.102	3.526	16.218	30.81	4	406.7	1.928	25.119	0.097	3.518	16.48	29.8	4.01	371.3	1.933	23.104	0.005	3.459	15.486	29.12	573.3	9.7169	13.727
1.94	27.579	0.1	3.573	15.679	31.64	4.05	374.8	1.901	27.724	0.015	3.555	16.324	34.49	4.02	351	1.902	25.201	0.024	3.485	14.86	33.62	553	9.3729	13.393
1.957	24.282	0.026	3.577	15.168	29.13	3.99	360.6	1.946	25.334	0.055	3.604	17.136	31.05	4	352.9	1.921	24.647	0.053	3.453	16.038	29.19	554.9	9.4051	13.405
1.949	28.251	0.087	3.494	18.12	30.24	3.96	395.7	1.899	27.551	0.041	3.468	18.496	29.62	3.98	364.6	1.902	26.26	0.08	3.466	16.167	29.64	566.6	9.6034	13.583
1.885	27.443	0.212	3.467	18.435	30.51	3.94	425.8	1.897	28.83	0.154	3.527	19.169	32.19	3.96	424	1.904	26.034	0.178	3.389	18.115	28.94	626	10.61	14.57
1.911	27.965	0.092	3.542	17.844	29.95	4.01	446.4	1.913	29.154	0.076	3.519	18.54	32.39	4	444	1.913	26.284	0.065	3.436	16.307	31.84	646	10.949	14.949
1.926	27.222	0.069	3.558	17.338	25.75	3.99	466.7	1.888	29.758	0.065	3.538	18.642	29.29	4.02	467.2	1.865	27.612	0.06	3.382	17.345	29.71	669.2	11.342	15.362
1.902	25.832	0.118	3.865	17.417	31.9	3.96	477.4	1.875	30.623	0.094	3.755	18.635	32.77	3.98	469.9	1.888	29.006	0.068	3.77	18.546	29.91	671.9	11.388	15.368
1.926	30.033	0.161	3.817	19.092	31.93	3.96	464.3	1.891	29.583	0.125	3.648	19.365	32.31	3.98	451.9	1.882	28.37	0.128	3.656	18.267	29.03	653.9	11.083	15.063
1.888						3.97	474.9	1.913						3.98	465.2	1.875						667.2	11.308	15.288
1.961						3.95	466.2	1.867						3.96	460.8	1.87						662.8	11.234	15.194

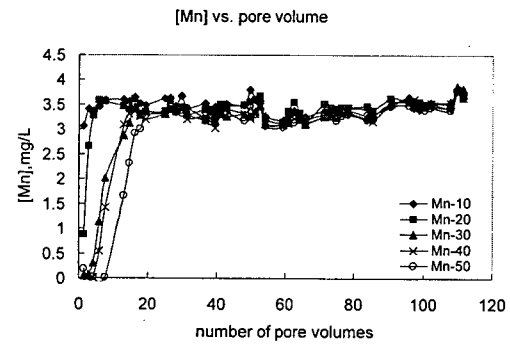

pH vs. pore volume
pH
number of pore volumes
pH-10
pH-20
pH-30

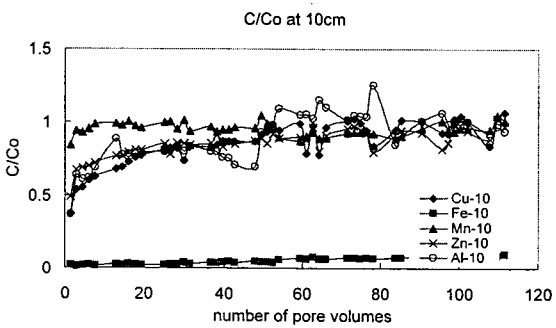

mV vs. pore volume
mV
number of pore volumes
mV-10
mV-20
mV-30
mV-40
mV-50

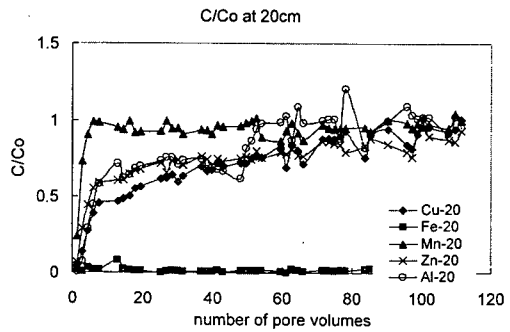

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-10
EC-20
EC-30
EC-40
EC-50

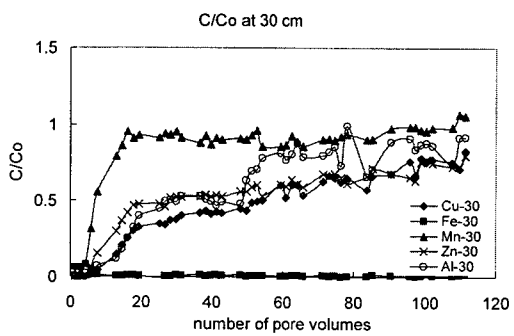

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-10
Cu-20
Cu-30
Cu-40
Cu-50


[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-10
Fe-20
Fe-30
Fe-40
Fe-50

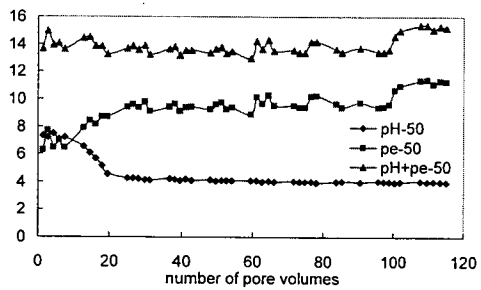

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50


C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

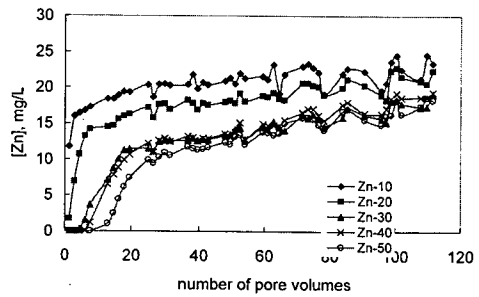

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20


C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30

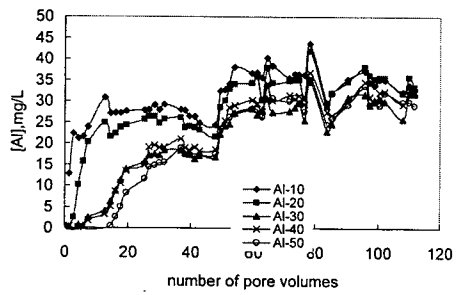
pH, pe and pH=pe vs. pore volume



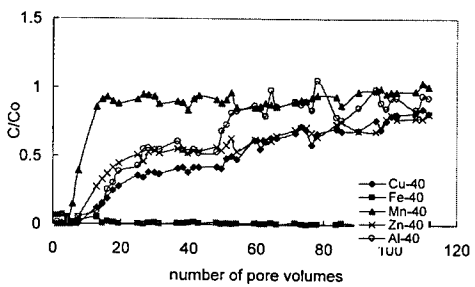
[Zn] vs. pore volume



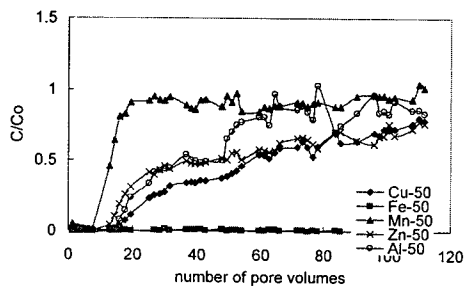
[Al] vs. pore volume



C/Co at 40 cm



C/Co at 50 cm



Cell ID PTB17

wt soil before filling column	g
wt soil after filling column	g
wt soil in column	417.28 g
Date start	Feb 19, 2003
leachate	filtered orig conc ARD 010902
pore volume	267.02 ml
flowrate	0.56316 L/day
	0.42039 m/day

initial concentration of metals, Co

[Cu]o	37.27 mg/L
[Fe]o	0.537 mg/L
[Mn]o	2.686 mg/L
[Zn]o	23.91 mg/L
[Al]o	30.71 mg/L
pH	3.09
redox pot	475.75 mV
EC	2.05 mS/cm

☑ 1 M NaCl pretreated ☐ No pretreatment

ARD concentration:

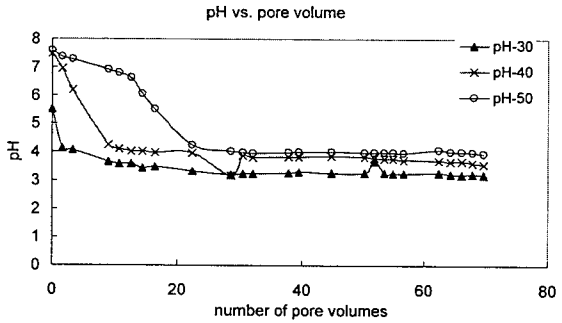
☑ Natural ☐ Maximum design

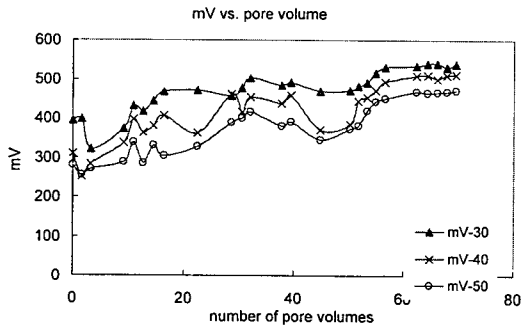
☑ Filtered ☐ Non-filtered

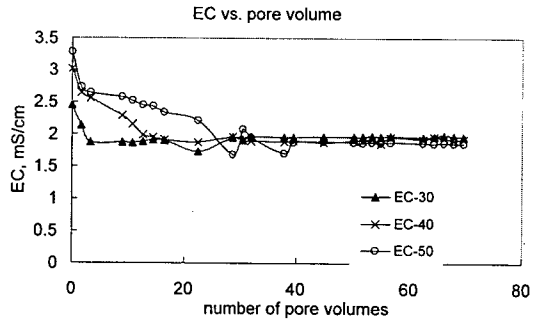
Linear flow rate: 0.5 m/day reactor bed

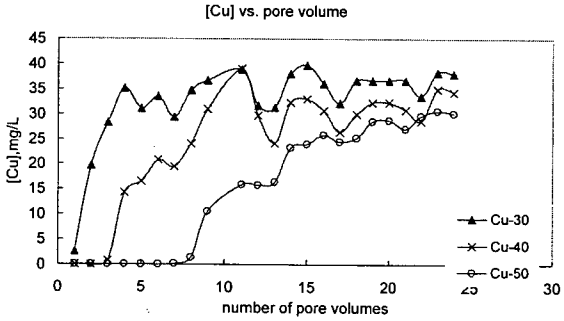
ID	Date	Time	vol effl (n	time used hh:mm:ss	(min)	Flowrate L/day	pv/day	#pore vol	10cm pH-10	mV-10	EC-10	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	20cm pH-20	mV-20	EC-20	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	30cm pH-30
1	Feb 19,2	9:00a	0	19:50:30	1190.5	0	0	0	3.3	437.7	1.943	36.012	0.545	3.486	22.2592	33.25	3.3	457.9	1.91	34.948	0.573	3.426	22.0533	33.5	5.51
2	Feb 20,2	8:45a	425.96	19:17:01	1157.02	0.53014	1.9854	1.59523	3.23	418.7	1.95	35.168	0.656	3.668	23.0135	33.58	3.22	450.8	1.955	36.125	0.575	3.586	22.5711	33.91	4.14
3	Feb 21,2	9:00a	448.68	19:49:08	1189.13	0.54334	2.03481	3.27556	3.19	440.7	1.94	37.699	0.61	3.115	23.394	36.37	3.2	438	1.919	37.832	0.605	3.138	22.6597	36.63	4.07
4	Feb 24,2	9:20a	1518.74	67:55:23	4075.38	0.53663	2.00971	8.96329	3.2	379.8	1.949	38.392	0.658	3.209	23.4172	35.68	3.2	417.5	1.94	37.266	0.639	3.156	23.2544	35.4	3.65
5	Feb 25,2	9:10a	479.35	19:19:11	1159.18	0.59547	2.23007	10.7585	3.2	468.2	1.97	37.61	0.574	3.092	22.9262	35.09	3.2	470.5	1.973	37.022	0.582	3.114	23.1199	35.63	3.59
6	Feb 26,2	9:30a	495.12	20:01:39	1201.65	0.59333	2.22203	12.6127	3.16	444.3	1.97	34.081	0.604	3.23	22.444	33.82	3.15	467.6	1.967	29.129	0.565	3.038	21.5343	32.39	3.58
7	Feb 27,2	9:15a	488.5	20:22:20	1222.33	0.57549	2.15523	14.4422	3.15	460.4	1.977	37.334	0.563	3.326	22.8807	32.91	3.16	451.6	1.956	36.864	0.597	3.136	23.4956	33.7	3.43
8	Feb 28,2	8:45a	523.88	19:07:10	1147.17	0.65761	2.46277	16.4041	3.14	467.9	1.956	37.07	0.6	3.227	23.1626	33.76	3.14	471.4	1.946	37.912	0.62	3.253	22.8877	34.33	3.47
9	Mar 3,20	8:45a	1610.31	67:50:31	4070.52	0.56967	2.13343	22.4348	3.17	395.8	1.964	37.563	0.609	3.262	24.0642	34.08	3.17	435.7	1.978	37.598	0.643	3.289	24.2691	34.3	3.33
10	Mar 4,20	9:30a	1190.26	20:47:47	1247.78	1.37362	5.14424	26.8923																	
11	Mar 5,20	8:45a	449.32	21:02:52	1262.87	0.51234	1.91874	28.5751	3.96	360.3	1.899	28.492	0.569	3.418	19.0713	31.67	3.3	477.1	1.938	35.973	0.815	3.307	23.26	33.77	3.19
12	Mar 6,20	8:50a	502.05	20:43:09	1243.15	0.58155	2.17792	30.4553	3.16	432	1.99	29.632	0.579	3.256	21.0295	31.28	3.12	478.2	1.982	31.541	0.58	3.265	20.6217	32.42	3.23
13	Mar 7,20	9:35a	412.06	20:26:40	1226.67	0.48372	1.81156	31.9984	3.14	470.3	1.976	36.194	0.572	3.225	23.2715	31.9	3.13	477.6	1.952	31.982	0.556	3.222	22.2497	31.98	3.23
14	Mar 10,2	9:25a	1566.35	67:33:12	4053.20	0.55648	2.08405	37.8645	3.15	467.1	1.696	38.757	0.577	3.122	23.6452	26.11	3.14	470.4	1.999	39.311	0.574	3.124	23.6521	26.45	3.26
15	Mar 11,2	9:15a	446.55	19:17:56	1157.93	0.55533	2.07972	39.5368	3.2	465.6	1.947	33.702	0.637	3.166	23.5283	28.43	3.19	470.3	1.966	38.559	0.625	3.11	23.5941	28.16	3.29
16	Mar 14,2	9:30a	1416.44	67:00:40	4020.67	0.5073	1.89985	44.8414	3.2	463.9	1.955	30.9	0.635	3.423	20.7231	32.1	3.2	464	1.975	32.309	0.602	3.355	20.2169	33.01	3.25
17	Mar 17,2	9:40a	1430.55	68:20:18	4100.30	0.5024	1.88151	50.1989	3.23	442.5	1.964	37.094	0.717	3.434	23.2331	33.36	3.21	459.6	1.988	33.915	0.663	3.402	22.9715	33.85	3.25
18	Mar 18,2	9:00a	411.03	18:50:32	1130.53	0.52354	1.96069	51.7382	3.18	445.6	1.986	37.562	0.669	3.452	21.1461	31.74	3.18	438	1.966	37.32	0.677	3.36	21.1227	31.4	3.67
19	Mar 19,2	8:45a	428.75	19:07:05	1147.08	0.53823	2.01571	53.3439	3.18	468.2	1.977	37.75	0.676	3.371	21.7661	30.2	3.19	476	1.973	37.83	0.661	3.415	24.4452	30.43	3.25
20	Mar 20,2	8:45a	411.78	19:24:12	1164.20	0.50933	1.90746	54.886	3.18	499	1.979	37.87	0.731	3.372	24.6208	29.8	3.17	500.4	1.937	37.939	0.758	3.331	24.5385	28.77	3.23
21	Mar 21,2	9:18a	452.96	20:26:23	1226.38	0.53186	1.99183	56.5824	3.22	505.9	1.945	30.552	0.613	3.384	21.1751	31.63	3.19	506.9	1.874	30.333	0.568	3.287	20.6227	31.55	3.24
22	Mar 24,2	9:05a	1538.17	67:50:07	4070.12	0.5442	2.03805	62.3429	3.18	521.1	2.08	37.947	0.624	3.4	23.849	31.04	3.19	520.7	1.976	37.838	0.665	3.282	24.5629	30.91	3.26
23	Mar 25,2	1040a	522.82	21:32:48	1292.80	0.58235	2.18092	64.3008	3.17	523.1	1.993	38.336	0.603	3.757	22.6026	31.75	3.17	522.3	2.07	38.633	0.582	3.688	22.3661	31.37	3.21
24	Mar 26,2	1005a	463.81	19:22:34	1162.57	0.57449	2.1515	66.0378	3.17	520	1.986	38.404	0.686	3.552	23.2846	29.91	3.17	520.3	1.992	37.562	0.701	3.639	23.787	28.53	3.2
25	Mar 27,2	10a	477.53	19:28:37	1168.62	0.58842	2.20367	67.8262	3.16	525.9	2.07						3.16	520.8	1.959						3.21
26	Mar 28,2	9:40a	466.87	19:28:38	1168.63	0.57528	2.15445	69.5746	3.15	518	1.996						3.15	521.7	2.07						3.19

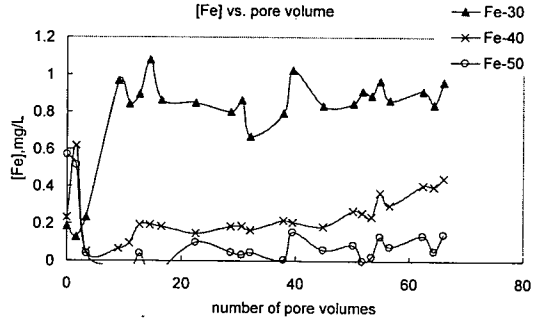
							40cm								50cm										
mV-30	EC-30	Cu-30	Fe-30	Mn-30	Zn-30	Al-30	pH-40	mV-40	EC-40	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-50	mV-50	EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	Eh-50	pe-50	pH+pe-5
393.6	2.45	2.538	0.189	2.855	4.9505	0.15	7.48	310	3.02	-0.01	0.233	0.034	0.0412	-0.71	7.58	280.5	3.28	0.057	0.57	0.846	0.2351	-0.66	482.5	8.178	15.758
399	2.13	19.719	0.129	4.042	16.4862	24.62	6.95	251.9	2.64	0.024	0.619	0.259	-0.108	0.28	7.36	255.7	2.73	0.026	0.514	0.072	0.0021	0.31	457.7	7.7576	15.118
321.8	1.875	28.25	0.234	3.469	18.4224	32	6.19	283.6	2.56	0.694	0.048	2.388	3.4678	0.24	7.27	270.2	2.64	-0.022	0.039	-0.054	-0.0014	0	472.2	8.0034	15.273
372.6	1.873	35.056	0.966	3.399	22.0027	36.9	4.25	336.8	2.29	14.285	0.065	3.541	12.941	18.38	6.91	288.5	2.58	0.03	-0.036	0.219	0.0069	-0.05	490.5	8.3136	15.224
431.1	1.865	31.008	0.843	3.449	21.4472	37.31	4.1	396.2	2.15	16.544	0.095	3.584	14.658	24.18	6.8	338.1	2.52	0.011	-0.093	0.824	0.0209	-0.02	540.1	9.1542	15.954
417.7	1.885	33.498	0.894	3.453	20.9771	35.45	4.02	363.2	1.986	20.849	0.194	3.663	16.253	28.83	6.63	284.8	2.45	0.006	0.041	1.843	0.5313	-0.32	486.8	8.2508	14.881
444.5	1.915	29.371	1.08	3.262	21.1724	36.98	4.03	381.8	1.95	19.461	0.195	3.356	16.057	29.34	6.05	331.2	2.43	0.098	-0.071	3.094	3.1276	0.1	533.2	9.0373	15.087
467.3	1.902	34.767	0.86	3.551	21.5744	36.03	3.97	406.7	1.911	24.099	0.183	3.46	18.009	35.25	5.51	304.6	2.34	1.404	-0.046	4.215	7.3406	1.75	506.6	8.5864	14.096
470.2	1.73	36.645	0.847	3.382	23.2692	37.27	3.96	361.6	1.874	30.994	0.147	3.681	20.386	33.88	4.25	327.8	2.21	10.557	0.097	4.513	14.769	14.53	529.8	8.9797	13.23
																							202		
457	1.953	38.837	0.8	3.272	23.8706	33.42	3.18	460.9	1.959	38.985	0.184	3.274	20.109	33.2	4.02	389.3	1.679	15.861	0.046	3.9	15.892	26.73	591.3	10.022	14.042
477.6	1.91	31.689	0.863	3.371	21.6098	34.75	3.87	416.1	1.901	29.686	0.187	3.456	18.521	33.45	3.98	400.7	2.08	15.786	0.032	3.626	14.775	30.84	602.7	10.215	14.195
502.4	1.957	31.357	0.666	3.258	21.3685	32.97	3.81	453.4	1.895	24.218	0.166	3.446	18.162	31.29	3.95	415.5	1.953	16.43	0.045	3.561	16.234	27.45	617.5	10.466	14.416
483.1	1.95	37.992	0.793	3.255	22.9365	27.76	3.83	437.7	1.883	32.301	0.218	3.296	20.455	27.34	3.98	379.1	1.704	23.257	0.008	3.28	18.136	25.25	581.1	9.8492	13.829
492.1	1.954	39.729	1.024	3.223	23.6453	30.54	3.83	457.8	1.906	32.97	0.206	3.386	20.821	32.72	4	390.7	1.877	23.968	0.153	3.284	18.22	29.66	592.7	10.046	14.046
468.6	1.961	36.089	0.832	3.498	21.8276	35.01	3.84	370.4	1.878	30.725	0.183	3.508	18.799	34.28	4.01	345.5	1.881	25.842	0.059	3.64	16.981	32.15	547.5	9.2797	13.29
470.1	1.966	32.161	0.846	3.413	21.1385	33.58	3.82	384.9	1.907	26.473	0.271	3.464	18.104	33.04	3.98	373.9	1.879	24.49	0.086	3.674	17.478	30.78	575.9	9.761	13.741
482.5	1.962	36.708	0.911	3.417	20.5352	33.46	3.78	444.3	1.903	29.94	0.258	3.522	17.343	32.9	3.98	381	1.862	25.154	0	3.62	15.936	31.73	583	9.8814	13.861
491.1	1.97	36.68	0.888	3.482	23.5026	31.45	3.77	452.9	1.921	32.322	0.236	3.414	20.85	29.59	3.98	419.1	1.874	28.511	0.024	3.548	18.521	29.12	621.1	10.527	14.507
516.1	1.962	36.72	0.966	3.442	23.1837	30.69	3.77	471	1.859	32.261	0.365	3.392	20.401	28.4	3.97	442.2	1.863	28.733	0.131	3.474	19.741	27.95	644.2	10.919	14.889
531	1.968	36.643	0.86	3.383	20.8965	32.97	3.71	492.3	1.95	30.788	0.298	3.452	18.037	30.18	3.96	450.6	1.879	27.035	0.074	3.574	16.51	30.93	652.6	11.061	15.021
533.3	1.952	33.481	0.911	3.259	23.4449	31.71	3.69	508.5	1.919	28.667	0.406	3.654	19.055	31	4.07	468	1.865	29.638	0.135	3.937	19.017	31.31	670	11.356	15.426
540.4	1.97	38.248	0.839	3.662	22.3447	32.49	3.65	509.6	1.957	34.919	0.399	3.718	20.215	29.61	4	464	1.852	30.596	0.051	3.56	18.67	31.06	666	11.288	15.288
539.5	1.983	38.07	0.96	3.733	22.9141	30.56	3.67	501.1	1.941	34.358	0.444	3.565	20.303	29.04	3.99	466.5	1.861	30.04	0.142	3.594	18.932	27.96	668.5	11.331	15.321
530.6	1.971						3.61	510.8	1.905						3.97	467.8	1.857						669.8	11.353	15.323
538.2	1.966						3.57	511.5	1.924						3.93	470.4	1.856						672.4	11.397	15.327

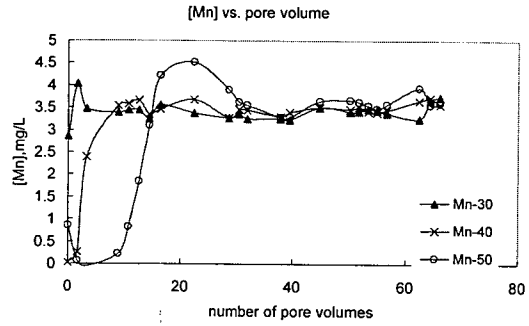

pH vs. pore volume
pH
number of pore volumes
pH-30
pH-40
pH-50

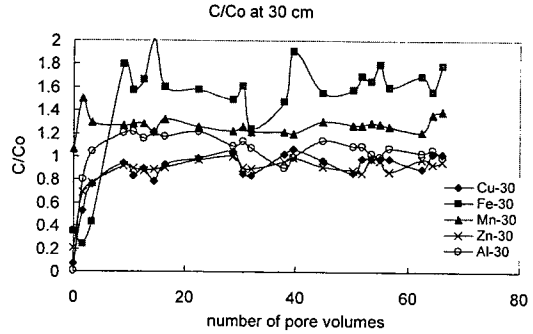

mV vs. pore volume
mV
number of pore volumes
mV-30
mV-40
mV-50

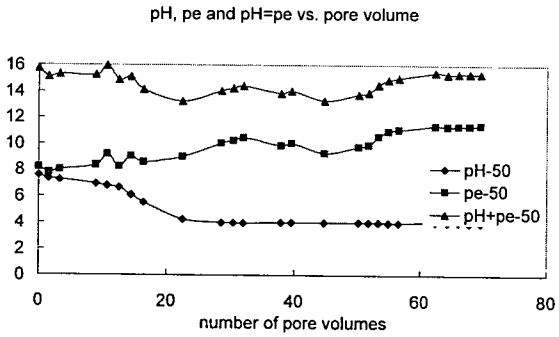

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-30
EC-40
EC-50

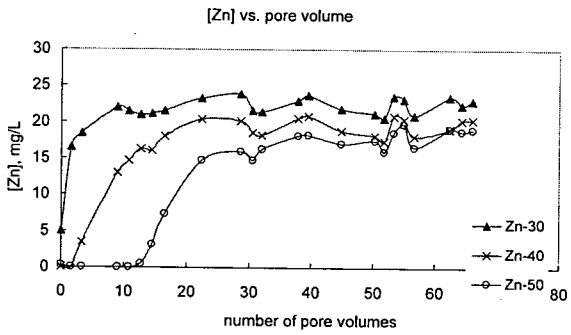

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-30
Cu-40
Cu-50

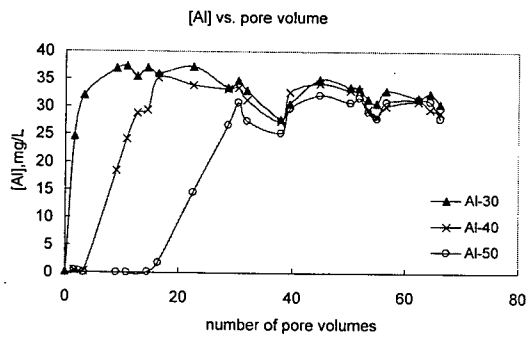

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-30
Fe-40
Fe-50

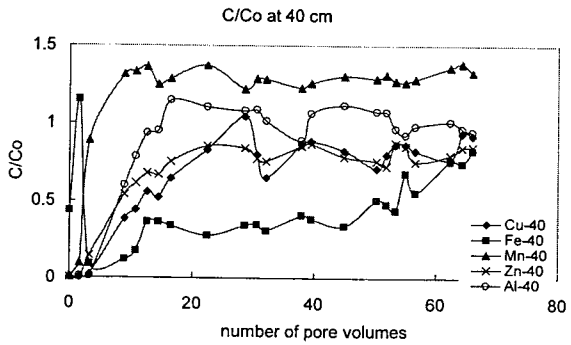

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-30
Mn-40
Mn-50

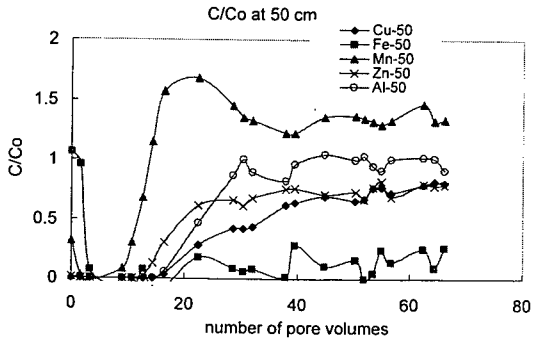

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
20
40
60
80
number of pore volumes
pH-50
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
30
25
20
15
10
5
0
0
10
20
30
40
50
60
80
number of pore volumes
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
40
35
30
25
20
15
10
5
0
0
20
40
60
80
number of pore volumes
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
2
1.5
1
0.5
0
0
20
40
60
80
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID PTB18

wt soil before filling column	g
wt soil after filling column	g
wt soil in column	417.28 g
Date start	Feb 19, 2003
leachate	non-filtered orig conc ARD 010902
pore volume	267.02 ml
flowrate	0.53502 L/day
	0.39939 m/day

initial concentration of metals, Co	
[Cu]o	36.23 mg/L
[Fe]o	10.74 mg/L
[Mn]o	3.62 mg/L
[Zn]o	23.92 mg/L
[Al]o	34.85 mg/L
pH	3.14
mV	504.9 mV
EC	1.99 mS/cm

☑ 1 M NaCl pretreated ☐ No pretreatment

ARD concentration:

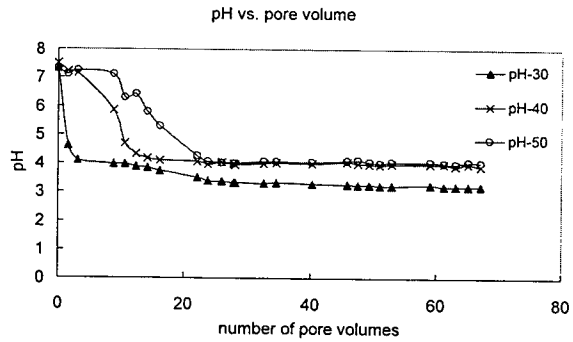
☑ Natural ☐ Maximum design

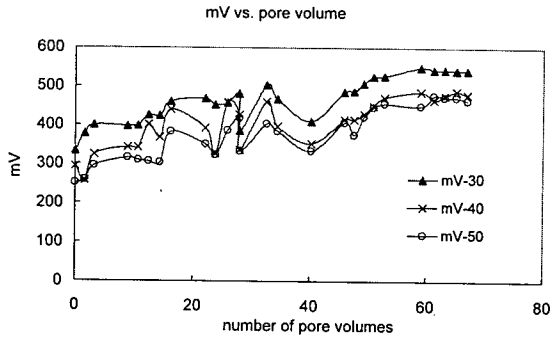
☐ Filtered ☑ Non-filtered

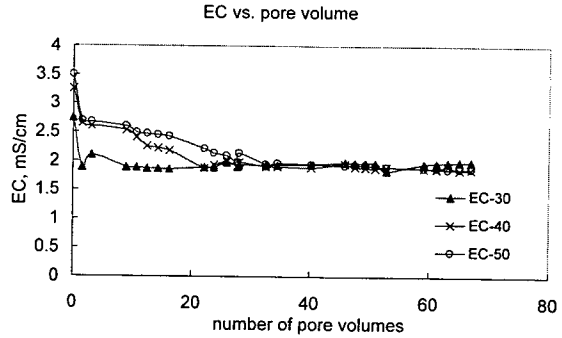
Linear flow rate: 0.5 m/day reactor bed

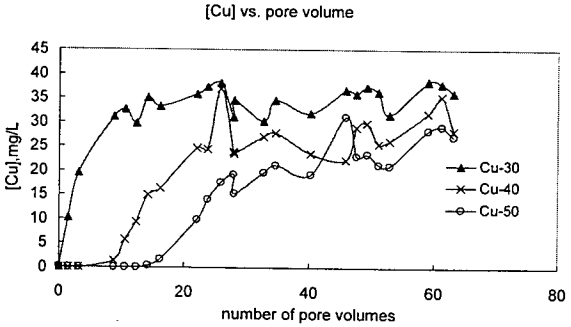
ID	Date	Time	vol effl (n	time used hh:mm:ss	(min)	Flowrate L/day	pv/day	#pore vol	10cm pH-10	mV-10	EC-10	Cu-10	Fe-10	Mn-10	Zn-10	Al-10	20cm pH-20	mV-20	EC-20	Cu-20	Fe-20	Mn-20	Zn-20	Al-20	30cm pH-30	mV-30
1	Feb 19,2	9:00a	0	19:50:30	1190.5	0	0	0	3.32	465	1.976	35.535	0.523	3.533	22.0135	32.93	3.32	460.9	1.943	34.41	0.448	3.534	22.1345	33.93	7.34	334
2	Feb 20,2	8:45a	408.14	19:17:01	1157.017	0.50796	1.90234	1.5285	3.19	443.7	1.976	35.019	0.543	3.518	23.3508	34.12	3.2	456.8	1.965	35.225	0.409	3.434	22.9493	33.67	4.62	377.1
3	Feb 21,2	9:00a	429.2	19:49:08	1189.133	0.51975	1.94647	3.13587	3.17	404.3	1.978	35.381	0.509	3.092	21.987	36.51	3.17	450.2	1.967	34.554	0.539	3.041	21.9909	37.34	4.11	399.5
4	Feb 24,2	9:20a	1527.48	67:55:23	4075.38	0.53972	2.02127	8.85633	3.15	440.5	1.97	37.498	0.488	3.152	22.949	35.11	3.14	449.9	1.983	37.146	0.522	3.116	23.0374	35.55	3.97	397.5
5	Feb 25,2	9:10a	465.76	19:19:11	1159.183	0.57859	2.16685	10.6006	3.17	466.7	1.987	37.548	0.542	3.174	23.4872	34.94	3.16	462.4	1.982	37.764	0.511	3.226	21.165	34.77	3.97	398.4
6	Feb 26,2	9:30a	483.19	20:01:39	1201.65	0.57903	2.16849	12.4102	3.14	442	1.979	35.619	0.527	3.117	23.015	35.8	3.14	448.5	1.969	35.808	0.582	3.039	21.6489	35.79	3.89	425.8
7	Feb 27,2	9:15a	481.66	20:22:20	1222.333	0.56743	2.12505	14.214	3.15	470.1	1.988	36.761	0.494	3.178	22.3112	34.57	3.14	472.8	1.973	37.095	0.431	3.178	22.8322	34.4	3.84	423.6
8	Feb 28,2	8:45a	512.08	19:07:10	1147.167	0.6428	2.4073	16.1318	3.13	466.6	1.918	32.281	0.532	3.258	23.8969	35.86	3.12	477.3	1.96	36.234	0.527	3.227	22.8542	33.82	3.75	460.2
9	Mar 3,20	8:45a	1611.94	67:50:31	4070.52	0.57025	2.13559	22.1685	3.15	422	1.965	38.1	0.556	3.376	24.3453	33.74	3.14	452.6	1.985	37.097	0.576	3.31	23.6246	34.64	3.5	467.6
10	Mar 4,20	9:30a	441.64	20:47:47	1247.783	0.50967	1.90874	23.8225	3.14	452.8	1.962	37.92	0.548	3.197	24.1354	33.83	3.12	462.6	1.976	37.478	0.633	3.247	24.2835	35.75	3.39	452.4
11	Mar 5,20	8:45a	563.74	21:12:52	1272.867	0.63776	2.38844	25.9337	3.14	349.8	1.902	27.603	0.194	3.45	19.1293	31.47	3.15	492	1.879	36.215	0.827	3.287	23.3292	36.56	3.38	457.9
12	Mar 6,20	8:50a	519.44	19:08:09	1148.15	0.65148	2.4398	27.879	3.13	467.7	1.979	33.153	0.481	3.256	20.9611	36.43	3.15	467.8	1.986	31.511	0.491	3.284	20.2354	36.86	3.33	481.2
13	Mar 7,20	9:35a	31.71	19:41:40	1181.667	0.03864	0.14472	27.9978	3.12	467.6	1.996	36.367	0.482	3.222	23.312	29.03	3.12	358.3	1.982	37.472	0.508	3.206	23.1489	28.44	3.34	385.4
14	Mar 10,2	9:25a	1233.65	67:33:12	4053.20	0.43828	1.64139	32.6179	3.16	463.5	1.942	35.181	0.516	3.081	23.168	31.47	3.15	467.7	1.977	36.367	0.54	3.123	23.279	30.99	3.3	503.7
15	Mar 11,2	9:15a	509.04	19:17:56	1157.933	0.63304	2.37075	34.5242	3.17	460.5	1.989	37.996	0.526	3.087	23.6737	30.98	3.18	453	1.949	34.781	0.546	3.103	23.9438	29.07	3.32	466.6
16	Mar 14,2	9:30a	1521.16	67:00:40	4020.67	0.5448	2.0403	40.221	3.19	387.1	1.98	36.702	0.576	3.436	21.7302	33.4	3.19	401.1	1.976	33.586	0.55	3.497	21.0608	33.3	3.29	409.3
17	Mar 17,2	9:40a	1512.74	68:20:18	4100.30	0.53126	1.98961	45.8863	3.19	458.8	1.992	35.431	0.549	3.42	21.6403	33.32	3.19	454.3	1.991	37.158	0.543	3.436	21.9688	33.68	3.27	486.4
18	Mar 18,2	9:00a	444.38	18:50:32	1130.53	0.56602	2.11977	47.5505	3.19	466.2	1.939	37.217	0.591	3.429	21.8677	31.89	3.17	466.5	1.991	34.945	0.551	3.419	22.263	31.91	3.25	487.1
19	Mar 19,2	8:45a	458.29	19:07:05	1147.08	0.57532	2.15459	49.2668	3.2	482.7	1.984	37.823	0.565	3.443	23.4942	31.05	3.17	490.8	1.989	37.633	0.521	3.577	22.6026	30.25	3.24	508.5
20	Mar 20,2	8:45a	456.68	19:24:12	1164.20	0.56487	2.11545	50.9771	3.2	496.2	1.964	37.256	0.645	3.359	24.6052	28.21	3.17	503.1	1.971	37.904	0.647	3.369	24.3607	27.77	3.23	525.6
21	Mar 21,2	9:18a	488.77	20:26:23	1226.38	0.57391	2.1493	52.8076	3.18	510.7	1.955	35.704	0.499	3.351	19.8026	31.53	3.17	510.2	1.99	34.217	0.513	3.331	18.9152	30.38	3.23	527.7
22	Mar 24,2	9:05a	1671.09	67:50:07	4070.12	0.59123	2.21417	59.0659	3.18	523	2.08	37.717	0.548	3.786	23.3563	32.29	3.19	519.7	1.975	40.343	0.555	3.513	23.8539	30.74	3.24	548.5
23	Mar 25,2	1040a	570.13	21:32:48	1292.80	0.63505	2.37827	61.201	3.17	521.8	1.985	38.707	0.576	3.433	23.6582	31.66	3.17	516.3	1.984	38.271	0.585	3.324	23.8843	29.87	3.2	542.3
24	Mar 26,2	1005a	511.32	19:22:34	1162.57	0.63334	2.37188	63.1159	3.17	522.4	2.07	38.569	0.604	3.473	22.5032	28.71	3.16	516.4	1.996	36.754	0.568	3.527	21.8553	28.19	3.2	542.6
25	Mar 27,2	10a	523.94	19:28:37	1168.617	0.64561	2.41784	65.0781	3.16	520.6	1.99						3.15	522.2	1.985						3.2	541.1
26	Mar 28,2	9:40a	515.02	19:28:38	1168.633	0.63461	2.37664	67.0069	3.14	525.9	1.99						3.16	518.4	1.993						3.19	541

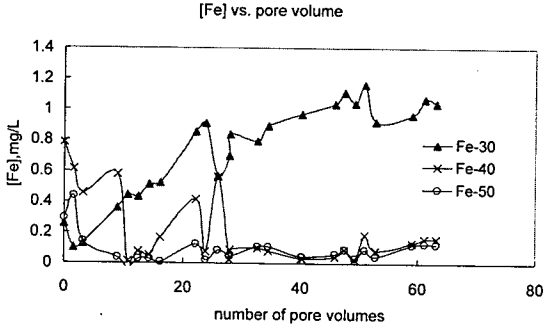
						40cm								50cm										
EC-30	Cu-30	Fe-30	Mn-30	Zn-30	Al-30	pH-40	mV-40	EC-40	Cu-40	Fe-40	Mn-40	Zn-40	Al-40	pH-50	mV-50	EC-50	Cu-50	Fe-50	Mn-50	Zn-50	Al-50	Eh-50	pe-50	pH+pe-5
2.74	0.022	0.254	0.409	0.1709	-0.71	7.51	294	3.25	0.017	0.785	0.075	-0.0071	-0.47	7.33	251.1	3.5	0.14	0.292	2.964	0.5889	-0.7	453.1	7.6797	15.01
1.886	10.252	0.099	4.62	13.5393	7.9	7.22	257.4	2.65	0.01	0.616	0.056	-0.0475	0.37	7.12	258.6	2.69	0.022	0.436	-0.012	-0.0066	0.27	460.6	7.8068	14.927
2.1	19.455	0.127	3.806	15.9727	26.63	7.16	323.7	2.61	-0.001	0.453	-0.019	-0.0258	0.24	7.25	294.7	2.67	-0.019	0.138	-0.134	-0.0214	0.02	496.7	8.4186	15.669
1.883	31.157	0.36	3.558	20.4696	35.52	5.87	343	2.53	1.36	0.579	2.814	4.9414	0.72	7.11	315.1	2.59	0.004	0.036	0.3	-0.0056	-0.02	517.1	8.7644	15.874
1.885	32.565	0.441	3.606	22.9355	38.2	4.7	342.5	2.4	5.673	0.012	3.699	9.3495	5.01	6.3	310.1	2.49	0.003	-0.032	0.945	0.0319	-0.01	512.1	8.6797	14.98
1.865	29.746	0.432	3.435	19.7541	39.21	4.32	401.7	2.25	9.326	0.074	3.594	10.706	15.67	6.43	306	2.47	-0.001	0.028	1.536	0.9442	-0.39	508	8.6102	15.04
1.868	34.969	0.511	3.412	21.6769	37.05	4.18	367.5	2.22	14.868	0.051	3.649	14.329	22.32	5.8	303.8	2.45	0.43	0.026	2.667	3.4679	0.48	505.8	8.5729	14.373
1.856	33.296	0.522	3.431	22.4619	38.69	4.1	439	2.18	16.274	0.169	3.573	14.889	24.36	5.29	382.2	2.42	1.644	0.007	3.243	5.7545	1.56	584.2	9.9017	15.192
1.888	35.822	0.855	3.406	23.4732	37.39	4.06	391.7	1.882	24.592	0.416	3.519	17.947	30.05	4.25	350.7	2.21	9.85	0.123	3.77	12.381	16.51	552.7	9.3678	13.618
1.883	37.26	0.91	3.535	23.1365	38.19	3.98	327.5	1.928	24.39	0.076	3.569	17.904	31.02	4.07	324.6	2.13	13.994	0.02	3.793	14.662	23.61	526.6	8.9254	12.995
1.974	38.093	0.566	3.153	24.4839	35.06	4.05	459.5	1.985	36.935	0.559	3.102	23.881	33.65	4.03	385.8	2.09	17.612	0.084	3.506	14.793	27.97	587.8	9.9627	13.993
1.901	31.066	0.699	3.392	19.7855	41.43	3.99	427	1.919	23.874	0.022	3.453	16.282	35.41	3.99	417.5	1.969	19.21	0.047	3.649	14.849	33.39	619.5	10.5	14.49
1.93	34.499	0.838	3.643	22.1494	31.11	3.96	336.6	1.978	23.452	0.087	3.53	16.656	24.93	4.01	334	2.13	15.283	0.045	3.582	14.307	24.23	536	9.0847	13.095
1.924	30.267	0.795	3.248	22.4557	34.65	4.01	460.1	1.902	27.01	0.1	3.475	19.118	27.86	4.07	402.4	1.945	19.642	0.108	3.389	15.975	26.08	604.4	10.244	14.314
1.931	34.452	0.894	3.172	23.0437	32.75	4.03	397.5	1.903	27.849	0.078	3.264	19.299	42.63	4.06	384.9	1.963	21.162	0.107	3.291	16.439	35.01	586.9	9.9475	14.007
1.945	31.87	0.969	3.467	20.7311	34.66	4.01	352.7	1.89	23.561	0.033	3.557	16.32	31	4.04	334	1.942	19.192	0.043	3.471	13.366	29.24	536	9.0847	13.125
1.975	36.696	1.037	3.484	21.4205	34.75	4.04	413.8	1.953	22.225	0.044	3.589	16.176	29.83	4.08	406.5	1.922	31.082	0.061	3.773	18.146	31.01	608.5	10.314	14.394
1.963	35.883	1.111	3.489	24.777	34.58	3.99	413.8	1.893	28.97	0.089	3.665	20.75	31.76	4.1	375.1	1.935	23.031	0.086	3.647	18.064	27.92	577.1	9.7814	13.881
1.967	37.306	1.042	3.548	22.3552	32.88	3.98	428.8	1.888	29.862	0.029	3.765	19.712	30.26	4.04	421.1	1.93	23.381	0.03	3.813	17.511	28.03	623.1	10.561	14.601
1.958	36.245	1.163	3.35	24.2562	29.41	3.95	450.5	1.88	25.573	0.182	3.477	20.405	28.34	4.01	446.4	1.912	21.185	0.088	3.48	18.464	35.73	648.4	10.99	15
1.834	31.626	0.923	3.328	18.3499	31.17	3.97	471.2	1.897	26.203	0.085	3.51	15.905	30.53	4.04	455.6	1.898	21.025	0.045	3.522	16.26	27.56	657.6	11.146	15.186
1.957	38.428	0.964	3.738	23.2328	32.12	3.98	485.5	1.88	31.872	0.131	3.942	20.401	33.75	4.04	449.4	1.874	28.34	0.118	3.821	19.196	31.22	651.4	11.041	15.081
1.963	37.976	1.07	3.616	23.5663	32.76	3.97	465.7	1.871	35.233	0.158	3.75	22.62	34.5	4	475.6	1.877	29.069	0.129	3.786	20.078	29.6	677.6	11.485	15.485
1.968	36.005	1.042	3.516	21.3372	29.47	3.92	476.2	1.907	28.236	0.161	3.679	20.292	31.61	3.98	471.7	1.858	26.99	0.124	3.694	18.396	28.02	673.7	11.419	15.399
1.982						3.97	487.7	1.848						4.04	471.3	1.869						673.3	11.412	15.452
1.98						3.89	478.8	1.858						4.03	463.7	1.868						665.7	11.283	15.313

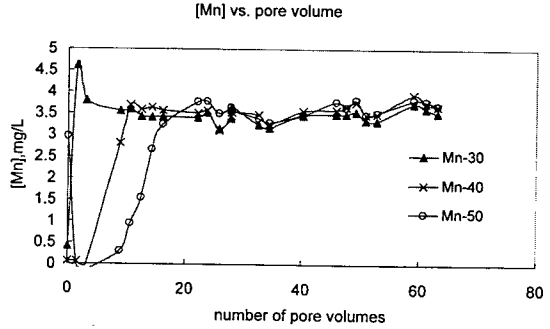

pH vs. pore volume
pH
number of pore volumes
pH-30
pH-40
pH-50

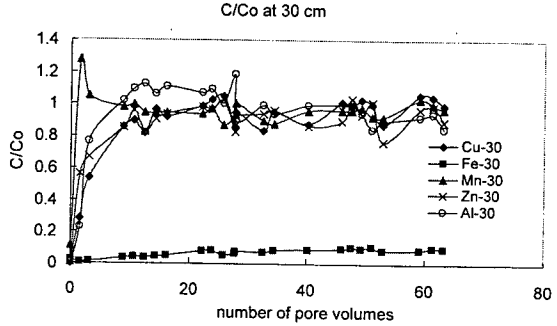

mV vs. pore volume
mV
number of pore volumes
mV-30
mV-40
mV-50

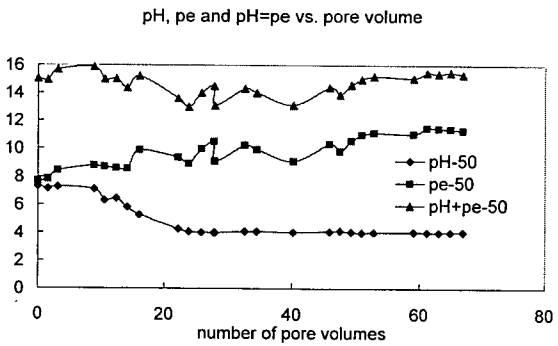

EC vs. pore volume
EC, mS/cm
number of pore volumes
EC-30
EC-40
EC-50

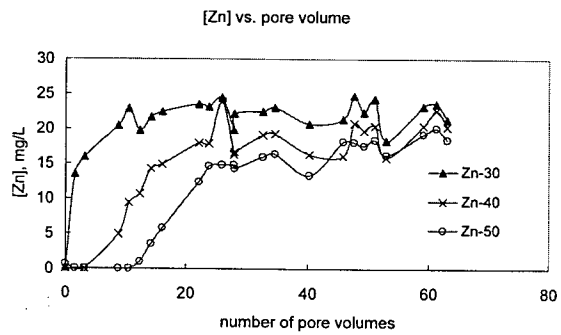

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu-30
Cu-40
Cu-50

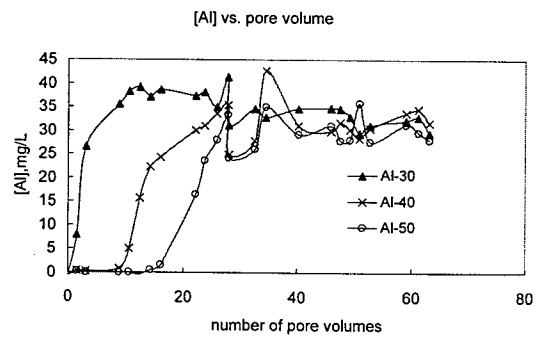

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe-30
Fe-40
Fe-50

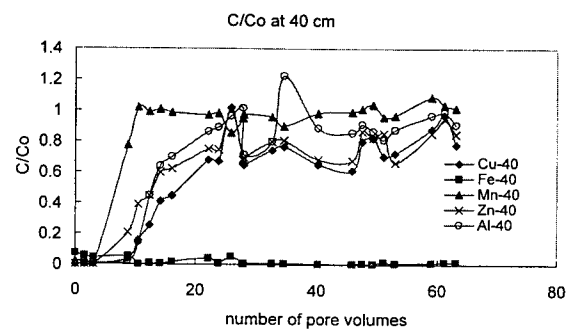

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-30
Mn-40
Mn-50

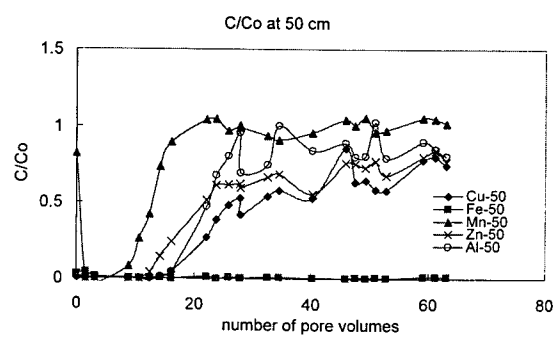

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


pH, pe and pH=pe vs. pore volume
16
14
12
10
8
6
4
2
0
0
20
40
60
80
number of pore volumes
pH-50
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
30
25
20
15
10
5
0
0
20
40
60
80
number of pore volumes
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
45
40
35
30
25
20
15
10
5
0
0
20
40
60
80
number of pore volumes
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Appendix H. Column leaching cell tests Soil Analyses Results

Appendix H-1. Results of metal fractionations on soil samples extracted from column leaching cells

Soil analysis

sample ID	Bulk Clinoptilolite
distance up column (cm)	10
wt. container(g)	1.02
wt. wet soil+container (g)	17.54
wt. dry soil + container (g)	17.01
water content, w%	0.033145716
soil pH	7.15

metals in soil, ppm (from AAS)

sample ID			Bulk Clinoptilolite
wt. wet soil (g)			2.0065
equiv. dry soil wt (g)			1.942126816
SSE-0	Initial rinse	Cu	0.001
		Fe	1.503
		Mn	0.133
		Zn	0.0444
		Al	0.66
SSE-1	Exchangeable	Cu	0.302
		Fe	0.317
		Mn	0.411
		Zn	0.194
		Al	3.82
SSE-2	Carbonates	Cu	0.451
		Fe	3.533
		Mn	2.662
		Zn	0.6118
		Al	3.87
SSE-3	Fe-, Mn-oxides	Cu	0.111
		Fe	40.228
		Mn	3.151
		Zn	0.7915
		Al	14.43
SSE-4	Organics	Cu	0.404
		Fe	8.37
		Mn	1.685
		Zn	1.2007
		Al	34.48
SSE-5	Residual	Cu	2.80275
		Fe	431.86
		Mn	2.528
		Zn	2.2789
		Al	924.9
wt. wet soil T.D. (g)			2.0009
amount of dry soil (g)			1.936706477
Total digestion initial rinse		Cu	-0.055
		Fe	1.98
		Mn	0.185
		Zn	-0.0128
		Al	0.85
Total digestion		Cu	3.02425
		Fe	535.41
		Mn	9.583
		Zn	4.5341
		Al	1090.5

Amount of metals in soil, mg metal/kg soil

sample ID			Bulk Clinoptilolite
wt. wet soil (g)			2.0065
equiv. dry soil wt (g)			1.942126816
SSE-0	Initial rinse	Cu	8.23839E-06
		Fe	0.012382302
		Mn	0.001095706
		Zn	0.000365785
		Al	0.005437338
SSE-1	Exchangeable	Cu	0.002487994
		Fe	0.00261157
		Mn	0.003385979
		Zn	0.001598248
		Al	0.031470653
SSE-2	Carbonates	Cu	0.003715514
		Fe	0.029106235
		Mn	0.021930597
		Zn	0.005040248
		Al	0.031882573
SSE-3	Fe-, Mn-oxides	Cu	0.002286153
		Fe	0.828534979
		Mn	0.064897925
		Zn	0.016301716
		Al	0.297199954
SSE-4	Organics	Cu	0.008320775
		Fe	0.172388331
		Mn	0.034704222
		Zn	0.02472959
		Al	0.710149301
SSE-5	Residual	Cu	0.057725376
		Fe	8.894578798
		Mn	0.052066631
		Zn	0.046936173
		Al	19.04921949
SSE total	SSE1+2+3+4+5	Cu	0.074535812
		Fe	9.927219912
		Mn	0.176985353
		Zn	0.094605974
		Al	20.11992197
wt. wet soil T.D. (g)			2.0009
amount of dry soil (g)			1.936706477
Total digestion initial rinse		Cu	-0.001135949
		Fe	0.040894168
		Mn	0.00382092
		Zn	-0.000264366
		Al	0.017555577
Total digestion		Cu	0.062461711
		Fe	11.05815479
		Mn	0.197923642
		Zn	0.093645579
		Al	22.52277282
Recovery rate	SSE/total*100%	Cu	119.330%
		Fe	89.773%
		Mn	89.421%
		Zn	101.026%
		Al	89.331%

Soil analysis

water content

sample ID	1 M NaCl Pretreated
distance up column (cm)	10
wt. container(g)	1.02
wt. wet soil+container (g)	18.15
wt. dry soil + container (g)	17.63
water content, w%	0.031306442
soil pH	7.5

metals in soil, ppm (from AAS)

sample ID			1 M NaCl Pretreated
wt. wet soil (g)			1.9911
equiv. dry soil wt (g)			1.930658
SSE-0	Initial rinse	Cu	0.057
		Fe	4.4308943
		Mn	0.186
		Zn	0.0902
		Al	5.75
SSE-1	Exchangeable	Cu	0.267
		Fe	0.209
		Mn	0.501
		Zn	0.182
		Al	0.78
SSE-2	Carbonates	Cu	0.417
		Fe	1.708
		Mn	2.413
		Zn	0.5672
		Al	1.82
SSE-3	Fe-, Mn-oxides	Cu	0.121
		Fe	36.779
		Mn	3.04
		Zn	0.8644
		Al	13.24
SSE-4	Organics	Cu	0.359
		Fe	9.486
		Mn	1.594
		Zn	1.0184
		Al	39.83
SSE-5	Residual	Cu	2.648
		Fe	407.96
		Mn	2.832
		Zn	2.2095
		Al	998.4
wt. wet soil T.D. (g)			2.0055
amount of dry soil (g)			1.9446208
Total digestion initial rinse		Cu	-0.019
		Fe	3.111
		Mn	0.195
		Zn	0.0269
		Al	11.24
Total digestion		Cu	3.1185
		Fe	487.83
		Mn	9.489
		Zn	4.1066
		Al	1117.9

Amount of metals in soil, mg metal/kg

sample ID			1 M NaCl Pretreated
wt. wet soil (g)			1.9911
equiv. dry soil wt (g)			1.93065797
SSE-0	Initial rinse	Cu	0.00047238
		Fe	0.03672028
		Mn	0.00154144
		Zn	0.00074752
		Al	0.04765215
SSE-1	Exchangeable	Cu	0.00221272
		Fe	0.00173205
		Mn	0.00415195
		Zn	0.00150829
		Al	0.00646412
SSE-2	Carbonates	Cu	0.00345582
		Fe	0.01415476
		Mn	0.01999733
		Zn	0.00470057
		Al	0.01508294
SSE-3	Fe-, Mn-oxides	Cu	0.00250692
		Fe	0.76199929
		Mn	0.06298371
		Zn	0.01790892
		Al	0.27431063
SSE-4	Organics	Cu	0.00743788
		Fe	0.19653403
		Mn	0.03302501
		Zn	0.02109954
		Al	0.8252109
SSE-5	Residual	Cu	0.05486213
		Fe	8.45224802
		Mn	0.0586743
		Zn	0.04577714
		Al	20.6851761
SSE total	SSE1+2+3+4+5	Cu	0.07047546
		Fe	9.42666816
		Mn	0.1788323
		Zn	0.09099447
		Al	21.8062447
wt. wet soil T.D. (g)			2.0055
amount of dry soil (g)			1.94462084
Total digestion initial rinse		Cu	-0.0003908
		Fe	0.06399191
		Mn	0.00401106
		Zn	0.00055332
		Al	0.23120188
Total digestion		Cu	0.06414618
		Fe	10.0344497
		Mn	0.19518458
		Zn	0.08447097
		Al	22.994714
Recovery rate	SSE/total*100%	Cu	109.867%
		Fe	93.943%
		Mn	91.622%
		Zn	107.723%
		Al	94.832%

Soil CELL analysis ID:

NTNFC1

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.01	1.02	1.02	1.02
wt. wet soil+container (g)	11.68	11.97	11.23	11.62	10.85
wt. dry soil + container (g)	11.38	11.69	10.98	11.33	10.6
water content, w%	2.896%	2.622%	2.510%	2.813%	2.610%
pH of soil	3.59	3.91	2.98	4.03	4.13

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0044	2.004	2.0046	2.0003	2.001
equiv. dry soil wt (g)			1.948	1.9528	1.95552	1.9456	1.95011
SSE-0	Initial rinse	Cu	1.245	0.51	0.347	0.149	0.07
		Fe	0.576	0.181	0.46	0.171	0.404
		Mn	0.134	0.088	0.075	0.038	0.031
		Zn	0.2044	0.1183	0.0897	0.0532	0.0396
		Al	0.39	0.18	0.24	0.1	0.14
SSE-1	Exchangeable	Cu	12.126	11.241	8.155	6.643	4.97
		Fe	0.651	0.328	0.314	0.245	0.15
		Mn	0.924	1.021	0.941	0.901	0.735
		Zn	4.1348	4.6728	4.4785	4.903	5.1338
		Al	31.53	28.38	23.84	25.86	16.48
SSE-2	Carbonates	Cu	21.395	17.788	18.153	13.672	11.687
		Fe	8	2.929	5.76	3.555	3.171
		Mn	1.77	1.492	2.668	2.657	2.88
		Zn	9.892	8.5479	7.9724	7.7582	15.9884
		Al	7.77	11.74	7.17	8.46	6.97
SSE-3	Fe-, Mn-oxides	Cu	12.764	10.235	12.375	9.041	8.312
		Fe	42.892	41.801	39.205	36.845	37.748
		Mn	1.704	2.722	2.593	2.6	2.697
		Zn	4.1785	4.6509	4.356	4.4119	4.6906
		Al	13.27	19.83	18.48	15.52	14.21
SSE-4	Organics	Cu	2.099	1.704	1.593	1.494	1.678
		Fe	15.91	15.138	17.868	14.529	15.141
		Mn	0.805	0.914	0.94	0.94	1.087
		Zn	1.9748	1.6109	1.7155	1.8045	2.2144
		Al	61.81	72.24	68.69	75.36	69.91
SSE-5	Residual	Cu	2.855	2.865	2.427	2.413	2.707
		Fe	493.82	560.29	609.61	554.8	629.86
		Mn	3.002	4.037	3.774	3.538	3.969
		Zn	4.6312	4.9361	4.7399	4.8473	5.8636
		Al	1102.3	1156.3	1136.6	1107.4	1210.5
wt. wet soil T.D. (g)			2.0039	2.0091	2.0029	2.001	2.0005
amount of dry soil (g)			1.9475	1.95777	1.95386	1.9463	1.94962
Total digestion initial rinse		Cu	1.269	0.437	0.254	0.193	0.092
		Fe	0.176	0.146	0.141	0.252	0.332
		Mn	0.115	0.077	0.059	0.059	0.037
		Zn	0.1779	0.0772	0.0506	0.0369	0.0068
		Al	0.14	0.07	0.03	0.17	0.2
Total digestion		Cu	27.453	28.087	22.438	20.199	17.534
		Fe	470.15	508.88	520.66	527.74	450
		Mn	4.497	5.629	5.913	6.92	6.857
		Zn	12.521	13.719	13.2956	12.946	13.6605
		Al	1099.4	1130.9	1080.6	1222.7	1149.1

Amount of metals in soil, mg metal/kg

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.004	2.004	2.005	2.0003	2.001
equiv. dry soil wt (g)			1.948	1.953	1.956	1.9456	1.95
SSE-0	Initial rinse	Cu	0.01	0.004	0.003	0.0012	6E-04
		Fe	0.005	0.001	0.004	0.0014	0.003
		Mn	0.001	7E-04	6E-04	0.0003	3E-04
		Zn	0.002	1E-03	7E-04	0.0004	3E-04
		Al	0.003	0.001	0.002	0.0008	0.001
SSE-1	Exchangeable	Cu	0.1	0.092	0.067	0.0546	0.041
		Fe	0.005	0.003	0.003	0.002	0.001
		Mn	0.008	0.008	0.008	0.0074	0.006
		Zn	0.034	0.038	0.037	0.0403	0.042
		Al	0.259	0.233	0.195	0.2127	0.135
SSE-2	Carbonates	Cu	0.176	0.146	0.149	0.1124	0.096
		Fe	0.066	0.024	0.047	0.0292	0.026
		Mn	0.015	0.012	0.022	0.0219	0.024
		Zn	0.081	0.07	0.065	0.0638	0.131
		Al	0.064	0.096	0.059	0.0696	0.057
SSE-3	Fe-, Mn-oxides	Cu	0.262	0.21	0.253	0.1859	0.17
		Fe	0.881	0.856	0.802	0.7575	0.774
		Mn	0.035	0.056	0.053	0.0535	0.055
		Zn	0.086	0.095	0.089	0.0907	0.096
		Al	0.272	0.406	0.378	0.3191	0.291
SSE-4	Organics	Cu	0.043	0.035	0.033	0.0307	0.034
		Fe	0.327	0.31	0.365	0.2987	0.311
		Mn	0.017	0.019	0.019	0.0193	0.022
		Zn	0.041	0.033	0.035	0.0371	0.045
		Al	1.269	1.48	1.405	1.5494	1.434
SSE-5	Residual	Cu	0.059	0.059	0.05	0.0496	0.056
		Fe	10.14	11.48	12.47	11.406	12.92
		Mn	0.062	0.083	0.077	0.0727	0.081
		Zn	0.095	0.101	0.097	0.0997	0.12
		Al	22.63	23.68	23.25	22.768	24.83
SSE total	SSE1+2+3+4+5	Cu	0.639	0.541	0.551	0.4333	0.397
		Fe	11.42	12.67	13.69	12.494	14.03
		Mn	0.135	0.178	0.179	0.1748	0.189
		Zn	0.337	0.338	0.323	0.3316	0.435
		Al	24.5	25.9	25.29	24.918	26.75
wt. wet soil T.D. (g)			2.004	2.009	2.003	2.001	2.001
amount of dry soil (g)			1.948	1.958	1.954	1.9463	1.95
Total digestion initial rinse		Cu	0.026	0.009	0.005	0.004	0.002
		Fe	0.004	0.003	0.003	0.0052	0.007
		Mn	0.002	0.002	0.001	0.0012	8E-04
		Zn	0.004	0.002	0.001	0.0008	1E-04
		Al	0.003	0.001	6E-04	0.0035	0.004
Total digestion		Cu	0.564	0.574	0.459	0.4151	0.36
		Fe	9.656	10.4	10.66	10.846	9.233
		Mn	0.092	0.115	0.121	0.1422	0.141
		Zn	0.257	0.28	0.272	0.2661	0.28
		Al	22.58	23.11	22.12	25.129	23.58
Recovery rate	SSE/total*100 %	Cu	113%	94%	120%	104%	110%
		Fe	118%	122%	128%	115%	152%
		Mn	146%	155%	148%	123%	134%
		Zn	131%	120%	119%	125%	155%
		Al	108%	112%	114%	99%	113%

Soil analysis	CELL ID:	sample ID	0-10	10-20	20-30	30-40	40-50
		distance up column	10	20	30	40	50
PTB1C1		wt. container(g)	1.03	1.02	1.02	1.01	1.02
		wt. wet soil+container (g)	11.99	15.34	12.33	10.36	13.29
		wt. dry soil + container	11.55	14.9	11.72	10	12.79
		water content,	4.183%	3.170%	5.701%	4.004%	######
		pH of soil	3.69	4.03	4.06	4.13	4.19

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0057	2.0082	2.0029	2.0039	2.0076
equiv. dry soil wt (g)			1.92518	1.9465	1.8949	1.9267	1.9258
SSE-0	Initial rinse	Cu	1.016	0.128	0.075	0.162	0.1
		Fe	0.271	0.411	0.543	0.166	0.24
		Mn	0.071	0.025	0.024	0.027	0.02
		Zn	0.1442	0.026	0.015	0.0092	0.025
		Al	0.25	0.14	0.27	0.17	0.12
SSE-1	Exchangeable	Cu	22.933	18.735	14.097	17.834	18.397
		Fe	0.753	0.421	0.356	0.393	0.482
		Mn	1.445	1.737	1.505	1.641	2.059
		Zn	6.5695	6.1004	5.5062	6.6151	8.4785
		Al	36.45	20.5	16.81	23.69	24.08
SSE-2	Carbonates	Cu	27.388	20.658	14.038	20.724	14.627
		Fe	6.53	3.759	3.126	3.39	3.709
		Mn	2.481	3.034	2.547	2.966	2.63
		Zn	11.478	10.7116	9.1403	12.0988	10.5695
		Al	15.01	9.71	10.7	20	20.35
SSE-3	Fe-, Mn-oxides	Cu	14.039	11.323	8.731	12.083	10.81
		Fe	38.847	45.419	35.696	37.617	35.74
		Mn	2.261	3.36	2.355	2.76	3.065
		Zn	4.7271	4.767	4.0385	5.4197	5.1226
		Al	22.55	22.76	21.41	25.65	22.83
SSE-4	Organics	Cu	2.287	1.917	1.439	1.945	2.324
		Fe	14.617	14.268	11.656	12.066	16.26
		Mn	0.868	1.408	0.755	1.099	1.396
		Zn	1.8428	1.8958	1.5929	2.3089	2.352
		Al	62.42	68.31	64.6	76.25	69.88
SSE-5	Residual	Cu	3.129	2.359	2.434	2.629	2.809
		Fe	563.94	611.9	583.2	564.36	533.87
		Mn	3.681	4.303	4.144	3.948	4.725
		Zn	5.779	4.889	4.8205	5.8088	5.5446
		Al	992.1	1128	1000.1	1174.1	1201.4
wt. wet soil T.D. (g)			2.0027	2.0072	2.0029	2.0043	2.0048
amount of dry soil (g)			1.9223	1.94553	1.8949	1.9271	1.9231
Total digestion initial rinse		Cu	0.768	0.115	0.063	0.107	0.074
		Fe	0.177	0.596	0.486	0.247	0.319
		Mn	0.054	0.03	0.025	0.025	0.02
		Zn	0.0729	0.033	0.0385	0.0276	-0.0027
		Al	0.09	0.31	0.12	0.08	0.25
Total digestion		Cu	34.2	28.407	22.746	27.708	25.624
		Fe	522.43	503.75	470.46	474.52	499.62
		Mn	7.631	7.4	6.477	6.762	6.36
		Zn	16.4947	15.9468	14.7221	16.9866	16.4975
		Al	1159.5	1224	1032.4	1159.1	1164

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0057	2.0082	2.0029	2.0039	2.0076
equiv. dry soil wt (g)			1.92518	1.9465	1.89487	1.92674	1.92579
SSE-0	Initial rinse	Cu	0.00844	0.00105	0.00063	0.00135	0.00083
		Fe	0.00225	0.00338	0.00459	0.00138	0.00199
		Mn	0.00059	0.00021	0.0002	0.00022	0.00017
		Zn	0.0012	0.00021	0.00013	7.6E-05	0.00021
		Al	0.00208	0.00115	0.00228	0.00141	0.001
SSE-1	Exchangeable	Cu	0.19059	0.154	0.11903	0.1481	0.15285
		Fe	0.00626	0.00346	0.00301	0.00326	0.004
		Mn	0.01201	0.01428	0.01271	0.01363	0.01711
		Zn	0.0546	0.05014	0.04649	0.05493	0.07044
		Al	0.30293	0.16851	0.14194	0.19673	0.20006
SSE-2	Carbonates	Cu	0.22762	0.16981	0.11853	0.1721	0.12153
		Fe	0.05427	0.0309	0.0264	0.02815	0.03082
		Mn	0.02062	0.02494	0.02151	0.02463	0.02185
		Zn	0.09539	0.08805	0.07718	0.10047	0.08781
		Al	0.12475	0.07982	0.09035	0.16608	0.16907
SSE-3	Fe-, Mn-oxides	Cu	0.29169	0.23268	0.18431	0.25085	0.22453
		Fe	0.80714	0.93335	0.75353	0.78094	0.74234
		Mn	0.04698	0.06905	0.04971	0.0573	0.06366
		Zn	0.09822	0.09796	0.08525	0.11252	0.1064
		Al	0.46853	0.46771	0.45196	0.5325	0.47419
SSE-4	Organics	Cu	0.04752	0.03939	0.03038	0.04038	0.04827
		Fe	0.3037	0.2932	0.24605	0.2505	0.33773
		Mn	0.01803	0.02893	0.01594	0.02282	0.029
		Zn	0.03829	0.03896	0.03363	0.04793	0.04885
		Al	1.29692	1.40375	1.36368	1.58298	1.45146
SSE-5	Residual	Cu	0.06501	0.04848	0.05138	0.05458	0.05834
		Fe	11.7171	12.5744	12.3111	11.7163	11.0888
		Mn	0.07648	0.08843	0.08748	0.08196	0.09814
		Zn	0.12007	0.10047	0.10176	0.12059	0.11517
		Al	20.6131	23.1801	21.1117	24.3748	24.9539
SSE total	SSE1+2+3+4+5	Cu	0.82244	0.64436	0.50363	0.666	0.60552
		Fe	12.8885	13.8353	13.3401	12.7792	12.2037
		Mn	0.17412	0.22562	0.18734	0.20033	0.22976
		Zn	0.40657	0.37558	0.34431	0.43645	0.42867
		Al	22.8063	25.2999	23.1596	26.8531	27.2487
wt. wet soil T.D. (g)			2.0027	.2.0072	2.0029	2.0043	2.00483
amount of dry soil (g)			1.9223	1.94553	1.89487	1.92713	1.92313
Total digestion initial rinse		Cu	0.01598	0.00236	0.00133	0.00222	0.00154
		Fe	0.00368	0.01225	0.01026	0.00513	0.00664
		Mn	0.00112	0.00062	0.00053	0.00052	0.00042
		Zn	0.00152	0.00068	0.00081	0.00057	-5.6E-05
		Al	0.00187	0.00637	0.00253	0.00166	0.0052
Total digestion		Cu	0.71165	0.58405	0.48016	0.57511	0.53296
		Fe	10.8709	10.3571	9.93121	9.84926	10.3918
		Mn	0.15879	0.15214	0.13673	0.14035	0.13228
		Zn	0.34323	0.32787	0.31078	0.35258	0.34314
		Al	24.1274	25.1654	21.7935	24.0586	24.2105
Recovery rate	SSE/total*100%	Cu	115.57%	110.33%	104.89%	115.80%	113.61%
		Fe	118.56%	133.58%	134.32%	129.75%	117.44%
		Mn	109.66%	148.30%	137.02%	142.73%	173.68%
		Zn	118.45%	114.55%	110.79%	123.79%	124.93%
		Al	94.52%	100.53%	106.27%	111.62%	112.55%

Soil analysis

CELL ID: PTB3

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	15.16	14.98	11.86	13.51	16.06
wt. dry soil + container (g)	14.84	14.7	11.64	13.28	15.77
water content, w%	0.02315	0.02047	0.02072	0.01876	0.01966
pH of soil	3.33	3.92	4.23	4.3	3.91

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0085	2.0091	2.0065	2.0055	2.0039
equiv. dry soil wt (g)			1.96305	1.9688	1.96578	1.96857	1.96526
SSE-0	Initial rinse	Cu	1.655	0.349	0.284	0.297	0.274
		Fe	0.205	1.843	1.668	2.506	1.648
		Mn	0.135	0.063	0.082	0.11	0.068
		Zn	0.2383	0.0595	0.0589	0.0905	0.046
		Al	0.11	0.5	0.94	0.73	0.59
SSE-1	Exchangeable	Cu	42.81	38.904	28.23	19.299	26.917
		Fe	2.911	0.658	0.363	0.333	0.368
		Mn	2.213	2.584	2.636	2.282	1.788
		Zn	8.7665	8.097	7.1976	6.3647	7.3599
		Al	35.57	19.42	16.04	16.68	26.4
SSE-2	Carbonates	Cu	64.02	28.823	19.357	18.51	38.037
		Fe	12.39	6.65	3.066	2.844	6.37
		Mn	3.165	2.923	2.417	2.427	3.806
		Zn	17.2184	11.7625	9.1962	9.4052	12.8603
		Al	3.51	3.76	4.92	5.23	4.9
SSE-3	Fe-, Mn-oxides	Cu	20.58	12.292	9.279	9.902	13.284
		Fe	90.593	60.393	43.155	43.621	52.895
		Mn	2.651	2.513	2.528	2.816	2.689
		Zn	6.2125	4.2747	3.6434	3.7641	5.4166
		Al	6.85	9.3	8.71	9.97	10.85
SSE-4	Organics	Cu	3.128	2.017	1.805	1.899	1.888
		Fe	31.496	20.638	19.873	17.677	14.542
		Mn	0.941	0.861	0.927	1.175	0.68
		Zn	2.0048	1.746	1.5727	1.7534	1.5645
		Al	51.95	62.44	66.65	68.22	66.56
SSE-5	Residual	Cu	3.104	1.982	1.988	2.037	2.282
		Fe	489.55	443.73	470.42	470.98	448.45
		Mn	3.174	3.168	3.468	3.626	3.058
		Zn	4.2127	3.7332	3.7425	3.8796	3.9739
		Al	1076.6	1076.4	1080.7	1153.2	1070.7
wt. wet soil T.D. (g)			2.002	2.0012	2.0056	2.0055	2.0065
amount of dry soil (g)			1.95669	1.96106	1.9649	1.96857	1.96781
Total digestion initial rinse		Cu	1.146	0.197	0.338	0.335	0.199
		Fe	0.214	1.024	2.024	2.096	0.85
		Mn	0.097	0.045	0.1	0.11	0.044
		Zn	0.1507	0.0057	0.0332	0.0332	0.0691
		Al	0.09	0.2	0.59	0.74	0.24
Total digestion		Cu	62.82	49.195	28.658	30.848	39.887
		Fe	604.86	603.73	532.89	520.11	497.42
		Mn	6.151	4.322	5.446	10.002	9.669
		Zn	20.5691	16.4001	12.8698	13.4604	17.4077
		Al	1075.1	1352.7	1175.1	1243	1147.2

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0085	2.0091	2.0065	2.0055	2.0039
equiv. dry soil wt (g)			1.96305	1.9688	1.96578	1.96857	1.96526
SSE-0	Initial rinse	Cu	0.01349	0.00284	0.00231	0.00241	0.00223
		Fe	0.00167	0.01498	0.01358	0.02037	0.01342
		Mn	0.0011	0.00051	0.00067	0.00089	0.00055
		Zn	0.00194	0.00048	0.00048	0.00074	0.00037
		Al	0.0009	0.00406	0.00765	0.00593	0.0048
SSE-1	Exchangeable	Cu	0.34893	0.31616	0.22977	0.15686	0.21914
		Fe	0.02373	0.00535	0.00295	0.00271	0.003
		Mn	0.01804	0.021	0.02146	0.01855	0.01456
		Zn	0.07145	0.0658	0.05858	0.05173	0.05992
		Al	0.28992	0.15782	0.13055	0.13557	0.21493
SSE-2	Carbonates	Cu	0.5218	0.23424	0.15755	0.15044	0.30967
		Fe	0.10099	0.05404	0.02496	0.02312	0.05186
		Mn	0.0258	0.02375	0.01967	0.01973	0.03099
		Zn	0.14034	0.09559	0.07485	0.07644	0.1047
		Al	0.02861	0.03056	0.04005	0.04251	0.03989
SSE-3	Fe-, Mn-oxides	Cu	0.41935	0.24974	0.18881	0.2012	0.27038
		Fe	1.84597	1.227	0.87813	0.88635	1.0766
		Mn	0.05402	0.05106	0.05144	0.05722	0.05473
		Zn	0.12659	0.08685	0.07414	0.07648	0.11025
		Al	0.13958	0.18895	0.17723	0.20258	0.22084
SSE-4	Organics	Cu	0.06374	0.04098	0.03673	0.03859	0.03843
		Fe	0.64178	0.4193	0.40438	0.35918	0.29598
		Mn	0.01917	0.01749	0.01886	0.02388	0.01384
		Zn	0.04085	0.03547	0.032	0.03563	0.03184
		Al	1.05856	1.26859	1.35621	1.38618	1.35473
SSE-5	Residual	Cu	0.06325	0.04027	0.04045	0.04139	0.04645
		Fe	9.97531	9.01522	9.57219	9.57	9.12754
		Mn	0.06468	0.06436	0.07057	0.07368	0.06224
		Zn	0.08584	0.07585	0.07615	0.07883	0.08088
		Al	21.9373	21.8691	21.9903	23.4322	21.7925
SSE total	SSE1+2+3+4+5	Cu	1.41706	0.88138	0.65331	0.58848	0.88407
		Fe	12.5878	10.7209	10.8826	10.8414	10.555
		Mn	0.1817	0.17767	0.182	0.19305	0.17636
		Zn	0.46507	0.35956	0.31572	0.31912	0.38759
		Al	23.454	23.515	23.6943	25.1991	23.6229
wt. wet soil T.D. (g)			2.002	2.0012	2.0056	2.0055	2.0065
amount of dry soil (g)			1.95669	1.96106	1.9649	1.96857	1.96781
Total digestion initial rinse		Cu	0.02343	0.00402	0.00688	0.00681	0.00405
		Fe	0.00437	0.02089	0.0412	0.04259	0.01728
		Mn	0.00198	0.00092	0.00204	0.00224	0.00089
		Zn	0.00308	0.00012	0.00068	0.00067	0.0014
		Al	0.00184	0.00408	0.01201	0.01504	0.00488
Total digestion		Cu	1.28421	1.00344	0.5834	0.62681	0.81079
		Fe	12.3649	12.3144	10.8482	10.5683	10.1111
		Mn	0.12574	0.08816	0.11087	0.20323	0.19654
		Zn	0.42049	0.33451	0.26199	0.27351	0.35385
		Al	21.9779	27.5912	23.9219	25.2569	23.3193
Recovery rate	SSE/total *100%	Cu	110.3%	87.8%	112.0%	93.9%	109.0%
		Fe	101.8%	87.1%	100.3%	102.6%	104.4%
		Mn	144.5%	201.5%	164.2%	95.0%	89.7%
		Zn	110.6%	107.5%	120.5%	116.7%	109.5%
		Al	106.7%	85.2%	99.0%	99.8%	101.3%

Soil analysis
CELL ID: PTB4

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container	14.69	11.77	14.45	14.42	14.42
wt. dry soil + container (g)	14.34	11.56	14.24	14.22	14.24
water content, ...%	0.0263	0.0199	0.0159	0.0152	0.0136
soil pH	3.17	3.42	4.26	4.59	4.26

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0027	2.0076	2.0005	2.0026	2.0069
equiv. dry soil wt (g)			1.9514	1.9684	1.9692	1.9727	1.9799
SSE-0	Initial rinse	Cu	5.632	1.444	0.443	0.593	0.354
		Fe	0.274	0.245	2.089	2.626	2.29
		Mn	0.316	0.094	0.085	0.12	0.088
		Zn	0.6581	0.174	0.0508	0.1319	0.0405
		Al	1	0.26	0.9	2.34	0.66
SSE-1	Exchangeable	Cu	40.12	28.61	10.928	28.021	30.596
		Fe	2.86	0.633	0.062	0.394	0.424
		Mn	1.483	1.078	0.915	3.659	3.553
		Zn	10.954	9.6019	6.7381	6.1073	5.4101
		Al	36.04	22.75	21.04	13.9	22.71
SSE-2	Carbonates	Cu	100.41	81.5	32.262	18.202	22.198
		Fe	15.88	10.92	6.81	3.539	3.705
		Mn	5.356	4.955	4.594	3.82	3.843
		Zn	23.12	22.3	11.145	8.7527	9.9818
		Al	4.2	4.48	5.26	7.62	6.7
SSE-3	Fe-, Mn-oxides	Cu	31.183	26.084	11.893	8.008	9.441
		Fe	98.417	56.556	51.194	41.591	43.323
		Mn	2.719	2.718	2.947	2.704	3.128
		Zn	9.2021	8.2887	4.7549	3.6143	3.9072
		Al	6.83	6.99	9.79	9.85	10.21
SSE-4	Organics	Cu	5.05	4.419	2.21	1.891	1.88
		Fe	36.648	22.598	19.488	23.353	16.874
		Mn	0.821	0.923	0.932	0.964	1.564
		Zn	2.6668	3.0316	1.9573	1.609	2.0676
		Al	48.17	53.17	71.46	67.9	71.27
SSE-5	Residual	Cu	4.146	3.471	1.987	1.622	1.698
		Fe	533.51	469.07	477.51	491.65	450.29
		Mn	3.062	3.095	3.18	3.069	3.757
		Zn	5.4092	5.391	4.348	3.691	4.0586
		Al	1155.7	1171.4	1131.7	1157	1115.4
wt. wet soil T.D. (g)			2.0086	2.0038	2.0054	2.0008	2.0021
amount of dry soil (g)			1.9572	1.9647	1.974	1.9709	1.9752
Total digestion initial rinse		Cu	4.111	1.647	0.304	0.485	0.485
		Fe	0.09	0.337	1.37	1.952	2.363
		Mn	0.247	0.109	0.06	0.103	0.091
		Zn	0.5561	0.2239	0.1123	0.2601	0.1268
		Al	0.45	0.2	0.36	13.42	1.02
Total digestion		Cu	92.4	96.995	35.447	24.875	30.576
		Fe	592.86	561.75	462.33	506.79	517.76
		Mn	10.232	11.312	10.558	11.614	11.988
		Zn	34.925	36.101	16.065	13.298	15.293
		Al	994.7	1083.9	1059.2	1161.5	1169.5

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0027	2.0076	2.0005	2.0026	2.0069
equiv. dry soil wt (g)			1.95142	1.96838	1.96922	1.97271	1.97994
SSE-0	Initial rinse	Cu	0.04618	0.01174	0.0036	0.00481	0.00286
		Fe	0.00225	0.00199	0.01697	0.0213	0.01851
		Mn	0.00259	0.00076	0.00069	0.00097	0.00071
		Zn	0.0054	0.00141	0.00041	0.00107	0.00033
		Al	0.0082	0.00211	0.00731	0.01898	0.00533
SSE-1	Exchangeable	Cu	0.32895	0.23256	0.08879	0.22727	0.24725
		Fe	0.02345	0.00515	0.0005	0.0032	0.00343
		Mn	0.01216	0.00876	0.00743	0.02968	0.02871
		Zn	0.08981	0.07805	0.05475	0.04953	0.04372
		Al	0.2955	0.18492	0.17095	0.11274	0.18352
SSE-2	Carbonates	Cu	0.82328	0.66247	0.26213	0.14763	0.17938
		Fe	0.1302	0.08876	0.05533	0.0287	0.02994
		Mn	0.04391	0.04028	0.03733	0.03098	0.03106
		Zn	0.18956	0.18126	0.09055	0.07099	0.08066
		Al	0.03444	0.03642	0.04274	0.0618	0.05414
SSE-3	Fe-, Mn-oxides	Cu	0.63918	0.53006	0.24158	0.16238	0.19073
		Fe	2.01734	1.14929	1.03988	0.84333	0.87524
		Mn	0.05573	0.05523	0.05986	0.05483	0.06319
		Zn	0.18862	0.16844	0.09658	0.07329	0.07894
		Al	0.14	0.14205	0.19886	0.19973	0.20627
SSE-4	Organics	Cu	0.10351	0.0898	0.04489	0.03834	0.03798
		Fe	0.75121	0.45922	0.39585	0.47352	0.3409
		Mn	0.01683	0.01876	0.01893	0.01955	0.0316
		Zn	0.05466	0.06161	0.03976	0.03263	0.04177
		Al	0.98738	1.08048	1.45154	1.37679	1.43984
SSE-5	Residual	Cu	0.08498	0.07054	0.04036	0.03289	0.0343
		Fe	10.9358	9.53209	9.69948	9.96903	9.09704
		Mn	0.06276	0.06289	0.06459	0.06223	0.0759
		Zn	0.11088	0.10955	0.08832	0.07484	0.08199
		Al	23.6894	23.8043	22.9878	23.4601	22.534
SSE total	SSE1+2+3+4+5	Cu	1.97991	1.58542	0.67775	0.60851	0.68965
		Fe	13.858	11.2345	11.1911	11.3178	10.3465
		Mn	0.1914	0.18592	0.18815	0.19726	0.23046
		Zn	0.63354	0.59891	0.36996	0.30128	0.32708
		Al	25.1467	25.2482	24.8519	25.2112	24.4178
wt. wet soil T.D. (g)			2.0086	2.0038	2.0054	2.0008	2.0021
amount of dry soil (g)			1.95717	1.96466	1.97404	1.97094	1.97521
Total digestion initial rinse		Cu	0.08402	0.03353	0.00616	0.00984	0.00982
		Fe	0.00184	0.00686	0.02776	0.03962	0.04785
		Mn	0.00505	0.00222	0.00122	0.00209	0.00184
		Zn	0.01137	0.00456	0.00228	0.00528	0.00257
		Al	0.0092	0.00407	0.00729	0.27236	0.02066
Total digestion		Cu	1.88844	1.9748	0.71826	0.50484	0.6192
		Fe	12.1167	11.4371	9.36819	10.2853	10.4852
		Mn	0.20912	0.23031	0.21394	0.23571	0.24277
		Zn	0.71377	0.735	0.32553	0.26988	0.3097
		Al	20.3293	22.068	21.4626	23.5725	23.6836
Recovery rate	SSE/total*100%	Cu	104.8%	80.3%	94.4%	120.5%	111.4%
		Fe	114.4%	98.2%	119.5%	110.0%	98.7%
		Mn	91.5%	80.7%	87.9%	83.7%	94.9%
		Zn	88.8%	81.5%	113.6%	111.6%	105.6%
		Al	123.7%	114.4%	115.8%	107.0%	103.1%

Soil analysis

CELL ID: PTB5

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	15.35	13.77	13.3	15.94	14.86
wt. dry soil + container (g)	15.03	13.52	13.08	15.74	14.71
water content, w%	0.02284	0.02	0.01824	0.01359	0.01096
soil pH	3.71	4.35	4.54	4.69	4.48

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0032	2.0075	2.0011	2.0025	2.0098
equiv. dry soil wt (g)			1.95847	1.96814	1.96525	1.97566	1.98802
SSE-0	Initial rinse	Cu	0.309	0.247	0.257	0.372	0.147
		Fe	0.48	1.799	2.419	2.794	1.451
		Mn	0.055	0.081	0.12	0.17	0.072
		Zn	0.0674	0.049	0.0769	0.1566	0.0318
		Al	1.05	4.74	2.21	7.31	1.09
SSE-1	Exchangeable	Cu	14.879	9.506	8.145	4.661	5.286
		Fe	0.728	0.36	0.295	0.15	0.126
		Mn	1.606	1.851	1.961	1.343	0.768
		Zn	3.8865	2.9571	3.3319	2.6814	2.4098
		Al	28.98	14.05	10.55	6.87	12.2
SSE-2	Carbonates	Cu	33.013	15.925	12.166	9.084	12.451
		Fe	7.41	5.43	3.568	2.648	2.959
		Mn	3.422	3.162	2.511	2.294	2.423
		Zn	9.7285	6.292	5.8332	4.9926	6.8616
		Al	7.3	2.75	2.55	2.96	6.16
SSE-3	Fe-, Mn-oxides	Cu	10.238	6.556	5.771	5.357	7.367
		Fe	32.748	34.652	31.504	29.009	37.432
		Mn	2.215	2.521	2.885	2.906	2.841
		Zn	4.2744	3.4506	2.9427	2.9517	3.6302
		Al	13.02	15.76	16.26	16.62	21.45
SSE-4	Organics	Cu	1.993	1.918	1.689	1.309	1.395
		Fe	19.328	19.955	19.302	15.795	14.108
		Mn	0.818	1.034	1.14	1.064	0.935
		Zn	1.7532	1.777	1.5018	1.437	1.6866
		Al	59.8	62.97	70.57	67.28	70.41
SSE-5	Residual	Cu	2.072	2.229	1.631	1.41	1.584
		Fe	447.66	465.13	419.37	459.8	491.38
		Mn	3.061	3.59	3.242	3.334	3.253
		Zn	4.2203	4.7214	3.4729	3.5403	4.0421
		Al	983.5	1169.8	1024.3	1104.8	1077.4
wt. wet soil T.D. (g)			2.0008	2.0034	2.0055	2.0069	2.0041
amount of dry soil (g)			1.95612	1.96412	1.96957	1.98	1.98238
Total digestion initial rinse		Cu	0.339	0.269	0.418	0.473	0.189
		Fe	0.591	2.266	2.805	3.388	2.059
		Mn	0.074	0.112	0.144	0.19	0.099
		Zn	0.1267	0.1127	0.1526	0.2453	0.1343
		Al	0.27	0.82	1.01	1.03	0.76
Total digestion		Cu	32.899	16.663	14.336	11.447	13.698
		Fe	520.6	468.83	476.4	516.48	487.68
		Mn	7.681	8.14	7.781	8.053	7.901
		Zn	15.745	13.8735	12.6879	12.3427	11.9873
		Al	1199.1	1064.8	1072.1	1157.2	1100.2

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0032	2.0075	2.0011	2.0025	2.0098
equiv. dry soil wt (g)			1.95847	1.96814	1.96525	1.97566	1.98802
SSE-0	Initial rinse	Cu	0.00252	0.00201	0.00209	0.00301	0.00118
		Fe	0.00392	0.01462	0.01969	0.02263	0.01168
		Mn	0.00045	0.00066	0.00098	0.00138	0.00058
		Zn	0.00055	0.0004	0.00063	0.00127	0.00026
		Al	0.00858	0.03853	0.01799	0.0592	0.00877
SSE-1	Exchangeable	Cu	0.12156	0.07728	0.06631	0.03775	0.04254
		Fe	0.00595	0.00293	0.0024	0.00121	0.00101
		Mn	0.01312	0.01505	0.01597	0.01088	0.00618
		Zn	0.03175	0.02404	0.02713	0.02172	0.01939
		Al	0.23676	0.11422	0.08589	0.05564	0.09819
SSE-2	Carbonates	Cu	0.2697	0.12946	0.09905	0.07357	0.10021
		Fe	0.06054	0.04414	0.02905	0.02145	0.02381
		Mn	0.02796	0.02571	0.02044	0.01858	0.0195
		Zn	0.07948	0.05115	0.04749	0.04043	0.05522
		Al	0.05964	0.02236	0.02076	0.02397	0.04958
SSE-3	Fe-, Mn-oxides	Cu	0.2091	0.13324	0.11746	0.10846	0.14823
		Fe	0.66885	0.70426	0.64122	0.58733	0.75315
		Mn	0.04524	0.05124	0.05872	0.05884	0.05716
		Zn	0.0873	0.07013	0.05989	0.05976	0.07304
		Al	0.26592	0.3203	0.33095	0.3365	0.43159
SSE-4	Organics	Cu	0.04071	0.03898	0.03438	0.0265	0.02807
		Fe	0.39476	0.40556	0.39287	0.31979	0.28386
		Mn	0.01671	0.02101	0.0232	0.02154	0.01881
		Zn	0.03581	0.03612	0.03057	0.02909	0.03394
		Al	1.22136	1.27979	1.43636	1.36218	1.41669
SSE-5	Residual	Cu	0.04232	0.0453	0.0332	0.02855	0.03187
		Fe	9.14307	9.4532	8.53571	9.30931	9.88683
		Mn	0.06252	0.07296	0.06599	0.0675	0.06545
		Zn	0.0862	0.09596	0.07069	0.07168	0.08133
		Al	20.0871	23.7748	20.8482	22.3683	21.6779
SSE total	SSE1+2+3+4+5	Cu	0.68339	0.42427	0.3504	0.27483	0.35092
		Fe	10.2732	10.6101	9.60125	10.2391	10.9487
		Mn	0.16554	0.18597	0.18432	0.17733	0.16711
		Zn	0.32053	0.27739	0.23577	0.22268	0.26292
		Al	21.8708	25.5114	22.7222	24.1465	23.6739
wt. wet soil T.D. (g)			2.0008	2.0034	2.0055	2.0069	2.0041
amount of dry soil (g)			1.95612	1.96412	1.96957	1.98	1.98238
Total digestion initial rinse		Cu	0.00693	0.00548	0.00849	0.00956	0.00381
		Fe	0.01209	0.04615	0.05697	0.06844	0.04155
		Mn	0.00151	0.00228	0.00292	0.00384	0.002
		Zn	0.00259	0.0023	0.0031	0.00496	0.00271
		Al	0.00552	0.0167	0.02051	0.02081	0.01534
Total digestion		Cu	0.67274	0.33935	0.29115	0.23125	0.2764
		Fe	10.6456	9.5479	9.6752	10.434	9.8403
		Mn	0.15707	0.16577	0.15802	0.16269	0.15942
		Zn	0.32196	0.28254	0.25768	0.24935	0.24188
		Al	24.52	21.6851	21.7733	23.3778	22.1996
Recovery rate	SSE/total*100%	Cu	101.6%	125.0%	120.3%	118.8%	127.0%
		Fe	96.5%	111.1%	99.2%	98.1%	111.3%
		Mn	105.4%	112.2%	116.6%	109.0%	104.8%
		Zn	99.6%	98.2%	91.5%	89.3%	108.7%
		Al	89.2%	117.6%	104.4%	103.3%	106.6%

Soil analysis

CELL ID:	PTB6	sample ID	0-10	10-20	20-30	30-40	40-50
		distance up column (cm)	10	20	30	40	50
		wt. container(g)	1.02	1.02	1.02	1.02	1.02
		wt. wet soil+container	16.08	14.64	16.11	17.98	14.6
		wt. dry soil + container (g)	15.73	14.35	15.85	17.75	14.5
		water content, ...o/	0.024	0.022	0.0175	0.014	0.01
		soil pH	3.57	4.03	4.37	4.34	4.12

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0055	2.0023	2.0053	2.0006	2.0059
equiv. dry soil wt (g)			1.95889	1.95967	1.97075	1.97347	1.97937
SSE-0	Initial rinse	Cu	0.337	0.206	0.349	0.321	0.146
		Fe	0.375	0.829	1.122	1.047	0.711
		Mn	0.044	0.052	0.08	0.07	0.04
		Zn	0.0242	0.0278	0.0654	0.0645	0.0399
		Al	0.43	1.14	1.38	1.06	0.54
SSE-1	Exchangeable	Cu	24.722	15.768	11.609	11.299	12.04
		Fe	0.884	0.481	0.377	0.375	0.369
		Mn	2.593	2.731	2.777	2.869	2.406
		Zn	8.3796	7.0439	6.4853	7.3519	7.758
		Al	30.79	23.12	13.72	15.63	22.23
SSE-2	Carbonates	Cu	30.547	15.064	10.004	12.325	15.98
		Fe	6.396	4.48	3.622	3.845	4.905
		Mn	4.148	3.532	3.223	3.534	3.259
		Zn	12.2561	8.1366	6.0457	7.3608	8.7551
		Al	4.33	4.95	5.9	8.85	11.31
SSE-3	Fe-, Mn-oxides	Cu	10.02	6.837	5.575	6.472	7.421
		Fe	36.739	32.739	31.822	33.217	33.167
		Mn	2.145	2.217	2.492	3.322	2.741
		Zn	3.9173	2.9971	2.6404	3.254	3.6068
		Al	14.86	15.98	16.31	16.59	16.91
SSE-4	Organics	Cu	3.527	2.803	2.407	2.548	2.518
		Fe	22.464	24.641	22.213	23.869	21.299
		Mn	2.236	2.425	2.593	3.416	2.792
		Zn	4.5846	3.7793	3.3443	3.8566	4.0796
		Al	57.86	66.83	62.3	85.83	83.81
SSE-5	Residual	Cu	1.331	1.528	1.271	1.483	1.47
		Fe	366.61	507.1	419	451.9	431.59
		Mn	2.279	3.276	2.984	3.41	3.101
		Zn	2.3221	3.1549	2.5715	3.1016	3.0763
		Al	789.8	1034.9	960.6	1097.3	959
wt. wet soil T.D. (g)			2.0082	2.0034	2.0046	2.0085	2.0011
amount of dry soil (g)			1.96153	1.96074	1.97006	1.98126	1.97463
Total digestion initial rinse		Cu	0.316	0.187	0.465	0.231	0.193
		Fe	0.316	0.774	1.532	0.802	0.746
		Mn	0.049	0.055	0.081	0.057	0.055
		Zn	0.0284	0.0164	0.1114	0.047	0.0166
		Al	0.51	0.65	1.22	0.97	1.45
Total digestion		Cu	29.343	21.41	14.658	16.762	18.159
		Fe	515.92	527.65	522.91	460.99	454.85
		Mn	8.049	8.592	8.376	8.622	8.376
		Zn	16.3874	13.1635	10.6887	11.9548	12.1221
		Al	679.5	655.2	636.8	715.5	703.9

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0055	2.0023	2.0053	2.0006	2.0059
equiv. dry soil wt (g)			1.95889	1.95967	1.97075	1.97347	1.97937
SSE-0	Initial rinse	Cu	0.00275	0.00168	0.00283	0.0026	0.00118
		Fe	0.00306	0.00677	0.00911	0.00849	0.00575
		Mn	0.00036	0.00042	0.00065	0.00057	0.00032
		Zn	0.0002	0.00023	0.00053	0.00052	0.00032
		Al	0.00351	0.00931	0.0112	0.00859	0.00437
SSE-1	Exchangeable	Cu	0.20193	0.12874	0.09425	0.09161	0.09732
		Fe	0.00722	0.00393	0.00306	0.00304	0.00298
		Mn	0.02118	0.0223	0.02255	0.02326	0.01945
		Zn	0.06844	0.05751	0.05265	0.05961	0.06271
		Al	0.25149	0.18877	0.11139	0.12672	0.17969
SSE-2	Carbonates	Cu	0.2495	0.12299	0.08122	0.09993	0.12917
		Fe	0.05224	0.03658	0.02941	0.03117	0.03965
		Mn	0.03388	0.02884	0.02617	0.02865	0.02634
		Zn	0.10011	0.06643	0.04908	0.05968	0.07077
		Al	0.03537	0.04042	0.0479	0.07175	0.09142
SSE-3	Fe-, Mn-oxides	Cu	0.20461	0.13955	0.11315	0.13118	0.14997
		Fe	0.7502	0.66826	0.64589	0.67327	0.67025
		Mn	0.0438	0.04525	0.05058	0.06733	0.05539
		Zn	0.07999	0.06118	0.05359	0.06595	0.07289
		Al	0.30344	0.32618	0.33104	0.33626	0.34172
SSE-4	Organics	Cu	0.07202	0.05721	0.04885	0.05165	0.05088
		Fe	0.45871	0.50296	0.45085	0.4838	0.43042
		Mn	0.04566	0.0495	0.05263	0.06924	0.05642
		Zn	0.09362	0.07714	0.06788	0.07817	0.08244
		Al	1.18148	1.36411	1.26449	1.73968	1.69367
SSE-5	Residual	Cu	0.02718	0.03119	0.0258	0.03006	0.02971
		Fe	7.48607	10.3507	8.50438	9.1595	8.72176
		Mn	0.04654	0.06687	0.06057	0.06912	0.06267
		Zn	0.04742	0.0644	0.05219	0.06287	0.06217
		Al	16.1275	21.124	19.4972	22.241	19.3799
SSE total	SSE1+2+3+4+5	Cu	0.75524	0.47969	0.36328	0.40442	0.45705
		Fe	8.75444	11.5625	9.63359	10.3508	9.86507
		Mn	0.19105	0.21275	0.21249	0.2576	0.22027
		Zn	0.38957	0.32666	0.2754	0.32627	0.35098
		Al	17.8993	23.0435	21.252	24.5154	21.6864
wt. wet soil T.D. (g)			2.0082	2.0034	2.0046	2.0085	2.0011
amount of dry soil (g)			1.96153	1.96074	1.97006	1.98126	1.97463
Total digestion initial rinse		Cu	0.00644	0.00381	0.00944	0.00466	0.00391
		Fe	0.00644	0.01579	0.03111	0.01619	0.01511
		Mn	0.001	0.00112	0.00164	0.00115	0.00111
		Zn	0.00058	0.00033	0.00226	0.00095	0.00034
		Al	0.0104	0.01326	0.02477	0.01958	0.02937
Total digestion		Cu	0.59837	0.43677	0.29762	0.33841	0.36785
		Fe	10.5208	10.7643	10.6171	9.307	9.21386
		Mn	0.16414	0.17528	0.17007	0.17407	0.16967
		Zn	0.33418	0.26854	0.21702	0.24136	0.24556
		Al	13.8565	13.3664	12.9295	14.4453	14.2588
Recovery rate	SSE/total*100%	Cu	126.22%	109.83%	122.06%	119.50%	124.25%
		Fe	83.21%	107.42%	90.74%	111.22%	107.07%
		Mn	116.40%	121.38%	124.94%	147.99%	129.82%
		Zn	116.58%	121.64%	126.90%	135.18%	142.93%
		Al	129.18%	172.40%	164.37%	169.71%	152.09%

Soil analysis		sample ID	0-10	10-20	20-30	30-40	40-50
CELL ID:	PTB8	distance up column (cm)	10	20	30	40	50
		wt. container(g)	1.02	1.02	1.02	1.02	1.02
		wt. wet soil+container (g)	14.49	14.57	13	17.82	16.94
		wt. dry soil + container (g)	14.22	14.35	12.82	17.56	16.78
		water content, w%	0.02045	0.0165	0.01525	0.01572	0.01015
		soil pH	3.75	4.68	4.78	5.11	4.77

metals in soil, ppm (from AAS)		sample ID	0-10	10-20	20-30	30-40	40-50
		wt. wet soil (g)	2.0027	2.0011	2.0032	2.0013	1.9934
		equiv. dry soil wt (g)	1.96256	1.96861	1.9731	1.97033	1.97337
SSE-0	Initial rinse	Cu	0.391	0.783	0.617	0.441	0.632
		Fe	0.248	1.902	1.591	2.689	2.233
		Mn	0.066	0.167	0.177	0.163	0.194
SSE-1	Exchangeable	Zn	0.0612	0.1566	0.1506	0.2464	0.2031
		Al	0.25	1.66	1.78	3.44	1.92
		Cu	20.133	6.99	6.078	3.469	5.511
		Fe	0.67	0.344	0.325	0.304	0.275
		Mn	2.574	2.93	2.834	2.472	3.039
		Zn	7.2436	5.4138	5.4145	4.179	5.0198
		Al	31.07	8.49	7.03	2.47	7.1
SSE-2	Carbonates	Cu	27.818	9.284	8.25	5.602	7.666
		Fe	6.394	3.41	3.176	2.784	3.107
		Mn	3.845	2.967	2.921	2.609	2.776
		Zn	11.4866	5.176	5.0974	3.669	5.007
		Al	7.67	10.32	14.23	11.38	9.9
SSE-3	Fe-, Mn-oxides	Cu	9.708	5.131	4.872	3.403	4.388
		Fe	33.646	32.928	33.665	31.062	31.437
		Mn	2.165	2.676	3.284	2.917	3.014
		Zn	3.6175	2.5663	2.7634	2.3151	2.5497
		Al	14.53	17.17	17.32	15.47	16.85
SSE-4	Organics	Cu	3.376	2.446	2.3	1.883	2.149
		Fe	24.861	21.268	22.76	21.02	23.512
		Mn	2.542	3.306	3.253	2.738	2.731
		Zn	4.7295	3.4732	3.3098	2.8544	3.1806
		Al	72.5	72.14	70.94	74.58	77.55
SSE-5	Residual	Cu	1.707	1.196	1.217	1.142	1.201
		Fe	483.13	448.22	490.69	483.72	461.63
		Mn	3.015	3.209	3.357	3.259	3.263
		Zn	3.3414	2.6592	2.7926	2.7248	2.9184
		Al	1251.1	1055.5	1059.7	1046.9	1096
wt. wet soil T.D. (g)			2.0047	1.9966	2.0015	2	2.0025
amount of dry soil (g)			1.96452	1.96418	1.97143	1.96905	1.98237
Total digestion initial rinse		Cu	0.253	0.5	0.5	0.693	0.234
		Fe	0.363	1.625	2.136	3.641	1.734
		Mn	0.052	0.14	0.167	0.206	0.113
		Zn	0.0457	0.1567	0.1571	0.3756	0.0651
		Al	0.53	3	2.9	2.19	4.37
Total digestion		Cu	27.774	11.575	10.593	7.763	12.538
		Fe	492.24	449.86	479.94	513.44	459.2
		Mn	7.973	8.022	8.354	9.156	9.817
		Zn	14.8888	9.3733	9.3346	8.014	10.5458
		Al	706.1	780.5	781.8	808.6	870.7

Amount of metals in soil, mg metal/kg soil		sample ID	0-10	10-20	20-30	30-40	40-50
		wt. wet soil (g)	2.0027	2.0011	2.0032	2.0013	1.9934
		equiv. dry soil wt (g)	1.96256	1.96861	1.9731	1.97033	1.97337
SSE-0	Initial rinse	Cu	0.00319	0.00636	0.005	0.00358	0.00512
		Fe	0.00202	0.01546	0.0129	0.02184	0.01811
		Mn	0.00054	0.00136	0.00144	0.00132	0.00157
SSE-1	Exchangeable	Zn	0.0005	0.00127	0.00122	0.002	0.00165
		Al	0.00204	0.01349	0.01443	0.02793	0.01557
		Cu	0.16414	0.05681	0.04929	0.02817	0.04468
		Fe	0.00546	0.0028	0.00264	0.00247	0.00223
		Mn	0.02098	0.02381	0.02298	0.02007	0.02464
		Zn	0.05905	0.044	0.04391	0.03394	0.0407
		Al	0.2533	0.069	0.05701	0.02006	0.05757
SSE-2	Carbonates	Cu	0.22679	0.07546	0.0669	0.04549	0.06216
		Fe	0.05213	0.02771	0.02575	0.02261	0.02519
		Mn	0.03135	0.02411	0.02369	0.02119	0.02251
		Zn	0.09365	0.04207	0.04134	0.02979	0.0406
		Al	0.06253	0.08388	0.11539	0.09241	0.08027
SSE-3	Fe-, Mn-oxides	Cu	0.19786	0.10426	0.09877	0.06908	0.08894
		Fe	0.68576	0.66906	0.68248	0.6306	0.63723
		Mn	0.04413	0.05437	0.06658	0.05922	0.06109
		Zn	0.07373	0.05214	0.05602	0.047	0.05168
		Al	0.29614	0.34888	0.35112	0.31406	0.34155
SSE-4	Organics	Cu	0.06881	0.0497	0.04663	0.03823	0.04356
		Fe	0.50671	0.43214	0.46141	0.42673	0.47659
		Mn	0.05181	0.06717	0.06595	0.05558	0.05536
		Zn	0.09639	0.07057	0.0671	0.05795	0.06447
		Al	1.47766	1.46581	1.43814	1.51406	1.57193
SSE-5	Residual	Cu	0.03479	0.0243	0.02467	0.02318	0.02434
		Fe	9.84695	9.10734	9.94759	9.82009	9.35721
		Mn	0.06145	0.0652	0.06806	0.06616	0.06614
		Zn	0.0681	0.05403	0.05661	0.05532	0.05916
		Al	25.4994	21.4466	21.4829	21.2533	22.2159
SSE total	SSE1+2+3+4+5	Cu	0.69239	0.31053	0.28625	0.20416	0.26369
		Fe	11.097	10.2391	11.1199	10.9025	10.4984
		Mn	0.20972	0.23468	0.24725	0.22222	0.22974
		Zn	0.39093	0.26282	0.26497	0.22399	0.25661
		Al	27.589	23.4142	23.4446	23.1939	24.2672
wt. wet soil T.D. (g)			2.0047	1.9966	2.0015	2	2.0025
amount of dry soil (g)			1.96452	1.96418	1.97143	1.96905	1.98237
Total digestion initial rinse		Cu	0.00515	0.01018	0.01014	0.01408	0.00472
		Fe	0.00739	0.03309	0.04334	0.07396	0.03499
		Mn	0.00106	0.00285	0.00339	0.00418	0.00228
		Zn	0.00093	0.00319	0.00319	0.00763	0.00131
		Al	0.01079	0.06109	0.05884	0.04449	0.08818
Total digestion		Cu	0.56551	0.23572	0.21493	0.1577	0.25299
		Fe	10.0226	9.16127	9.73792	10.4302	9.26566
		Mn	0.16234	0.16337	0.1695	0.186	0.19809
		Zn	0.30315	0.19088	0.1894	0.1628	0.21279
		Al	14.3771	15.8947	15.8626	16.4262	17.5688
Recovery rate	SSE/total*100%	Cu	122.4%	131.7%	133.2%	129.5%	104.2%
		Fe	110.7%	111.8%	114.2%	104.5%	113.3%
		Mn	129.2%	143.7%	145.9%	119.5%	116.0%
		Zn	129.0%	137.7%	139.9%	137.6%	120.6%
		Al	191.9%	147.3%	147.8%	141.2%	138.1%

Soil analysis

CELL ID:	PTB9	sample ID	0-10	10-20	20-30	30-40	40-50
		distance up column (cm)	10	20	30	40	50
		wt. container(g)	1.02	1.02	1.02	1.02	1.02
		wt. wet soil+container (g)	17.72	16.83	18.17	16.71	15.11
		wt. dry soil + container (g)	17.38	16.53	17.88	16.48	14.94
		water content, w%	0.02078	0.01934	0.0172	0.01488	0.01221
		soil pH	3.58	4.27	4.65	5.11	4.9

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.008	2.0014	2.0077	1.9965	2.0026
equiv. dry soil wt (g)			1.96712	1.96342	1.97375	1.96723	1.97844
SSE-0	Initial rinse	Cu	1.443	0.184	0.452	0.698	0.484
		Fe	0.023	0.801	1.52	2.794	2.651
		Mn	0.184	0.049	0.128	0.317	0.189
		Zn	0.2149	0.0409	0.124	0.4494	0.2948
SSE-1	Exchangeable	Al	0.13	0.65	1.09	2	2.08
		Cu	19.15	8.934	6.228	2.363	2.557
		Fe	0.862	0.241	0.22	0.207	0.248
		Mn	2.034	2.04	2.326	2.277	2.362
		Zn	7.4477	5.6148	5.5316	3.8929	3.4607
SSE-2	Carbonates	Al	25.45	9.82	4.45	1.66	3.03
		Cu	33.102	15.175	8.829	4.735	4.876
		Fe	7.487	3.828	3.257	2.435	2.457
		Mn	3.326	3.247	2.99	2.322	2.327
		Zn	12.5279	8.1713	6.0203	3.378	3.4249
SSE-3	Fe-, Mn-oxides	Al	6.66	12.63	9.54	5.75	6.68
		Cu	11.236	7.316	5.353	3.035	3.023
		Fe	36.775	32.768	35.323	30.372	32.421
		Mn	2.094	3.242	3.052	3.114	3.626
		Zn	4.0192	3.4292	2.9623	2.3271	2.2311
SSE-4	Organics	Al	14.88	19.61	19.68	15.2	16.34
		Cu	3.789	2.958	2.332	1.728	1.699
		Fe	19.471	19.445	21.135	22.795	21.884
		Mn	2.284	3.847	3.026	2.762	3.586
		Zn	4.9643	4.2233	3.4293	2.8155	2.7035
SSE-5	Residual	Al	64.3	71.45	79.97	74.52	66.8
		Cu	1.975	1.603	1.45	1.034	1.058
		Fe	442.91	444.35	480.04	470.23	481.88
		Mn	3.304	3.955	3.325	3.195	3.603
		Zn	3.4695	3.1257	3.0336	2.7265	2.6472
		Al	979.2	1115.9	1122.6	1103.5	1127.3
wt. wet soil T.D. (g)			2.0075	1.9922	2.0078	2.0066	1.9924
amount of dry soil (g)			1.96663	1.9544	1.97385	1.97719	1.96836
Total digestion initial rinse		Cu	1.652	0.246	0.367	0.606	0.603
		Fe	0.266	0.825	1.394	3.157	2.43
		Mn	0.22	0.06	0.113	0.221	0.238
		Zn	0.251	0.0226	0.0739	0.4725	0.5502
		Al	0.62	0.92	1.76	5.76	5.87
Total digestion		Cu	33.928	17.545	11.492	6.4	6.533
		Fe	483.26	446.16	429.36	413.93	375.28
		Mn	7.971	8.459	8.477	8.359	7.765
		Zn	17.0838	11.5191	9.9287	7.4721	7.566
		Al	758.1	863.9	934.6	849	855.7

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.008	2.0014	2.0077	1.9965	2.0026
equiv. dry soil wt (g)			1.96712	1.96342	1.97375	1.96723	1.97844
SSE-0	Initial rinse	Cu	0.01174	0.0015	0.00366	0.00568	0.00391
		Fe	0.00019	0.00653	0.01232	0.02272	0.02144
		Mn	0.0015	0.0004	0.00104	0.00258	0.00153
		Zn	0.00175	0.00033	0.00101	0.00366	0.00238
SSE-1	Exchangeable	Al	0.00106	0.0053	0.00884	0.01627	0.01682
		Cu	0.15576	0.0728	0.05049	0.01922	0.02068
		Fe	0.00701	0.00196	0.00178	0.00168	0.00201
		Mn	0.01654	0.01662	0.01886	0.01852	0.0191
		Zn	0.06058	0.04576	0.04484	0.03166	0.02799
SSE-2	Carbonates	Al	0.207	0.08002	0.03607	0.0135	0.0245
		Cu	0.26924	0.12366	0.07157	0.03851	0.03943
		Fe	0.0609	0.03119	0.0264	0.0198	0.01987
		Mn	0.02705	0.02646	0.02424	0.01889	0.01882
		Zn	0.1019	0.06659	0.0488	0.02747	0.0277
SSE-3	Fe-, Mn-oxides	Al	0.05417	0.10292	0.07734	0.04677	0.05402
		Cu	0.22848	0.14905	0.10848	0.06171	0.06112
		Fe	0.74779	0.66757	0.71586	0.61756	0.65549
		Mn	0.04258	0.06605	0.06185	0.06332	0.07331
		Zn	0.08173	0.06986	0.06003	0.04732	0.04511
SSE-4	Organics	Al	0.30257	0.39951	0.39883	0.30906	0.33036
		Cu	0.07705	0.06026	0.04726	0.03514	0.03435
		Fe	0.39593	0.39614	0.42832	0.46349	0.44245
		Mn	0.04644	0.07837	0.06132	0.05616	0.0725
		Zn	0.10095	0.08604	0.0695	0.05725	0.05466
SSE-5	Residual	Al	1.3075	1.45562	1.62067	1.51522	1.35056
		Cu	0.04016	0.03266	0.02939	0.02102	0.02139
		Fe	9.00627	9.05256	9.72848	9.56125	9.74264
		Mn	0.06718	0.08057	0.06738	0.06496	0.07285
		Zn	0.07055	0.06368	0.06148	0.05544	0.05352
		Al	19.9114	22.7338	22.7506	22.4376	22.7917
SSE total	SSE1+2+3+4+5	Cu	0.77069	0.43843	0.30719	0.1756	0.17697
		Fe	10.2179	10.1494	10.9008	10.6638	10.8624
		Mn	0.1998	0.26808	0.23365	0.22185	0.25658
		Zn	0.4157	0.33192	0.28466	0.21914	0.20897
		Al	21.7826	24.7718	24.8835	24.3222	24.5512
wt. wet soil T.D. (g)			2.0075	1.9922	2.0078	2.0066	1.9924
amount of dry soil (g)			1.96663	1.9544	1.97385	1.97719	1.96836
Total digestion initial rinse		Cu	0.0336	0.00503	0.00744	0.01226	0.01225
		Fe	0.00541	0.01689	0.02825	0.06387	0.04938
		Mn	0.00447	0.00123	0.00229	0.00447	0.00484
		Zn	0.00511	0.00046	0.0015	0.00956	0.01118
		Al	0.01261	0.01883	0.03567	0.11653	0.11929
Total digestion		Cu	0.69007	0.35909	0.23289	0.12948	0.13276
		Fe	9.82921	9.13141	8.70097	8.37413	7.62624
		Mn	0.16213	0.17313	0.17179	0.16911	0.1578
		Zn	0.34747	0.23576	0.2012	0.15117	0.15375
		Al	15.4193	17.6812	18.9396	17.1759	17.3891
Recovery rate	SSE/total*100%	Cu	111.7%	122.1%	131.9%	135.6%	133.3%
		Fe	104.0%	111.1%	125.3%	127.3%	142.4%
		Mn	123.2%	154.8%	136.0%	131.2%	162.6%
		Zn	119.6%	140.8%	141.5%	145.0%	135.9%
		Al	141.3%	140.1%	131.4%	141.6%	141.2%

Soil analysis

CELL ID:	PTB11	sample ID	0-10	10-20	20-30	30-40	40-50
		distance up column (cm)	10	20	30	40	50
		wt. container(g)	1.02	1.02	1.02	1.02	1.02
		wt. wet soil+container (g)	14.86	14.46	14.96	15.14	15.15
		wt. dry soil + container (g)	14.32	14.25	14.78	15.01	15.08
		water content, w%	0.0406	0.01587	0.01308	0.00929	0.00498
		soil pH	2.79	3.18	3.44	3.68	3.68

metals in soil, ppm (from AAS)

		sample ID	0-10	10-20	20-30	30-40	40-50
		wt. wet soil (g)	2.0071	2.0003	2.0004	2.0025	1.9958
		equiv. dry soil wt (g)	1.92879	1.96905	1.97457	1.98406	1.98591
SSE-0	Initial rinse	Cu	4.549	1.573	1.423	0.316	1.781
		Fe	0.283	0.068	0.083	0.313	0.059
		Mn	0.279	0.116	0.118	0.038	0.161
		Zn	0.6007	0.1908	0.1895	0.0307	0.2267
		Al	1.12	0.14	0.11	0.21	0.21
SSE-1	Exchangeable	Cu	38.231	34.021	33.859	26.457	29.055
		Fe	3.845	1.255	0.796	0.295	0.321
		Mn	2.571	2.348	2.407	2.371	2.297
		Zn	14.3034	11.7527	11.6671	9.2179	10.9418
		Al	49.98	46.08	50.91	45.32	50.67
SSE-2	Carbonates	Cu	91.006	75.804	75.97	57.251	88.694
		Fe	6.309	6.557	6.631	6.074	5.973
		Mn	5.178	5.126	5.452	5.209	5.489
		Zn	20.3947	26.088	26.1683	20.3805	19.812
		Al	3.27	5.88	7.73	14.22	17.94
SSE-3	Fe-, Mn-oxides	Cu	28.057	24.239	26.751	21.406	31.717
		Fe	95.396	60.54	56.256	46.356	44.497
		Mn	3.353	3.032	3.462	3.994	3.676
		Zn	7.3458	6.9348	7.7616	6.6243	8.3988
		Al	9.18	11.65	15.33	21.46	22.83
SSE-4	Organics	Cu	7.581	7.246	7.583	5.328	8.228
		Fe	39.115	29.343	27.661	24.018	25.356
		Mn	2.88	2.921	3.439	4.556	3.507
		Zn	6.0464	6.825	7.8064	6.9798	8.6863
		Al	55.59	65.72	74.61	75.61	77.48
SSE-5	Residual	Cu	3.144	3.073	3.021	2.603	4.031
		Fe	510.58	450.78	502.57	501.46	501.36
		Mn	3.223	3.308	3.41	4.156	3.893
		Zn	4.3255	4.6369	4.8041	4.6348	5.8381
		Al	1088.8	1154.3	1242.8	1273.6	1284.9
		wt. wet soil T.D. (g)	1.9992	1.9979	2.0086	2.0038	1.9942
		amount of dry soil (g)	1.9212	1.96668	1.98266	1.98535	1.98432
Total digestion initial rinse		Cu	5.471	2.192	1.761	0.476	1.549
		Fe	0.379	0.08	0.103	0.248	0.091
		Mn	0.324	0.17	0.145	0.05	0.143
		Zn	0.7608	0.2941	0.2402	0.0568	0.2253
		Al	1.29	0.26	0.3	0.2	0.14
Total digestion		Cu	120.536	104.146	98.176	76.547	117.714
		Fe	429.71	441.41	406.2	389.9	349.83
		Mn	7.472	9.242	9.312	10.105	11.308
		Zn	45.13	35.856	31.201	36.413	37.906
		Al	676.9	753.5	825.3	925.5	939.8

Amount of metals in soil, mg metal/kg soil

		sample ID	0-10	10-20	20-30	30-40	40-50
		wt. wet soil (g)	2.0071	2.0003	2.0004	2.0025	1.9958
		equiv. dry soil wt (g)	1.92879	1.96905	1.97457	1.98406	1.98591
SSE-0	Initial rinse	Cu	0.03774	0.01278	0.01153	0.00255	0.01435
		Fe	0.00235	0.00055	0.00067	0.00252	0.00048
		Mn	0.00231	0.00094	0.00096	0.00031	0.0013
		Zn	0.00498	0.00155	0.00154	0.00025	0.00183
		Al	0.00929	0.00114	0.00089	0.00169	0.00169
SSE-1	Exchangeable	Cu	0.31714	0.27645	0.27436	0.21336	0.23409
		Fe	0.0319	0.0102	0.00645	0.00238	0.00259
		Mn	0.02133	0.01908	0.0195	0.01912	0.01851
		Zn	0.11865	0.0955	0.09454	0.07434	0.08816
		Al	0.4146	0.37444	0.41253	0.36547	0.40824
SSE-2	Carbonates	Cu	0.75493	0.61597	0.61559	0.46169	0.71459
		Fe	0.05234	0.05328	0.05373	0.04898	0.04812
		Mn	0.04295	0.04165	0.04418	0.04201	0.04422
		Zn	0.16918	0.21198	0.21204	0.16435	0.15962
		Al	0.02713	0.04778	0.06264	0.11467	0.14454
SSE-3	Fe-, Mn-oxides	Cu	0.58186	0.4924	0.54191	0.43156	0.63884
		Fe	1.97836	1.22983	1.13961	0.93457	0.89625
		Mn	0.06954	0.06159	0.07013	0.08052	0.07404
		Zn	0.15234	0.14088	0.15723	0.13355	0.16917
		Al	0.19038	0.23666	0.31055	0.43265	0.45984
SSE-4	Organics	Cu	0.15722	0.1472	0.15361	0.10742	0.16573
		Fe	0.81118	0.59609	0.56034	0.48422	0.51072
		Mn	0.05973	0.05934	0.06967	0.09185	0.07064
		Zn	0.12539	0.13865	0.15814	0.14072	0.17496
		Al	1.15285	1.33506	1.51142	1.52435	1.56059
SSE-5	Residual	Cu	0.0652	0.06243	0.0612	0.05248	0.08119
		Fe	10.5886	9.15733	10.1809	10.1098	10.0983
		Mn	0.06684	0.0672	0.06908	0.08379	0.07841
		Zn	0.0897	0.0942	0.09732	0.09344	0.11759
		Al	22.58	23.4489	25.1761	25.6766	25.8803
SSE total	SSE1+2+3+4+5	Cu	1.87634	1.59444	1.64667	1.2665	1.83443
		Fe	13.4624	11.0467	11.941	11.5799	11.556
		Mn	0.26038	0.24886	0.27256	0.31729	0.28582
		Zn	0.65527	0.6812	0.71927	0.6064	0.70949
		Al	24.3649	25.4429	27.4732	28.1137	28.4535
		wt. wet soil T.D. (g)	1.9992	1.9979	2.0086	2.0038	1.9942
		amount of dry soil (g)	1.9212	1.96668	1.98266	1.98535	1.98432
Total digestion initial rinse		Cu	0.11391	0.04458	0.03553	0.00959	0.03122
		Fe	0.00789	0.00163	0.00208	0.005	0.00183
		Mn	0.00675	0.00346	0.00293	0.00101	0.00288
		Zn	0.01584	0.00598	0.00485	0.00114	0.00454
		Al	0.02686	0.00529	0.00605	0.00403	0.00282
Total digestion		Cu	2.50961	2.11821	1.98069	1.54224	2.37288
		Fe	8.94672	8.97776	8.19503	7.85554	7.05188
		Mn	0.15557	0.18797	0.18787	0.20359	0.22795
		Zn	0.93962	0.72927	0.62948	0.73363	0.76411
		Al	14.0933	15.3253	16.6503	18.6466	18.9445
Recovery rate	SSE/total*100%	Cu	74.8%	75.3%	83.1%	82.1%	77.3%
		Fe	150.5%	123.0%	145.7%	147.4%	163.9%
		Mn	167.4%	132.4%	145.1%	155.8%	125.4%
		Zn	69.7%	93.4%	114.3%	82.7%	92.9%
		Al	172.9%	166.0%	165.0%	150.8%	150.2%

Soil analysis

CELL ID: **PTB12**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	19.92	15.2	14.38	17.03	17.46
wt. dry soil + container (g)	19.58	15.02	14.25	16.89	17.38
water content, w%	0.01832	0.01286	0.00983	0.00882	0.00489
soil pH	2.84	3.15	3.34	3.58	3.75

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2	2.002	2.0004	2.0021	2.008
equiv. dry soil wt (g)			1.96	1.97659	1.98094	1.98459	1.99823
SSE-0	Initial rins	Cu	5.14	2.474	2.066	0.816	0.503
		Fe	0.16	0.229	0.293	0.223	0.234
		Mn	0.31	0.169	0.153	0.071	0.063
		Zn	0.64	0.303	0.2614	0.0793	0.0402
		Al	1.28	0.92	1.23	1.04	1.19
SSE-1	Exchang	Cu	37	34.27	31.454	24.409	18.605
		Fe	3.8	1.439	0.799	0.314	0.139
		Mn	2.12	2.129	1.889	1.786	1.703
		Zn	16.1	14.3969	11.9457	9.3634	8.4803
		Al	48.5	63.08	50.21	51.7	49.95
SSE-2	Carbona	Cu	98.1	95.174	73.997	72.093	56.831
		Fe	6.39	7.781	7.603	7.364	6.045
		Mn	6.33	6.3999	6.0802	6.3764	6.276
		Zn	21.2	20.2726	24.7461	24.5241	20.5955
		Al	1.71	1.3	6.53	13.92	13.14
SSE-3	Fe-, Mn-	Cu	30.6	29.938	26.864	26.661	20.633
		Fe	109	67.65	49.419	44.264	43.556
		Mn	3.18	3.049	3.007	3.261	3.741
		Zn	8.29	8.1284	6.7897	7.4823	6.6486
		Al	9.24	12.21	14.24	18.53	22.38
SSE-4	Organics	Cu	8.4	7.555	5.93	7.429	4.686
		Fe	51.3	35.239	27.57	28.02	22.446
		Mn	2.69	2.857	3.175	3.274	3.187
		Zn	6.31	7.5348	7.3286	7.5402	6.4769
		Al	49.7	56.87	61.91	60.05	63.17
SSE-5	Residual	Cu	3.51	3.428	3.033	3.163	2.392
		Fe	505	480.02	454.77	478.84	185.28
		Mn	3.11	3.442	3.411	3.212	2.166
		Zn	4.66	5.4074	5.0896	4.8725	3.5276
		Al	1024	1013.3	899.7	1061.2	635.7
wt. wet soil T.D. (g)			2	1.9988	1.992	1.9975	1.9979
amount of dry soil (g)			1.97	1.97343	1.97262	1.98003	1.98818
Total digestion initial rinse		Cu	5.51	3.288	1.817	1.363	0.581
		Fe	0.14	0.141	0.044	0.326	0.211
		Mn	0.33	0.241	0.147	0.122	0.062
		Zn	0.73	0.4364	0.2277	0.1832	0.0736
		Al	1.22	0.44	0.24	0.57	0.43
Total digestion		Cu	131	121.512	120.829	111.95	101.058
		Fe	489	462.99	483.38	392.02	523.12
		Mn	8.06	9.454	10.236	10.588	11.197
		Zn	42	30.632	30.402	26.76	28.508
		Al	558	642.1	635	682.7	732.6

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9986	2.002	2.0004	2.0021	2.008
equiv. dry soil wt (g)			1.9626	1.9766	1.98094	1.98459	1.99823
SSE-0	Initial rinse	Cu	0.0419	0.02	0.01669	0.00658	0.00403
		Fe	0.0013	0.0019	0.00237	0.0018	0.00187
		Mn	0.0025	0.0014	0.00124	0.00057	0.0005
		Zn	0.0052	0.0025	0.00211	0.00064	0.00032
		Al	0.0104	0.0074	0.00993	0.00838	0.00953
SSE-1	Exchangeable	Cu	0.3017	0.2774	0.25405	0.19679	0.14897
		Fe	0.031	0.0116	0.00645	0.00253	0.00111
		Mn	0.0173	0.0172	0.01526	0.0144	0.01364
		Zn	0.1309	0.1165	0.09649	0.07549	0.0679
		Al	0.3955	0.5106	0.40555	0.41681	0.39995
SSE-2	Carbonates	Cu	0.7994	0.7704	0.59767	0.58122	0.45505
		Fe	0.0521	0.063	0.06141	0.05937	0.0484
		Mn	0.0516	0.0518	0.04911	0.05141	0.05025
		Zn	0.173	0.1641	0.19987	0.19772	0.16491
		Al	0.0139	0.0105	0.05274	0.11222	0.10521
SSE-3	Fe-, Mn- oxides	Cu	0.6245	0.6059	0.54245	0.53736	0.41303
		Fe	2.2123	1.369	0.99789	0.89215	0.87189
		Mn	0.0647	0.0617	0.06072	0.06573	0.07489
		Zn	0.1689	0.1645	0.1371	0.15081	0.13309
		Al	0.1883	0.2471	0.28754	0.37348	0.448
SSE-4	Organics	Cu	0.1711	0.1529	0.11974	0.14973	0.0938
		Fe	1.0458	0.7131	0.55671	0.56475	0.44932
		Mn	0.0547	0.0578	0.06411	0.06599	0.0638
		Zn	0.1285	0.1525	0.14798	0.15197	0.12965
		Al	1.0131	1.1509	1.25012	1.21032	1.26452
SSE-5	Residual	Cu	0.0715	0.0694	0.06124	0.06375	0.04788
		Fe	10.283	9.7141	9.18294	9.65115	3.70888
		Mn	0.0634	0.0697	0.06888	0.06474	0.04336
		Zn	0.0949	0.1094	0.10277	0.09821	0.07061
		Al	20.87	20.506	18.1672	21.3888	12.7253
SSE tota	SSE1+2+3+4+	Cu	1.9682	1.8759	1.57516	1.52885	1.15873
		Fe	13.625	11.871	10.8054	11.17	5.07961
		Mn	0.2517	0.2582	0.25807	0.26226	0.24593
		Zn	0.6963	0.707	0.68421	0.67419	0.56617
		Al	22.481	22.425	20.1631	23.5016	14.943
wt. wet soil T.D. (g)			2.0013	1.9988	1.992	1.9975	1.9979
amount of dry soil (g)			1.9653	1.9734	1.97262	1.98003	1.98818
Total digestion initial rinse		Cu	0.112	0.0666	0.03684	0.02753	0.01169
		Fe	0.0028	0.0029	0.00089	0.00659	0.00425
		Mn	0.0067	0.0049	0.00298	0.00246	0.00125
		Zn	0.0148	0.0088	0.00462	0.0037	0.00148
		Al	0.0248	0.0089	0.00487	0.01151	0.00865
Total digestion		Cu	2.6567	2.463	2.45012	2.26158	2.03318
		Fe	9.9621	9.3845	9.8018	7.91946	10.5246
		Mn	0.164	0.1916	0.20756	0.2139	0.22527
		Zn	0.8551	0.6209	0.61648	0.5406	0.57355
		Al	11.353	13.015	12.8763	13.7917	14.7391
Recover	SSE/total*100%	Cu	74.1%	76.2%	64.3%	67.6%	57.0%
		Fe	136.8%	126.5%	110.2%	141.0%	48.3%
		Mn	153.5%	134.7%	124.3%	122.6%	109.2%
		Zn	81.4%	113.9%	111.0%	124.7%	98.7%
		Al	198.0%	172.3%	156.6%	170.4%	101.4%

Soil analysis

Cell ID PTB13

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	16.27	17.12	14.96	14.28	17.39
wt. dry soil + container (g)	15.99	16.87	14.76	14.13	17.26
water content, w%	0.0187	0.0158	0.0146	0.0114	0.008
soil pH	2.91	3.08	3.43	3.34	3.72

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0057	2.074	2.0074	2.0026	1.994
equiv. dry soil wt (g)			1.9689	2.0418	1.9786	1.9799	1.9782
SSE-0	Initial rinse	Cu	8.52	5.398	2.026	4.533	2.649
		Fe	0.224	0.051	0.15	0.05	0.088
		Mn	0.587	0.455	0.213	0.425	0.309
		Zn	1.3639	0.9719	0.4139	0.7623	0.5066
		Al	0.64	2.15	2.15	2.57	2.72
SSE-1	Exchangeable	Cu	65.61	56.25	47.79	53.65	45.3
		Fe	8.16	3.061	1.101	1.156	0.532
		Mn	3.055	2.965	2.958	2.894	2.87
		Zn	18.261	15.084	12.373	13.174	12.465
		Al	48.94	53.39	49.54	52.93	53.4
SSE-2	Carbonates	Cu	65.21	60.32	45.37	61.39	46.66
		Fe	6.36	7.62	7.09	8.09	6.35
		Mn	2.865	3.073	2.538	2.698	2.095
		Zn	19.842	18.908	13.484	17.432	13.726
		Al	1.36	1.41	3.6	4.72	12.64
SSE-3	Fe-, Mn-oxides	Cu	86.195	71.214	52.326	75.389	58.813
		Fe	146.42	88.925	65.807	60.975	53.08
		Mn	3.616	4.695	4.573	4.887	4.824
		Zn	13.696	13.771	10.826	13.254	11.601
		Al	12.43	15.35	18.84	21.54	31.13
SSE-4	Organics	Cu	9.019	8.871	6.935	9.614	6.878
		Fe	56.178	45.111	35.521	37.497	32.411
		Mn	2.871	3.576	3.987	4.85	4.148
		Zn	8.8232	10.057	9.2801	12.055	10.611
		Al	28.81	35.73	39.23	39.16	41.9
SSE-5	Residual	Cu	2.317	2.774	1.877	2.369	1.936
		Fe	508.78	448.99	447.13	444.32	389.99
		Mn	2.388	2.132	2.239	2.109	2.092
		Zn	2.9152	3.217	2.8538	3.1188	2.7869
		Al	1008.1	980.5	1018.3	964.7	865.1
wt. wet soil T.D. (g)			1.9923	1.9948	2.0043	1.9936	2.0041
amount of dry soil (g)			1.9557	1.9638	1.9755	1.971	1.9882
Total digestion initial rinse		Cu	7.275	5.538	2.057	4.1	2.772
		Fe	0.147	0.223	0.293	0.042	0.085
		Mn	0.491	0.439	0.203	0.379	0.346
		Zn	1.2105	1.0252	0.4544	0.744	0.5761
		Al	1.69	1.16	0.25	0.27	0.24
Total digestion		Cu	148.11	138.87	124.62	126.23	112.72
		Fe	371.67	273.09	269.29	236.41	238.72
		Mn	7.824	8.517	8.735	9.126	9.515
		Zn	38.982	38.199	30.266	34.244	31.357
		Al	680.6	693.6	664.1	646.3	643.6

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0057	2.074	2.0074	2.0026	1.994
equiv. dry soil wt (g)			1.96887	2.0418	1.9786	1.97995	1.97816
SSE-0	Initial rinse	Cu	0.06924	0.0423	0.01638	0.03663	0.02143
		Fe	0.00182	0.0004	0.00121	0.0004	0.00071
		Mn	0.00477	0.00357	0.00172	0.00343	0.0025
		Zn	0.01108	0.00762	0.00335	0.00616	0.0041
		Al	0.0052	0.01685	0.01739	0.02077	0.022
SSE-1	Exchangeable	Cu	0.53318	0.44079	0.38646	0.43355	0.3664
		Fe	0.06631	0.02399	0.0089	0.00934	0.0043
		Mn	0.02483	0.02323	0.02392	0.02339	0.02321
		Zn	0.1484	0.1182	0.10005	0.10646	0.10082
		Al	0.39771	0.41838	0.40061	0.42773	0.43192
SSE-2	Carbonates	Cu	0.52993	0.47268	0.36689	0.49609	0.3774
		Fe	0.05168	0.05971	0.05733	0.06538	0.05136
		Mn	0.02328	0.02408	0.02052	0.0218	0.01694
		Zn	0.16124	0.14816	0.10904	0.14087	0.11102
		Al	0.01105	0.01105	0.02911	0.03814	0.10224
SSE-3	Fe-, Mn-oxides	Cu	1.75115	1.39513	1.05784	1.52305	1.18924
		Fe	2.97474	1.74209	1.33038	1.23185	1.07332
		Mn	0.07346	0.09198	0.09245	0.09873	0.09754
		Zn	0.27825	0.26979	0.21886	0.26776	0.23459
		Al	0.25253	0.30072	0.38088	0.43516	0.62947
SSE-4	Organics	Cu	0.18323	0.17379	0.1402	0.19423	0.13908
		Fe	1.14132	0.88375	0.7181	0.75754	0.65538
		Mn	0.05833	0.07006	0.0806	0.09798	0.08388
		Zn	0.17925	0.19702	0.18761	0.24354	0.21456
		Al	0.58531	0.69997	0.79309	0.79113	0.84725
SSE-5	Residual	Cu	0.04707	0.05434	0.03795	0.04786	0.03915
		Fe	10.3365	8.79599	9.03932	8.97641	7.88589
		Mn	0.04852	0.04177	0.04526	0.04261	0.0423
		Zn	0.05923	0.06302	0.05769	0.06301	0.05635
		Al	20.4807	19.2086	20.5863	19.4894	17.493
SSE total	SSE1+2+3+4+5	Cu	3.04456	2.53673	1.98933	2.69478	2.11127
		Fe	14.5705	11.5055	11.154	11.0405	9.67025
		Mn	0.22841	0.25112	0.26276	0.28451	0.26388
		Zn	0.82637	0.7962	0.67326	0.82163	0.71735
		Al	21.7273	20.6387	22.19	21.1816	19.5039
wt. wet soil T.D. (g)			1.9923	1.9948	2.0043	1.9936	2.0041
amount of dry soil (g)			1.95572	1.96382	1.97554	1.97105	1.98818
Total digestion initial rinse		Cu	0.14879	0.1128	0.04165	0.0832	0.05577
		Fe	0.00301	0.00454	0.00593	0.00085	0.00171
		Mn	0.01004	0.00894	0.00411	0.00769	0.00696
		Zn	0.02476	0.02088	0.0092	0.0151	0.01159
		Al	0.03457	0.02363	0.00506	0.00548	0.00483
Total digestion		Cu	3.02933	2.82852	2.52331	2.56161	2.26778
		Fe	7.6017	5.56241	5.45247	4.79765	4.80277
		Mn	0.16002	0.17348	0.17686	0.1852	0.19143
		Zn	0.79729	0.77805	0.61281	0.69494	0.63087
		Al	13.9202	14.1275	13.4464	13.1159	12.9485
Recovery rate	SSE/total*100%	Cu	100.5%	89.7%	78.8%	105.2%	93.1%
		Fe	191.7%	206.8%	204.6%	230.1%	201.3%
		Mn	142.7%	144.8%	148.6%	153.6%	137.8%
		Zn	103.6%	102.3%	109.9%	118.2%	113.7%
		Al	156.1%	146.1%	165.0%	161.5%	150.6%

Soil analysis

Cell ID PTB14

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	15.76	17.49	18.48	17.92	17.55
wt. dry soil + container (g)	15.43	17.26	18.26	17.73	17.42
water content, w%	-16.885	0	0	0	0
soil pH	2.72	3.03	3.38	3.5	3.73

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0046	2.0019	1.9931	1.9971	2.001
equiv. dry soil wt (g)			-0.1262	2.0019	1.9931	1.9971	2.001
SSE-0	Initial rinse	Cu	9.576	5.972	2.121	0.818	0.817
		Fe	0.759	0.086	0.157	0.228	0.265
		Mn	0.56	0.448	0.229	0.114	0.103
		Zn	1.4045	0.9283	0.4161	0.1905	0.1708
		Al	5.11	4.38	4.07	4.27	4.89
SSE-1	Exchangeable	Cu	70.08	57.28	34.973	29.584	33.06
		Fe	12.62	2.373	0.915	0.612	0.467
		Mn	2.319	2.719	2.552	2.444	2.765
		Zn	15.4117	14.2851	10.9477	9.8554	10.2146
		Al	47.35	53.86	51.51	53.61	44.4
SSE-2	Carbonates	Cu	76.66	59.7	47.71	29.55	40.13
		Fe	6.22	7.97	7.83	5.09	6.72
		Mn	1.952	1.639	3.781	3.635	3.552
		Zn	23.3761	17.629	14.4345	14.876	14.1769
		Al	1.32	1.66	2.83	7.49	10.52
SSE-3	Fe-, Mn-oxides	Cu	85.931	74.509	53.679	37.522	37.591
		Fe	131.506	83.144	61.531	57.334	53.85
		Mn	3.977	4.322	4.631	5.134	4.468
		Zn	12.6037	13.3801	10.7646	10.3314	9.5963
		Al	10.51	14.18	18.49	23.25	24.65
SSE-4	Organics	Cu	10.312	9.336	7.12	5.878	6.246
		Fe	58.688	42.666	37.094	31.6	32.544
		Mn	5.151	3.69	4.263	4.303	4.801
		Zn	8.1584	10.5938	9.4346	8.3213	9.3009
		Al	28.72	34.45	38.15	39.19	43.86
SSE-5	Residual	Cu	2.376	2.248	1.922	1.699	1.826
		Fe	450.67	420.94	431.52	427.79	408.94
		Mn	1.902	1.787	2.166	2.157	1.998
		Zn	2.5515	2.7256	2.7475	2.8203	2.8159
		Al	936.6	1010.7	971.4	958.3	944
wt. wet soil T.D. (g)			2.0004	1.999	1.9915	2.0085	1.9999
amount of dry soil (g)			-0.1259	1.999	1.9915	2.0085	1.9999
Total digestion initial rinse		Cu	8.97	5.49	1.92	0.416	0.919
		Fe	0.265	0.212	0.088	0.17	0.138
		Mn	0.562	0.433	0.209	0.076	0.121
		Zn	1.4872	0.9216	0.3935	0.1285	0.214
		Al	2.3	0.92	0.4	0.23	0.3
Total digestion		Cu	140.472	130.896	94.474	70.813	87.077
		Fe	353.56	265.47	242.73	247.65	249.23
		Mn	6.703	8.498	8.772	9	10.402
		Zn	36.545	35.229	29.362	26.926	29.272
		Al	598.1	621.5	607.2	629.7	655.9

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0046	2.0019	1.9931	1.9971	2.001
equiv. dry soil wt (g)			-0.1262	2.0019	1.9931	1.9971	2.001
SSE-0	Initial rinse	Cu	-1.2141	0.04773	0.01703	0.00655	0.00653
		Fe	-0.0962	0.00069	0.00126	0.00183	0.00212
		Mn	-0.071	0.00358	0.00184	0.00091	0.00082
		Zn	-0.1781	0.00742	0.00334	0.00153	0.00137
		Al	-0.6479	0.03501	0.03267	0.03421	0.0391
SSE-1	Exchangeable	Cu	-8.8854	0.45781	0.28075	0.23702	0.26435
		Fe	-1.6001	0.01897	0.00735	0.0049	0.00373
		Mn	-0.294	0.02173	0.02049	0.01958	0.02211
		Zn	-1.954	0.11417	0.08788	0.07896	0.08168
		Al	-6.0035	0.43047	0.41351	0.4295	0.35502
SSE-2	Carbonates	Cu	-9.7197	0.47715	0.383	0.23674	0.32088
		Fe	-0.7886	0.0637	0.06286	0.04078	0.05373
		Mn	-0.2475	0.0131	0.03035	0.02912	0.0284
		Zn	-2.9638	0.1409	0.11588	0.11918	0.11336
		Al	-0.1674	0.01327	0.02272	0.06001	0.08412
SSE-3	Fe-, Mn-oxides	Cu	-27.238	1.48877	1.0773	0.75153	0.75144
		Fe	-41.684	1.6613	1.23488	1.14835	1.07646
		Mn	-1.2606	0.08636	0.09294	0.10283	0.08932
		Zn	-3.995	0.26735	0.21604	0.20693	0.19183
		Al	-3.3314	0.28333	0.37108	0.46568	0.49275
SSE-4	Organics	Cu	-3.2686	0.18654	0.14289	0.11773	0.12486
		Fe	-18.603	0.85251	0.74445	0.63292	0.65055
		Mn	-1.6327	0.07373	0.08556	0.08618	0.09597
		Zn	-2.586	0.21167	0.18935	0.16667	0.18593
		Al	-9.1035	0.68835	0.76564	0.78494	0.87676
SSE-5	Residual	Cu	-0.7531	0.04492	0.03857	0.03403	0.0365
		Fe	-142.85	8.41081	8.66028	8.56822	8.17471
		Mn	-0.6029	0.03571	0.04347	0.0432	0.03994
		Zn	-0.8088	0.05446	0.05514	0.05649	0.05629
		Al	-296.88	20.1948	19.4953	19.1938	18.8706
SSE total	SSE1+2+3+4+5	Cu	-49.865	2.65518	1.92252	1.37705	1.49803
		Fe	-205.53	11.0073	10.7098	10.3952	9.9592
		Mn	-4.0377	0.23062	0.27281	0.28092	0.27574
		Zn	-12.308	0.78855	0.66428	0.62822	0.62908
		Al	-315.48	21.6102	21.0682	20.934	20.6792
wt. wet soil T.D. (g)			2.0004	1.999	1.9915	2.0085	1.9999
amount of dry soil (g)			-0.1259	1.999	1.9915	2.0085	1.9999
Total digestion initial rinse		Cu	-2.8492	0.10985	0.03856	0.00828	0.01838
		Fe	-0.0842	0.00424	0.00177	0.00339	0.00276
		Mn	-0.1785	0.00866	0.0042	0.00151	0.00242
		Zn	-0.4724	0.01844	0.0079	0.00256	0.00428
		Al	-0.7306	0.01841	0.00803	0.00458	0.006
Total digestion		Cu	-44.619	2.61923	1.89754	1.41027	1.74163
		Fe	-112.3	5.31206	4.87532	4.93204	4.98485
		Mn	-2.1291	0.17005	0.17619	0.17924	0.20805
		Zn	-11.608	0.70493	0.58975	0.53624	0.58547
		Al	-189.98	12.4362	12.1958	12.5407	13.1187
Recovery rate	SSE/total*100%	Cu	111.8%	101.4%	101.3%	97.6%	86.0%
		Fe	183.0%	207.2%	219.7%	210.8%	199.8%
		Mn	189.6%	135.6%	154.8%	156.7%	132.5%
		Zn	106.0%	111.9%	112.6%	117.2%	107.4%
		Al	166.1%	173.8%	172.7%	166.9%	157.6%

Soil analysis

CELL ID: **PTB15**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	18.64	17.21	17.35	17.5	17.22
wt. dry soil + container (g)	18.24	16.79	16.93	17.1	16.8
water content, w%	0.02323	0.02663	0.0264	0.02488	0.02662
soil pH	3.24	3.48	3.73	3.93	4.07

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9914	1.9919	2.073	2.0057	2.0005
equiv. dry soil wt (g)			1.94619	1.94023	2.01968	1.95702	1.94864
SSE-0	Initial rins	Cu	3.02	1.86	0.94	0.313	0.17
		Fe	0.053	0.344	0.167	0.791	0.629
		Mn	0.381	0.294	0.202	0.09	0.072
		Zn	0.7158	0.4968	0.3251	0.1282	0.0657
		Al	-1.84	-2.07	-2.22	-1.81	-1.82
SSE-1	Exchang	Cu	25.073	18.856	15.459	12.543	12.849
		Fe	1.429	0.553	0.366	0.316	0.298
		Mn	1.728	1.706	1.864	1.868	2.094
		Zn	8.5242	7.8233	7.3292	6.1634	6.5922
		Al	45.87	43.79	34.37	26.97	24.92
SSE-2	Carbonat	Cu	37.127	31.732	27.077	20.703	17.371
		Fe	3.892	0.781	0.826	0.731	0.699
		Mn	2.631	2.59	2.515	2.615	2.453
		Zn	16.6945	14.1018	12.0005	9.9923	8.6673
		Al	5.02	6.99	14.29	12.53	11.31
SSE-3	Fe-, Mn-	Cu	32.024	30.596	27.309	21.025	18.513
		Fe	68.432	62.195	54.305	55.238	54.86
		Mn	4.508	5.089	5.462	4.933	6.131
		Zn	10.9016	10.8171	10.7557	9.5035	9.1512
		Al	17.64	22.74	24.65	30.47	28.15
SSE-4	Organics	Cu	5.399	4.63	4.486	3.374	3.251
		Fe	37.885	33.508	31.556	28.035	26.619
		Mn	4.637	5.136	5.19	4.048	6.019
		Zn	8.8271	8.4753	8.3796	6.8864	6.6366
		Al	45.95	43.31	47.95	46.2	49.85
SSE-5	Residual	Cu	1.902	1.716	1.688	1.312	1.419
		Fe	514.45	463.58	506.35	486.6	504.44
		Mn	2.45	2.316	2.524	2.219	2.546
		Zn	3.1696	2.9674	3.1483	3.0104	2.9767
		Al	1069.3	1003.7	1074.5	1007.9	962.8
wt. wet soil T.D. (g)			1.9926	1.9921	1.9977	1.9938	2.0082
amount of dry soil (g)			1.94737	1.94042	1.94632	1.94541	1.95614
Total digestion initial rinse		Cu	2.574	1.721	1.27	0.278	0.1
		Fe	0.078	0.085	0.057	0.673	1.287
		Mn	0.325	0.284	0.245	0.088	0.055
		Zn	0.6479	0.5206	0.4538	0.1462	0.0695
		Al	0.59	0.54	0.52	1.17	1.71
Total digestion		Cu	76.773	106.465	98.489	65.223	59.362
		Fe	272.94	521.87	557.26	541.91	509.62
		Mn	8.115	10.191	10.86	11.294	10.659
		Zn	30.397	36.468	37.328	31.503	29.816
		Al	792.1	1216.3	1219.4	1277.9	1184.5

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9914	1.9919	2.073	2.0057	2.0005
equiv. dry soil wt (g)			1.94619	1.94023	2.01968	1.95702	1.94864
SSE-0	Initial rins	Cu	0.02483	0.01534	0.00745	0.00256	0.0014
		Fe	0.00044	0.00284	0.00132	0.00647	0.00516
		Mn	0.00313	0.00242	0.0016	0.00074	0.00059
		Zn	0.00588	0.0041	0.00258	0.00105	0.00054
		Al	-0.0151	-0.0171	-0.0176	-0.0148	-0.0149
SSE-1	Exchang	Cu	0.20613	0.1555	0.12247	0.10255	0.1055
		Fe	0.01175	0.00456	0.0029	0.00258	0.00245
		Mn	0.01421	0.01407	0.01477	0.01527	0.01719
		Zn	0.07008	0.06451	0.05806	0.05039	0.05413
		Al	0.37711	0.36111	0.27228	0.2205	0.20462
SSE-2	Carbonat	Cu	0.30523	0.26168	0.2145	0.16926	0.14263
		Fe	0.032	0.00644	0.00654	0.00598	0.00574
		Mn	0.02163	0.02136	0.01992	0.02138	0.02014
		Zn	0.13725	0.11629	0.09507	0.08169	0.07117
		Al	0.04127	0.05764	0.11321	0.10244	0.09286
SSE-3	Fe-, Mn-	Cu	0.65819	0.63077	0.54086	0.42974	0.38002
		Fe	1.40648	1.28222	1.07552	1.12902	1.12612
		Mn	0.09265	0.10492	0.10818	0.10083	0.12585
		Zn	0.22406	0.22301	0.21302	0.19424	0.18785
		Al	0.36255	0.46881	0.4882	0.62278	0.57784
SSE-4	Organics	Cu	0.11097	0.09545	0.08885	0.06896	0.06673
		Fe	0.77865	0.69081	0.62497	0.57301	0.54641
		Mn	0.0953	0.10588	0.10279	0.08274	0.12355
		Zn	0.18142	0.17473	0.16596	0.14075	0.13623
		Al	0.94441	0.89289	0.94965	0.94429	1.02328
SSE-5	Residual	Cu	0.03909	0.03538	0.03343	0.02682	0.02913
		Fe	10.5735	9.55724	10.0283	9.94574	10.3547
		Mn	0.05035	0.04775	0.04999	0.04535	0.05226
		Zn	0.06514	0.06118	0.06235	0.06153	0.0611
		Al	21.9773	20.6924	21.2806	20.6007	19.7636
SSE tota	SSE1+2-	Cu	1.3196	1.17877	1.00011	0.79732	0.72401
		Fe	12.8023	11.5413	11.7382	11.6563	12.0355
		Mn	0.27415	0.29397	0.29564	0.26557	0.339
		Zn	0.67796	0.63972	0.59446	0.52861	0.51048
		Al	23.7026	22.4729	23.1039	22.4907	21.6622
wt. wet soil T.D. (g)			1.9926	1.9921	1.9977	1.9938	2.0082
amount of dry soil (g)			1.94737	1.94042	1.94632	1.94541	1.95614
Total digestion initial rinse		Cu	0.05287	0.03548	0.0261	0.00572	0.00204
		Fe	0.0016	0.00175	0.00117	0.01384	0.02632
		Mn	0.00668	0.00585	0.00504	0.00181	0.00112
		Zn	0.01331	0.01073	0.00933	0.00301	0.00142
		Al	0.01212	0.01113	0.01069	0.02406	0.03497
Total digestion		Cu	1.57696	2.19468	2.02411	1.34107	1.21386
		Fe	5.60634	10.7579	11.4526	11.1423	10.421
		Mn	0.16669	0.21008	0.22319	0.23222	0.21796
		Zn	0.62437	0.75175	0.76715	0.64774	0.60969
		Al	16.2702	25.0729	25.0606	26.2752	24.2212
Recovery	SSE/tota	Cu	83.68%	53.71%	49.41%	59.45%	59.65%
		Fe	228.35%	107.28%	102.49%	104.61%	115.49%
		Mn	164.47%	139.94%	132.46%	114.36%	155.53%
		Zn	108.58%	85.10%	77.49%	81.61%	83.73%
		Al	145.68%	89.63%	92.19%	85.60%	89.43%

Soil analysis

Cell ID **PTB17**

sample ID	25-30	30-40	40-50
distance up column (cm)	30	40	50
wt. container(g)	1.02	1.02	1.02
wt. wet soil+container (g)	18.03	14.37	14.88
wt. dry soil + container (g)	17.55	14.07	14.51
water content, w%	0.029	0.023	0.0274
soil pH	3.25	3.67	3.75

metals in soil, ppm (from AAS)

sample ID			25-30	30-40	40-50
wt. wet soil (g)			2.0055	1.9961	2.0055
equiv. dry soil wt (g)			1.9489	1.9512	1.952
SSE-0	Initial rinse	Cu	2.236	0.484	1.487
		Fe	0.058	0.387	0.034
		Mn	0.392	0.116	0.302
		Zn	0.5586	0.183	0.4117
		Al	-1.8	-2.02	-2.06
SSE-1	Exchangeable	Cu	23.588	18.045	18.497
		Fe	1.902	0.477	0.459
		Mn	1.866	1.966	1.864
		Zn	8.7715	7.5552	7.8113
		Al	41.73	34.31	38.98
SSE-2	Carbonates	Cu	32.969	23.437	27.736
		Fe	0.999	0.751	0.857
		Mn	2.328	2.42	2.357
		Zn	12.56	9.5943	11.163
		Al	-0.15	8.33	10.08
SSE-3	Fe-, Mn-oxides	Cu	28.478	21.146	27.217
		Fe	57.777	62.49	53.511
		Mn	3.857	4.635	4.689
		Zn	9.1837	10.143	9.6623
		Al	15.35	22.7	27.34
SSE-4	Organics	Cu	5.078	4.045	4.543
		Fe	33.572	33.74	34.488
		Mn	3.829	4.552	5.26
		Zn	7.6082	6.9208	7.9371
		Al	45.88	48.76	54.45
SSE-5	Residual	Cu	1.548	1.344	1.525
		Fe	481.51	484.68	490.84
		Mn	1.793	2.054	2.073
		Zn	2.8789	2.718	3.0328
		Al	1183.2	1129.5	1117.7
wt. wet soil T.D. (g)			2.0049	2.0096	2.0075
amount of dry soil (g)			1.9483	1.9644	1.9539
Total digestion initial rinse		Cu	1.959	0.627	1.396
		Fe	0.145	0.429	0.055
		Mn	0.346	0.139	0.277
		Zn	0.5709	0.2001	0.4134
		Al	1.4	1.16	1.28
Total digestion		Cu	97.56	77.271	80.194
		Fe	467.1	520.89	507.43
		Mn	8.767	10.554	10.675
		Zn	32.162	30.576	33.973
		Al	1255.5	1200	1340.3

Amount of metals in soil, mg metal/kg soil

sample ID			25-30	30-40	40-50
wt. wet soil (g)			2.0055	1.9961	2.0055
equiv. dry soil wt (g)			1.9489	1.9512	1.952
SSE-0	Initial rinse	Cu	0.0184	0.004	0.0122
		Fe	0.0005	0.0032	0.0003
		Mn	0.0032	0.001	0.0025
		Zn	0.0046	0.0015	0.0034
		Al	-0.0148	-0.0166	-0.0169
SSE-1	Exchangeable	Cu	0.1937	0.148	0.1516
		Fe	0.0156	0.0039	0.0038
		Mn	0.0153	0.0161	0.0153
		Zn	0.072	0.062	0.064
		Al	0.3426	0.2813	0.3195
SSE-2	Carbonates	Cu	0.2707	0.1922	0.2273
		Fe	0.0082	0.0062	0.007
		Mn	0.0191	0.0198	0.0193
		Zn	0.1031	0.0787	0.0915
		Al	-0.0012	0.0683	0.0826
SSE-3	Fe-, Mn-oxides	Cu	0.5845	0.4335	0.5577
		Fe	1.1858	1.281	1.0966
		Mn	0.0792	0.095	0.0961
		Zn	0.1885	0.2079	0.198
		Al	0.315	0.4653	0.5603
SSE-4	Organics	Cu	0.1042	0.0829	0.0931
		Fe	0.689	0.6917	0.7067
		Mn	0.0786	0.0933	0.1078
		Zn	0.1562	0.1419	0.1626
		Al	0.9417	0.9996	1.1158
SSE-5	Residual	Cu	0.0318	0.0276	0.0313
		Fe	9.8827	9.9358	10.058
		Mn	0.0368	0.0421	0.0425
		Zn	0.0591	0.0557	0.0621
		Al	24.284	23.154	22.904
SSE total	SSE1+2+3+4+5	Cu	1.1848	0.8841	1.061
		Fe	11.781	11.919	11.872
		Mn	0.229	0.2664	0.281
		Zn	0.5789	0.5461	0.5783
		Al	25.882	24.969	24.982
wt. wet soil T.D. (g)			2.0049	2.0096	2.0075
amount of dry soil (g)			1.9483	1.9644	1.9539
Total digestion initial rinse		Cu	0.0402	0.0128	0.0286
		Fe	0.003	0.0087	0.0011
		Mn	0.0071	0.0028	0.0057
		Zn	0.0117	0.0041	0.0085
		Al	0.0287	0.0236	0.0262
Total digestion		Cu	2.003	1.5734	1.6417
		Fe	9.5898	10.606	10.388
		Mn	0.18	0.2149	0.2185
		Zn	0.6603	0.6226	0.6955
		Al	25.776	24.434	27.438
Recovery rate	SSE/total*100%	Cu	59.2%	56.2%	64.6%
		Fe	122.9%	112.4%	114.3%
		Mn	127.2%	124.0%	128.6%
		Zn	87.7%	87.7%	83.2%
		Al	100.4%	102.2%	91.0%

Soil analysis

Cell ID PTB18

sample ID	25-30	30-40	40-50
distance up column (cm)	30	40	50
wt. container(g)	1.02	1.02	1.02
wt. wet soil+container (g)	16.07	18.45	17.19
wt. dry soil + container (g)	15.62	18	16.75
water content, w%	0.0308	0.0265	0.027972
soil pH	3.1	3.54	3.79

metals in soil, ppm (from AAS)

sample ID			20-30	30-40	40-50
wt. wet soil (g)			2.0048	1.998	2.0092
equiv. dry soil wt (g)			1.9449	1.9464	1.9545
SSE-0	Initial rinse	Cu	2.604	1.591	0.847
		Fe	0.173	0.036	0.046
		Mn	0.414	0.293	0.214
		Zn	0.7013	0.4124	0.3218
		Al	-1.63	-1.96	0.04
SSE-1	Exchangeable	Cu	27.949	18.639	14.138
		Fe	3.710	0.493	0.306
		Mn	1.843	1.767	1.732
		Zn	9.1585	7.3256	6.7997
		Al	41.1	43.3	40.28
SSE-2	Carbonates	Cu	34.754	26.61	22.448
		Fe	0.963	0.917	0.75
		Mn	2.054	2.318	2.277
		Zn	14.48	11.907	10.457
		Al	3.95	14.97	13.92
SSE-3	Fe-, Mn-oxides	Cu	29.997	28.643	24.652
		Fe	61.792	57.036	52.601
		Mn	3.397	4.613	5.117
		Zn	8.955	10.005	10.272
		Al	14.95	22.87	29.75
SSE-4	Organics	Cu	5.255	4.938	4.606
		Fe	37.297	34.575	39.267
		Mn	3.285	4.787	4.32
		Zn	7.2652	8.6061	9.0834
		Al	45.73	54.37	51.35
SSE-5	Residual	Cu	1.551	1.643	1.642
		Fe	477.52	525.23	541.53
		Mn	2.028	2.151	2.233
		Zn	2.7874	3.1843	3.5595
		Al	1094.5	1426.6	1378.3
wt. wet soil T.D. (g)			1.9968	2.0009	2.001
amount of dry soil (g)			1.9371	1.9492	1.9466
Total digestion initial rinse		Cu	2.55	1.355	0.724
		Fe	0.213	0.177	0.144
		Mn	0.424	0.249	0.18
		Zn	0.775	0.3643	0.2432
		Al	2.13	0.8	1.12
Total digestion		Cu	122.92	96.118	116.26
		Fe	543.02	523.12	484.89
		Mn	9.155	10.874	11.079
		Zn	35.217	35.856	33.904
		Al	1314.6	1420.4	1256.5

Amount of metals in soil, mg metal/kg soil

sample ID			25-30	30-40	40-50
wt. wet soil (g)			2.0048	1.998	2.0092
equiv. dry soil wt (g)			1.9448558	1.94642	1.95453
SSE-0	Initial rinse	Cu	0.0214227	0.01308	0.00693
		Fe	0.0014232	0.0003	0.00038
		Mn	0.0034059	0.00241	0.00175
		Zn	0.0057695	0.00339	0.00263
		Al	-0.01341	-0.0161	0.00033
SSE-1	Exchangeable	Cu	0.2299317	0.15322	0.11574
		Fe	0.0305215	0.00405	0.0025
		Mn	0.015162	0.01453	0.01418
		Zn	0.0753454	0.06022	0.05566
		Al	0.3381228	0.35594	0.32974
SSE-2	Carbonates	Cu	0.2859153	0.21874	0.18376
		Fe	0.0079224	0.00754	0.00614
		Mn	0.0168979	0.01905	0.01864
		Zn	0.1191262	0.09788	0.08561
		Al	0.032496	0.12306	0.11395
SSE-3	Fe-, Mn-oxides	Cu	0.6169506	0.58863	0.50451
		Fe	1.2708808	1.17212	1.0765
		Mn	0.0698664	0.0948	0.10472
		Zn	0.1841782	0.20561	0.21021
		Al	0.3074778	0.46999	0.60884
SSE-4	Organics	Cu	0.10808	0.10148	0.09426
		Fe	0.7670903	0.71054	0.80361
		Mn	0.0675628	0.09838	0.08841
		Zn	0.1494239	0.17686	0.18589
		Al	0.9405324	1.11734	1.05089
SSE-5	Residual	Cu	0.0318995	0.03376	0.0336
		Fe	9.8211908	10.7938	11.0826
		Mn	0.04171	0.0442	0.0457
		Zn	0.0573287	0.06544	0.07285
		Al	22.510666	29.3175	28.2073
SSE total	SSE1+2+3+4+5	Cu	1.2727771	1.09583	0.93188
		Fe	11.897606	12.688	12.9713
		Mn	0.2111992	0.27096	0.27165
		Zn	0.5854024	0.606	0.61022
		Al	24.129295	31.3838	30.3107
wt. wet soil T.D. (g)			1.9968	2.0009	2.001
amount of dry soil (g)			1.937095	1.94924	1.94655
Total digestion initial rinse		Cu	0.0526562	0.02781	0.01488
		Fe	0.0043983	0.00363	0.00296
		Mn	0.0087554	0.00511	0.0037
		Zn	0.0160033	0.00748	0.005
		Al	0.0439834	0.01642	0.02302
Total digestion		Cu	2.5383273	1.97242	2.38894
		Fe	11.213079	10.7348	9.96409
		Mn	0.189046	0.22314	0.22766
		Zn	0.7272126	0.73579	0.6967
		Al	27.145803	29.1477	25.82
Recovery rate	SSE/total*100%	Cu	50.14%	55.56%	39.01%
		Fe	106.10%	118.19%	130.18%
		Mn	111.72%	121.43%	119.32%
		Zn	80.50%	82.36%	87.59%
		Al	88.89%	107.67%	117.39%

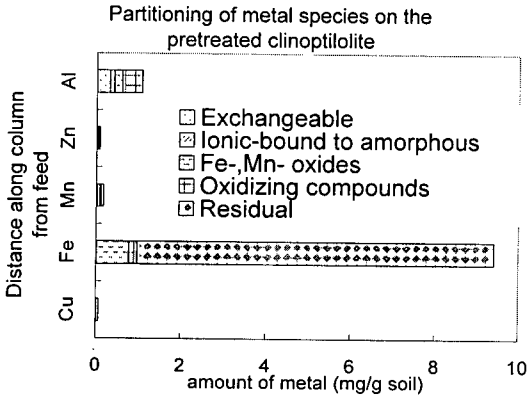
Appendix H. Column leaching cell tests Soil Analyses Results

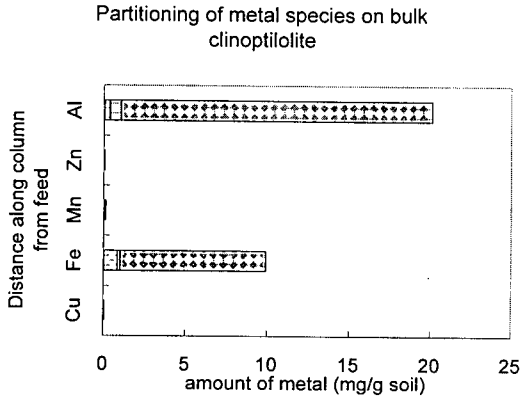
Appendix H-2. Numerical and graphical presentation of metal fractionations on soil samples after deducting background metal concentrations

Fractionation of metals from treated and bulk clinoptilolite

Treated	Cu	Fe	Mn	Zn	Al
Initial Rinse	0.00047	0.03672	0.00154	0.00075	-0.04557
Exchangeable	0.00221	0.00173	0.00415	0.00151	0.296469
Ionic-bound to amo	0.00346	0.01415	0.02	0.0047	0.109664
Fe-,Mn- oxides	0.00251	0.762	0.06298	0.01791	0.194217
Oxidizing compoun	0.00744	0.19653	0.03303	0.0211	0.471707
Residual	0.05486	8.45225	0.05867	0.04578	-0.07203
SSE-sum	0.07048	9.42667	0.17883	0.09099	1.000027
Total digestion initia	-0.0004	0.06399	0.00401	0.00055	-0.22933
Total digestion	0.06415	10.0344	0.19518	0.08447	1.132638

Bulk	Cu	Fe	Mn	Zn	Al
Initial Rinse	8.2E-06	0.01238	0.0011	0.00037	0.005437
Exchangeable	0.00249	0.00261	0.00339	0.0016	0.031471
Ionic-bound to amo	0.00372	0.02911	0.02193	0.00504	0.031883
Fe-,Mn- oxides	0.00229	0.82853	0.0649	0.0163	0.2972
Oxidizing compoun	0.00832	0.17239	0.0347	0.02473	0.710149
Residual	0.05773	8.89458	0.05207	0.04694	19.04922
SSE-sum	0.07454	9.92722	0.17699	0.09461	20.11992
Total digestion initia	-0.0011	0.04089	0.00382	-0.0003	0.017556
Total digestion	0.06246	11.0582	0.19792	0.09365	22.52277



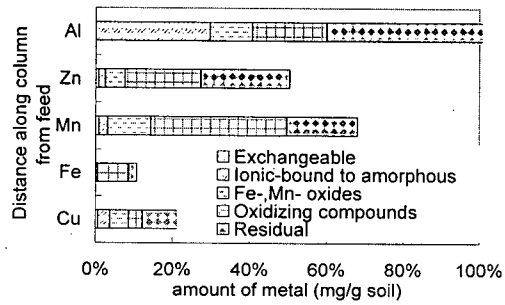


Fractionation of metals from treated and bulk clinoptilolite (%)

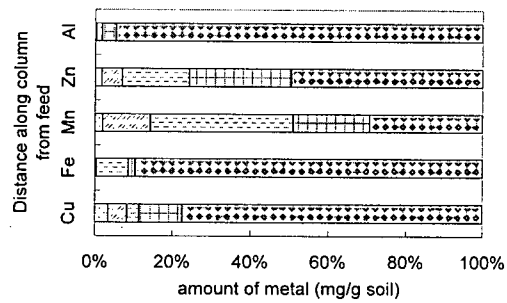
	Cu	Fe	Mn	Zn	Al
Exchangeable	0.67%	0.39%	0.86%	0.82%	-4.56%
Ionic-bound to amorp	3.14%	0.02%	2.32%	1.66%	29.65%
Fe-,Mn- oxides	4.90%	0.15%	11.18%	5.17%	10.97%
Oxidizing compound	3.56%	8.08%	35.22%	19.68%	19.42%
Residual	10.55%	2.08%	18.47%	23.19%	47.17%
SSE-sum	23%	11%	68%	51%	103%
Total digestion initial	0.015981	0.00236	0.00133	0.00222	0.00154
Total digestion	0.455063	0.32746	0.22357	0.31853	0.27638

	Cu	Fe	Mn	Zn	Al
Exchangeable	3.34%	0.03%	1.91%	1.69%	0.16%
Ionic-bound to amorp	4.98%	0.29%	12.39%	5.33%	0.16%
Fe-,Mn- oxides	3.07%	8.35%	36.67%	17.23%	1.48%
Oxidizing compound	11.16%	1.74%	19.61%	26.14%	3.53%
Residual	77.45%	89.60%	29.42%	49.61%	94.68%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestion initial	-0.06031	-0.05174	-0.0537	-0.05887	-0.0574
Total digestion	0.836488	0.32265	-0.1032	-0.18519	0.35734

Partition of metals in pretreated clinoptilolite in % of the amount of each metal species



Partition of metals in bulk clinoptilolite in % of the amount of each metal species



PTB1C1 **Minus concentration leached by treated clinoptilolite**

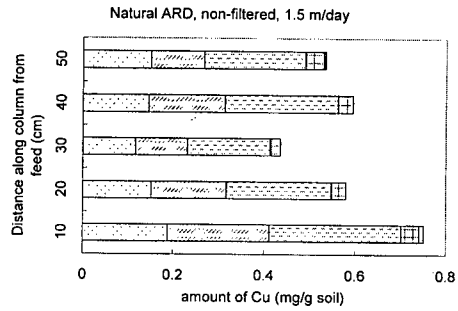
Cu	10	20	30	40	50
Initial Rinse	0.00797	0.00058	0.00016	0.00087	0.000358
Exchangeabl	0.18838	0.15179	0.11682	0.14588	0.150635
Ionic-bound t	0.22416	0.16635	0.11508	0.16864	0.118069
Fe-,Mn- oxide	0.28919	0.23018	0.1818	0.24834	0.222024
Oxidizing con	0.04008	0.03196	0.02294	0.03294	0.040833
Residual	0.01015	0	0	0	0.003483
SSE-sum	0.75196	0.57389	0.43316	0.59552	0.535044
Total digestio	0.01637	0.00276	0.00172	0.00261	0.00193
Total digestio	0.6475	0.5199	0.41601	0.51097	0.468817

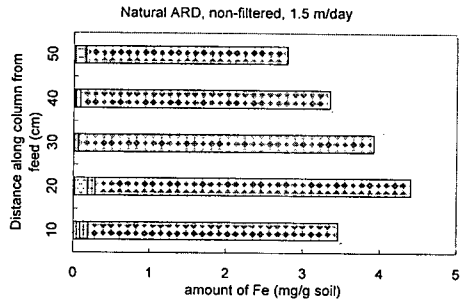
Fe	10	20	30	40	50
Initial Rinse	-0.0345	-0.0333	-0.0321	-0.0353	-0.03473
Exchangeabl	0.00453	0.00173	0.00127	0.00153	0.002273
Ionic-bound t	0.04012	0.01674	0.01224	0.014	0.016661
Fe-,Mn- oxide	0.04514	0.17135	-0.0085	0.01894	-0.01965
Oxidizing con	0.10717	0.09667	0.04952	0.05396	0.141197
Residual	3.2649	4.12215	3.85886	3.2641	2.6366
SSE-sum	3.46184	4.40864	3.91342	3.35253	2.777075
Total digestio	-0.0603	-0.0517	-0.0537	-0.0589	-0.05736
Total digestio	0.83649	0.32265	-0.1032	-0.1852	0.35734

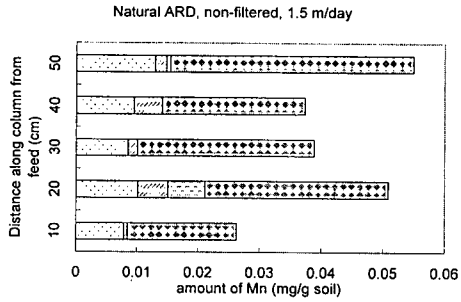
Mn	10	20	30	40	50
Initial Rinse	-0.001	-0.0013	-0.0013	-0.0013	-0.00138
Exchangeabl	0.00786	0.01013	0.00856	0.00948	0.012955
Ionic-bound t	0.00062	0.00494	0.00151	0.00463	0.001853
Fe-,Mn- oxide	-0.016	0.00606	-0.0133	-0.0057	0.000678
Oxidizing con	-0.015	-0.0041	-0.0171	-0.0102	-0.00403
Residual	0.01781	0.02975	0.0288	0.02329	0.039467
SSE-sum	-0.0047	0.04679	0.00851	0.0215	0.050925
Total digestio	-0.0029	-0.0034	-0.0035	-0.0035	-0.0036
Total digestio	-0.0364	-0.043	-0.0585	-0.0548	-0.0629

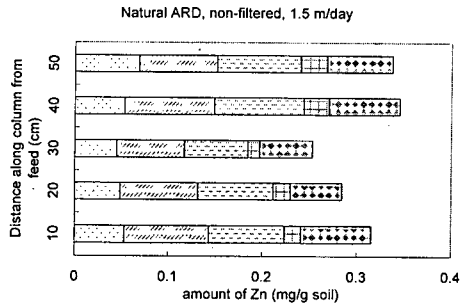
Zn	10	20	30	40	50
Initial Rinse	0.00045	-0.0005	-0.0006	-0.0007	-0.00054
Exchangeabl	0.05309	0.04864	0.04499	0.05342	0.068933
Ionic-bound t	0.09069	0.08335	0.07248	0.09577	0.083114
Fe-,Mn- oxide	0.08031	0.08005	0.06734	0.09461	0.088491
Oxidizing con	0.01719	0.01786	0.01253	0.02683	0.027753
Residual	0.07429	0.05469	0.05598	0.07482	0.069388
SSE-sum	0.31557	0.28459	0.25331	0.34545	0.337679
Total digestio	0.00096	0.00013	0.00026	2E-05	-0.00061
Total digestio	0.25876	0.2434	0.22631	0.26811	0.258667

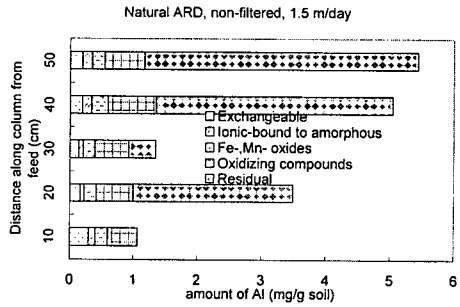
Al	10	20	30	40	50
Initial Rinse	-0.0456	-0.0465	-0.0454	-0.0462	-0.04666
Exchangeabl	0.29647	0.16204	0.13548	0.19026	0.193599
Ionic-bound t	0.10966	0.06473	0.07527	0.151	0.15399
Fe-,Mn- oxide	0.19422	0.1934	0.17765	0.25819	0.199884
Oxidizing con	0.47171	0.57854	0.53847	0.75777	0.626245
Residual	-0.072	2.49494	0.42651	3.68962	4.26873
SSE-sum	1.00003	3.49366	1.35337	5.04684	5.442448
Total digestio	-0.2293	-0.2248	-0.2287	-0.2295	-0.226
Total digestio	1.13264	2.17071	-1.2012	1.06387	1.215773





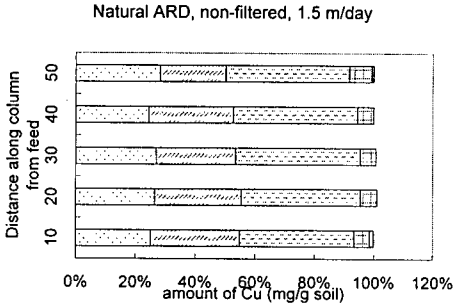




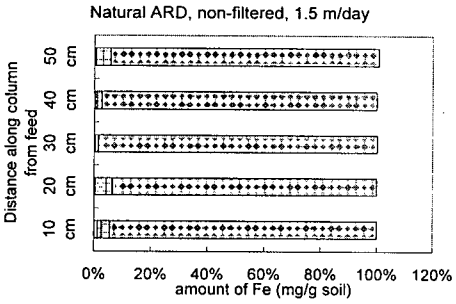


PTB1C1 **Minus concentration leached by treated clinoptilolite (%)**

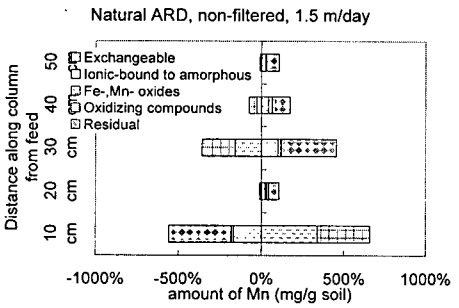
Cu	10 cm	20 cm	30 cm	40 cm	50 cm	average
	25.05%	26.45%	26.97%	24.50%	28.15%	26.22%
Exchangeabl	29.81%	28.99%	26.57%	28.32%	22.07%	27.15%
Ionic-bound t	38.46%	40.11%	41.97%	41.70%	41.50%	40.75%
Fe-,Mn- oxide	5.33%	5.57%	5.30%	5.53%	7.63%	5.87%
Oxidizing con	1.35%	0.00%	0.00%	0.00%	0.65%	0.40%
Residual	100%	101%	101%	100%	100%	100.39%
Total digestio	0.0159809	0.0023644	0.0013299	0.0022209	0.00154	
Total digestio	0.4550629	0.3274629	0.2235737	0.3185298	0.27638	



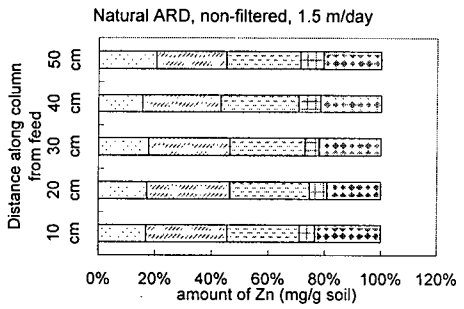
Fe	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	0.13%	0.04%	0.03%	0.05%	0.08%	0.07%
Ionic-bound t	1.16%	0.38%	0.31%	0.42%	0.60%	0.57%
Fe-,Mn- oxide	1.30%	3.89%	-0.22%	0.57%	-0.71%	0.97%
Oxidizing con	3.10%	2.19%	1.27%	1.61%	5.08%	2.65%
Residual	94.31%	93.50%	98.61%	97.36%	94.94%	95.74%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.0603088	-0.051738	-0.0537327	-0.058865	-0.0574	
Total digestio	0.8364882	0.3226452	-0.1032376	-0.185187	0.35734	



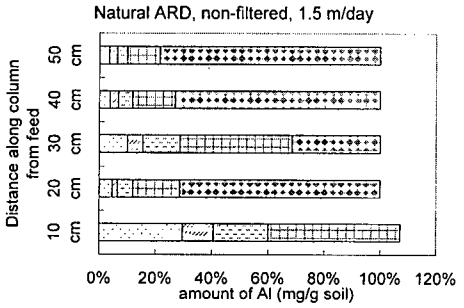
Mn	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	-166.81%	21.64%	100.53%	44.07%	25.44%	4.97%
Ionic-bound t	-13.21%	10.56%	17.73%	21.55%	3.64%	8.05%
Fe-,Mn- oxide	339.81%	12.96%	-155.92%	-26.44%	1.33%	34.35%
Oxidizing con	318.24%	-8.74%	-200.77%	-47.48%	-7.91%	10.67%
Residual	-378.04%	63.58%	338.43%	108.31%	77.50%	41.96%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.0028874	-0.003394	-0.0034833	-0.003492	-0.0036	
Total digestio	-0.0363956	-0.043041	-0.0584578	-0.054831	-0.0629	



Zn	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	16.82%	17.09%	17.76%	15.47%	20.41%	17.51%
Ionic-bound t	28.74%	29.29%	28.61%	27.72%	24.61%	27.79%
Fe-,Mn- oxide	25.45%	28.13%	26.58%	27.39%	26.21%	26.75%
Oxidizing con	5.45%	6.28%	4.94%	7.77%	8.22%	6.53%
Residual	23.54%	19.22%	22.10%	21.66%	20.55%	21.41%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	0.0009636	0.0001252	0.0002594	1.955E-05	-0.0006	
Total digestio	0.2587575	0.2433951	0.2263064	0.2681074	0.25867	



Al	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	29.65%	4.64%	10.01%	3.77%	3.56%	10.32%
Ionic-bound t	10.97%	1.85%	5.56%	2.99%	2.83%	4.84%
Fe-,Mn- oxide	19.42%	5.54%	13.13%	5.12%	3.67%	9.37%
Oxidizing con	47.17%	16.56%	39.79%	15.01%	11.51%	26.01%
Residual	-7.20%	71.41%	31.51%	73.11%	78.43%	49.45%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.2293291	-0.224828	-0.2286687	-0.229541	-0.226	
Total digestio	1.1326381	2.1707136	-1.2011856	1.0638715	1.21577	



NTNFC1 minus conc leached by bulk clinop

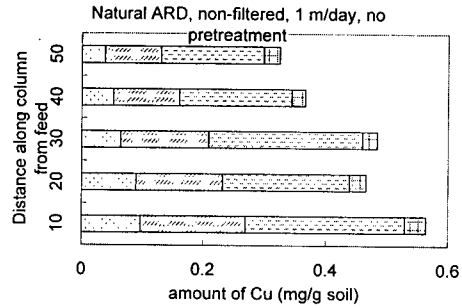
Cu	10	20	30	40	50
Initial Rins	0.010218	0.00417	0.00283	0.00122	0.00057
Exchange	0.09711	0.08961	0.06424	0.05214	0.03829
Ionic-bour	0.172014	0.14203	0.14481	0.10872	0.09217
Fe-,Mn- o	0.25981	0.20736	0.25084	0.18359	0.16821
Oxidizing	0.03478	0.02658	0.02426	0.0224	0.0261
Residual	0.000899	0.00096	-0.0081	-0.0081	-0.0022
SSE-sum	0.564613	0.46654	0.47607	0.35873	0.32257
Total dige	0.0272	0.01006	0.00634	0.0051	0.00302
Total dige	0.501398	0.51139	0.3969	0.35267	0.29728

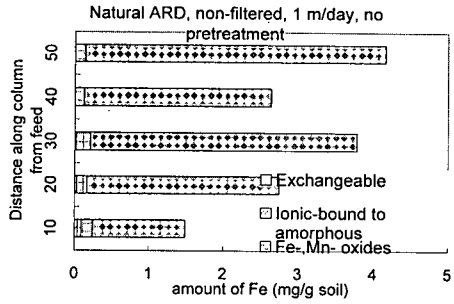
Fe	10	20	30	40	50
Initial Rins	-0.00765	-0.0109	-0.0086	-0.011	-0.0091
Exchange	0.002735	7.6E-05	-4E-05	-0.0006	-0.0014
Ionic-bour	0.036602	-0.0051	0.01802	0.00013	-0.0031
Fe-,Mn- o	0.052208	0.02769	-0.0266	-0.071	-0.0543
Oxidizing	0.154307	0.13769	0.1931	0.12632	0.13818
Residual	1.245509	2.58205	3.57497	2.51182	4.0249
SSE-sum	1.491363	2.7424	3.75945	2.56665	4.10435
Total dige	-0.03728	-0.0379	-0.038	-0.0357	-0.0341
Total dige	-1.4017	-0.661	-0.399	-0.2119	-1.8256

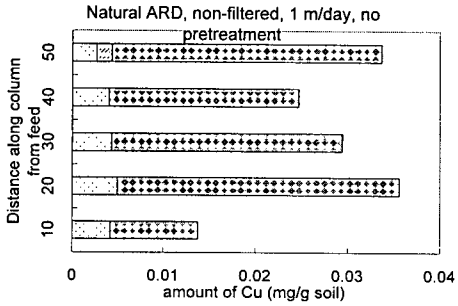
Mn	10	20	30	40	50
Initial Rins	4.92E-06	-0.0004	-0.0005	-0.0008	-0.0008
Exchange	0.004203	0.00498	0.00431	0.00402	0.00264
Ionic-bour	-0.00739	-0.0097	-0.0001	-8E-05	0.0017
Fe-,Mn- o	-0.02991	-0.0091	-0.0119	-0.0114	-0.0096
Oxidizing	-0.01817	-0.016	-0.0155	-0.0154	-0.0124
Residual	0.009576	0.03062	0.02513	0.02067	0.02934
SSE-sum	-0.0417	0.00077	0.00201	-0.0022	0.0117
Total dige	-0.00146	-0.0022	-0.0026	-0.0026	-0.0031
Total dige	-0.10556	-0.0829	-0.0769	-0.0557	-0.0572

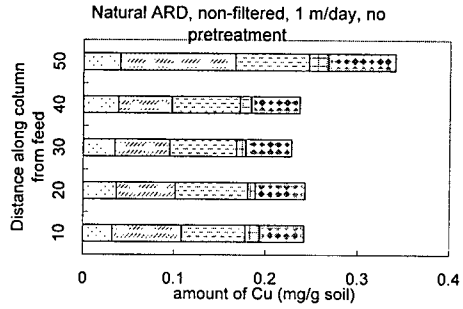
Zn	10	20	30	40	50
Initial Rins	0.001313	0.0006	0.00037	7.2E-05	-4E-05
Exchange	0.032363	0.03669	0.03504	0.03872	0.04052
Ionic-bour	0.076209	0.065	0.06019	0.05876	0.12614
Fe-,Mn- o	0.0695	0.07896	0.0728	0.0744	0.07991
Oxidizing	0.015821	0.00827	0.01036	0.01237	0.02069
Residual	0.048161	0.05417	0.05002	0.05272	0.07334
SSE-sum	0.242053	0.24309	0.22841	0.23698	0.3406
Total dige	0.003918	0.00184	0.0013	0.00102	0.0004
Total dige	0.163527	0.18665	0.17855	0.17242	0.18662

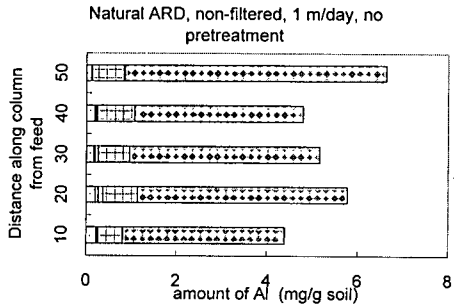
Al	10	20	30	40	50
Initial Rins	-0.00223	-0.004	-0.0035	-0.0046	-0.0043
Exchange	0.227504	0.20106	0.16359	0.1812	0.10374
Ionic-bour	0.031937	0.06431	0.02678	0.03769	0.0253
Fe-,Mn- o	-0.02471	0.10899	0.08081	0.02188	-0.0057
Oxidizing	0.559056	0.76957	0.6949	0.83921	0.72382
Residual	3.585382	4.63571	4.19989	3.71835	5.78015
SSE-sum	4.379165	5.77963	5.16597	4.79833	6.62729
Total dige	-0.01468	-0.0161	-0.0169	-0.0141	-0.0135
Total dige	0.057913	0.58308	-0.4004	2.60651	1.05307





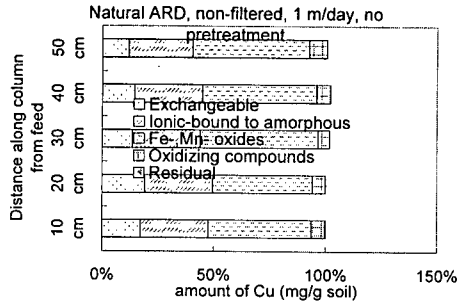




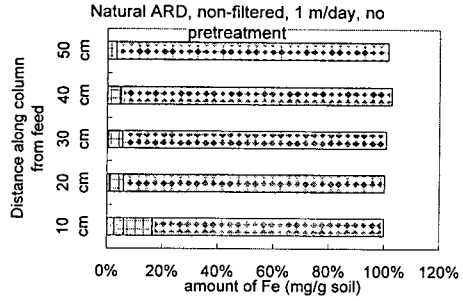


NTNFC1 minus conc leached by bulk clino (%)

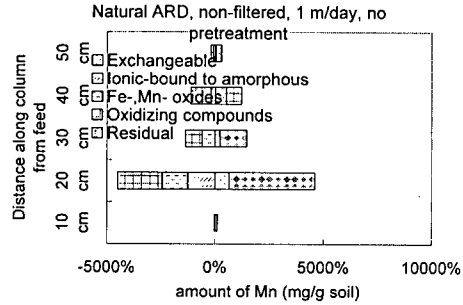
Cu	10 cm	20 cm	30 cm	40 cm	50 cm	
Initial Rinse						
Exchange	17.20%	19.21%	13.49%	14.54%	11.87%	15.26%
Ionic-bour	30.47%	30.44%	30.42%	30.31%	28.57%	30.04%
Fe-,Mn- o	46.02%	44.45%	52.69%	51.18%	52.15%	49.30%
Oxidizing	6.16%	5.70%	5.10%	6.24%	8.09%	6.26%
Residual	0.16%	0.21%	-1.70%	-2.26%	-0.68%	-0.86%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0.0272	0.010064	0.006336	0.005103	0.003023	
Total dige	0.501398	0.511395	0.396896	0.352674	0.29728	



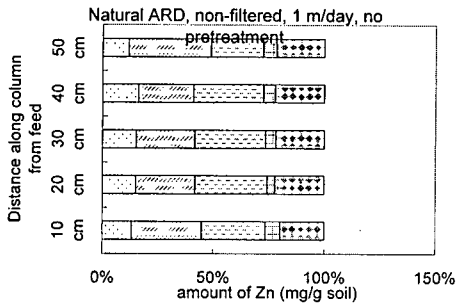
Fe	10 cm	20 cm	30 cm	40 cm	50 cm	
Initial Rinse						
Exchange	0.18%	0.00%	0.00%	-0.02%	-0.03%	0.03%
Ionic-bour	2.45%	-0.19%	0.48%	0.01%	-0.08%	0.54%
Fe-,Mn- o	3.50%	1.01%	-0.71%	-2.77%	-1.32%	-0.06%
Oxidizing	10.35%	5.02%	5.14%	4.92%	3.37%	5.76%
Residual	83.51%	94.15%	95.09%	97.86%	98.06%	93.74%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	-0.03728	-0.037911	-0.03801	-0.03571	-0.03408	
Total dige	-1.4017	-0.661033	-0.39904	-0.21189	-1.8256	



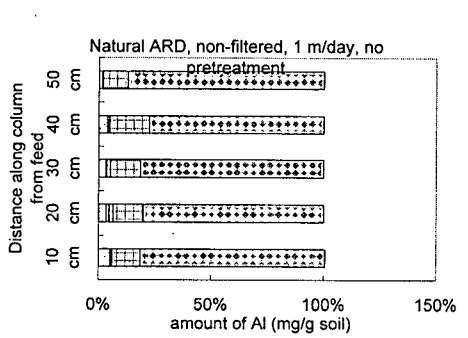
Mn	10 cm	20 cm	30 cm	40 cm	50 cm	
Initial Rinse						
Exchange	-10.08%	643.76%	214.82%	-182.47%	22.60%	137.73%
Ionic-bour	17.73%	-1254.84%	-5.03%	3.63%	14.52%	-244.80%
Fe-,Mn- o	71.73%	-1181.93%	-590.60%	518.94%	-81.85%	-252.74%
Oxidizing	43.59%	-2066.26%	-770.81%	697.39%	-106.04%	-440.43%
Residual	-22.97%	3959.26%	1251.62%	-937.49%	250.77%	900.24%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	-0.00146	-0.002248	-0.00261	-0.00261	-0.00306	
Total dige	-0.10556	-0.082915	-0.07687	-0.0557	-0.05724	



Zn	10 cm	20 cm	30 cm	40 cm	50 cm	
Initial Rinse						
Exchange	13.37%	15.09%	15.34%	16.34%	11.90%	14.41%
Ionic-bour	31.48%	26.74%	26.35%	24.80%	37.03%	29.28%
Fe-,Mn- o	28.71%	32.48%	31.87%	31.40%	23.46%	29.59%
Oxidizing	6.54%	3.40%	4.54%	5.22%	6.07%	5.15%
Residual	19.90%	22.28%	21.90%	22.25%	21.53%	21.57%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0.003918	0.001842	0.0013	0.001023	0.000404	
Total dige	0.163527	0.186653	0.178546	0.172424	0.186624	



Al	10 cm	20 cm	30 cm	40 cm	50 cm	
Initial Rinse						
Exchange	5.20%	3.48%	3.17%	3.78%	1.57%	3.44%
Ionic-bour	0.73%	1.11%	0.52%	0.79%	0.38%	0.71%
Fe-,Mn- o	-0.56%	1.89%	1.56%	0.46%	-0.09%	0.65%
Oxidizing	12.77%	13.32%	13.45%	17.49%	10.92%	13.59%
Residual	81.87%	80.21%	81.30%	77.49%	87.22%	81.62%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	-0.01468	-0.016125	-0.01694	-0.01406	-0.01345	
Total dige	0.057913	0.583077	-0.40038	2.606505	1.053072	



PTB3,4Avg minus background leaching of treated clinoptilolite

Cu	10	20	30	40	50
Initial Rinse	0.029361	0.00681	0.00248	0.00314	0.00207
Exchangeat	0.336726	0.27215	0.15707	0.18985	0.23098
Ionic-bound	0.669083	0.4449	0.20639	0.14558	0.24107
Fe-,Mn- oxi	0.52676	0.38739	0.21269	0.17928	0.22805
Oxidizing co	0.076188	0.05795	0.03337	0.03103	0.03077
Residual	0.019254	0.00054	-0.0145	-0.0177	-0.0145
SSE-sum	1.62801	1.16293	0.59506	0.52802	0.71638
Total digest	0.054114	0.01917	0.00691	0.00872	0.00732
Total digest	1.522177	1.42497	0.58668	0.50168	0.65085

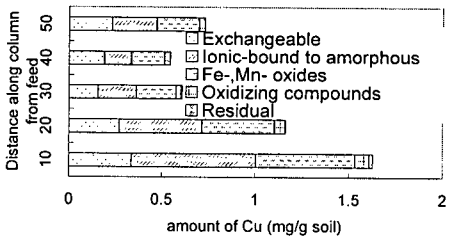
Fe	10	20	30	40	50
Initial Rinse	-0.03476	-0.0282	-0.0214	-0.0159	-0.0208
Exchangeat	0.021856	0.00351	-3E-06	0.00122	0.00148
Ionic-bound	0.101439	0.05725	0.02599	0.01175	0.02675
Fe-,Mn- oxi	1.169653	0.42615	0.19701	0.10284	0.21392
Oxidizing co	0.499958	0.24273	0.20358	0.21982	0.12191
Residual	2.003314	0.82141	1.18359	1.31726	0.66004
SSE-sum	3.79622	1.55105	1.61016	1.65289	1.02409
Total digest	-0.06088	-0.0501	-0.0295	-0.0229	-0.0314
Total digest	2.206353	1.84128	0.07375	0.39232	0.26371

Mn	10	20	30	40	50
Initial Rinse	0.000304	-0.0009	-0.0009	-0.0006	-0.0009
Exchangeat	0.010946	0.01073	0.01029	0.01996	0.01748
Ionic-bound	0.014858	0.01202	0.0085	0.00536	0.01102
Fe-,Mn- oxi	-0.00811	-0.0098	-0.0073	-0.007	-0.004
Oxidizing co	-0.01502	-0.0149	-0.0141	-0.0113	-0.0103
Residual	0.005045	0.00495	0.00891	0.00928	0.0104
SSE-sum	0.007719	0.00296	0.00624	0.01632	0.02457
Total digest	-0.0005	-0.0024	-0.0024	-0.0018	-0.0026
Total digest	-0.02775	-0.036	-0.0328	0.02428	0.02447

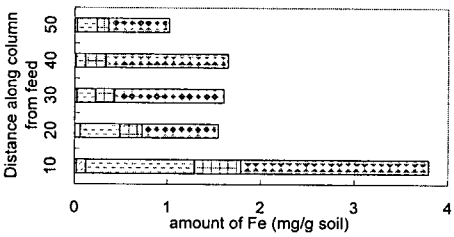
Zn	10	20	30	40	50
Initial Rinse	0.002922	0.0002	-0.0003	0.00016	-0.0004
Exchangeat	0.079123	0.07042	0.05516	0.04912	0.05031
Ionic-bound	0.160252	0.13373	0.078	0.06902	0.08798
Fe-,Mn- oxi	0.139697	0.10973	0.06745	0.05698	0.07668
Oxidizing co	0.026658	0.02744	0.01478	0.01303	0.01571
Residual	0.052581	0.04692	0.03646	0.03106	0.03566
SSE-sum	0.458311	0.38824	0.25185	0.2192	0.26634
Total digest	0.00667	0.00178	0.00092	0.00242	0.00143
Total digest	0.48266	0.45029	0.20929	0.18722	0.2473

Al	10	20	30	40	50
Initial Rinse	-0.0431	-0.0446	-0.0402	-0.0352	-0.0426
Exchangeat	0.286243	0.16491	0.14429	0.11769	0.19276
Ionic-bound	0.01644	0.0184	0.02631	0.03707	0.03194
Fe-,Mn- oxi	-0.13452	-0.1088	-0.0863	-0.0732	-0.0608
Oxidizing co	0.197759	0.34932	0.57866	0.55627	0.57207
Residual	2.128177	2.15155	1.80386	2.761	1.47809
SSE-sum	2.494098	2.57537	2.46686	3.39888	2.2141
Total digest	-0.22568	-0.2271	-0.2215	-0.0875	-0.2184
Total digest	-1.8411	1.83487	-0.3025	1.42002	0.50675

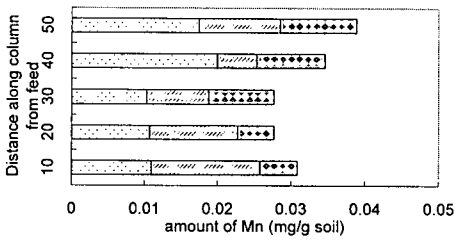
Maximum design concentration, fitlered, 1.5 m/day



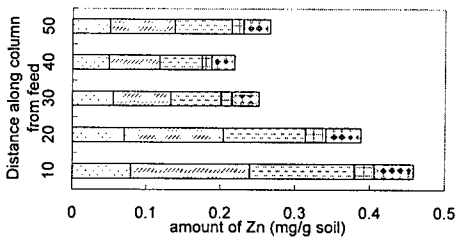
Maximum design concentration, fitlered, 1.5 m/day



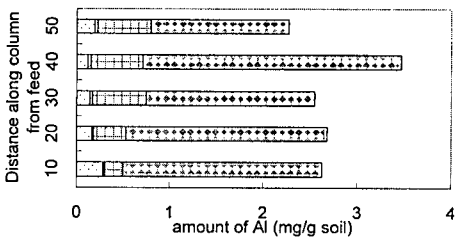
Maximum design concentration, fitlered, 1.5 m/day



Maximum design concentration, fitlered, 1.5 m/day

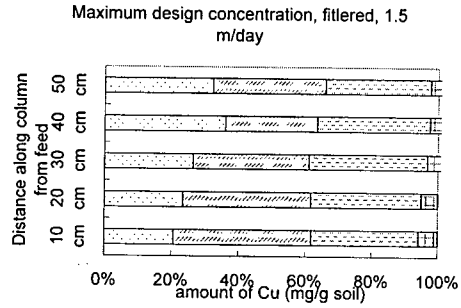


Maximum design concentration, fitlered, 1.5 m/day

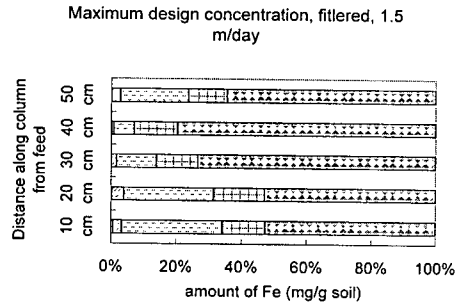


PTB3,4Avg minus background leaching of treated clinoptilolite (%)

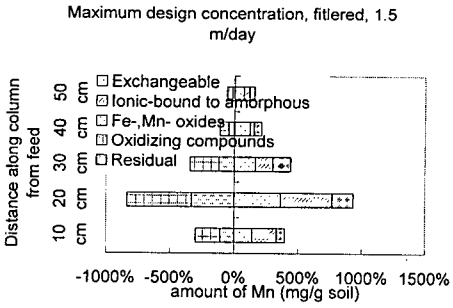
Cu	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	20.68%	23.40%	26.40%	35.96%	32.24%	27.7%
Ionic-bound t	41.10%	38.26%	34.68%	27.57%	33.65%	35.1%
Fe-,Mn- oxide	32.36%	33.31%	35.74%	33.95%	31.83%	33.4%
Oxidizing com	4.68%	4.98%	5.61%	5.88%	4.29%	5.1%
Residual	1.18%	0.05%	-2.43%	-3.36%	-2.02%	-1.3%
SSE-sum	100%	100%	100%	100%	100%	100.0%
Total digestio	0.01598086	0.002364	0.00133	0.002221	0.001539	
Total digestio	0.45506292	0.327463	0.223574	0.31853	0.276379	



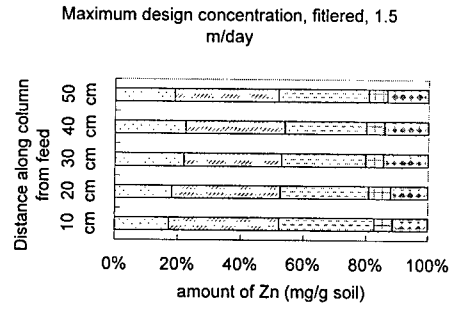
Fe	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	0.58%	0.23%	0.00%	0.07%	0.14%	0.2%
Ionic-bound t	2.67%	3.69%	1.61%	0.71%	2.61%	2.3%
Fe-,Mn- oxide	30.81%	27.47%	12.24%	6.22%	20.89%	19.5%
Oxidizing com	13.17%	15.65%	12.64%	13.30%	11.90%	13.3%
Residual	52.77%	52.96%	73.51%	79.69%	64.45%	64.7%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.0%
Total digestio	-0.0603088	-0.051738	-0.053733	-0.058865	-0.05736	
Total digestio	0.83648823	0.322645	-0.103238	-0.185187	0.35734	



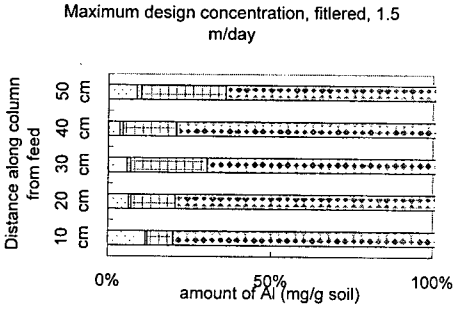
Mn	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	141.82%	362.10%	164.93%	122.29%	71.14%	172.5%
Ionic-bound t	192.50%	405.61%	136.24%	32.82%	44.86%	162.4%
Fe-,Mn- oxide	-105.04%	-332.06%	-117.50%	-42.64%	-16.36%	-122.7%
Oxidizing com	-194.64%	-502.88%	-226.39%	-69.32%	-41.94%	-207.0%
Residual	65.37%	167.22%	142.72%	56.85%	42.31%	94.9%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.0%
Total digestio	-0.0028874	-0.003394	-0.003483	-0.003492	-0.0036	
Total digestio	-0.0363956	-0.043041	-0.058458	-0.054831	-0.0629	



Zn	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	17.26%	18.14%	21.90%	22.41%	18.89%	19.7%
Ionic-bound t	34.97%	34.44%	30.97%	31.49%	33.03%	33.0%
Fe-,Mn- oxide	30.48%	28.26%	26.78%	25.99%	28.79%	28.1%
Oxidizing com	5.82%	7.07%	5.87%	5.94%	5.90%	6.1%
Residual	11.47%	12.09%	14.48%	14.17%	13.39%	13.1%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.0%
Total digestio	0.00096361	0.000125	0.000259	1.96E-05	-0.00061	
Total digestio	0.25875752	0.243395	0.226306	0.268107	0.258667	



Al	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchangeabl	11.48%	6.40%	5.85%	3.46%	8.71%	7.2%
Ionic-bound t	0.66%	0.71%	1.07%	1.09%	1.44%	1.0%
Fe-,Mn- oxide	-5.39%	-4.23%	-3.50%	-2.15%	-2.74%	-3.6%
Oxidizing com	7.93%	13.56%	23.46%	16.37%	25.84%	17.4%
Residual	85.33%	83.54%	73.12%	81.23%	66.76%	78.0%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%	100.0%
Total digestio	-0.2293291	-0.224828	-0.228669	-0.229541	-0.226	
Total digestio	1.13263806	2.170714	-1.201186	1.063872	1.215773	



PTB5,6Avg minus background leaching of treated clinoptilolite

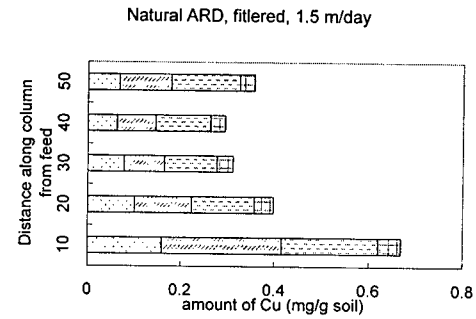
Cu	10	20	30	40	50
Initial Rinse	0.002166	0.00137	0.00199	0.00234	0.00071
Exchangeab	0.159529	0.1008	0.07807	0.06246	0.06772
Ionic-bound	0.256149	0.12277	0.08668	0.08329	0.11123
Fe-,Mn- oxic	0.204347	0.13389	0.1128	0.11731	0.14659
Oxidizing co	0.048925	0.04066	0.03418	0.03164	0.03204
Residual	-0.02011	-0.0166	-0.0254	-0.0256	-0.0241
SSE-sum	0.648836	0.3815	0.28636	0.26915	0.33351
Total digest	0.007079	0.00504	0.00936	0.0075	0.00425
Total digest	0.571409	0.32391	0.23024	0.22069	0.25797

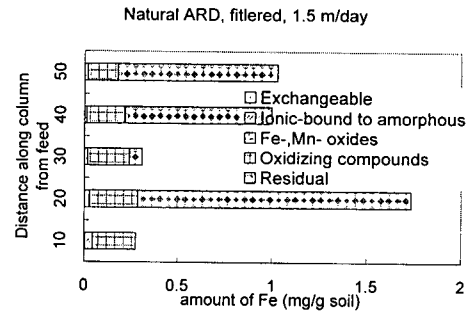
Fe	10	20	30	40	50
Initial Rinse	-0.03323	-0.026	-0.0223	-0.0212	-0.028
Exchangeab	0.004852	0.00169	0.001	0.0004	0.00027
Ionic-bound	0.042235	0.02621	0.01507	0.01215	0.01758
Fe-,Mn- oxic	-0.05247	-0.0757	-0.1184	-0.1317	-0.0503
Oxidizing co	0.230199	0.25773	0.22533	0.20526	0.16061
Residual	-0.13768	1.44972	0.0678	0.78216	0.85205
SSE-sum	0.087133	1.65961	0.19075	0.86827	0.9802
Total digest	-0.05473	-0.033	-0.02	-0.0217	-0.0357
Total digest	0.548718	0.12164	0.11172	-0.164	-0.5074

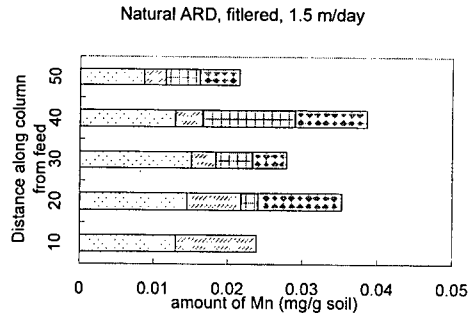
Mn	10	20	30	40	50
Initial Rinse	-0.00114	-0.001	-0.0007	-0.0006	-0.0011
Exchangeab	0.012998	0.01452	0.0151	0.01292	0.00866
Ionic-bound	0.010921	0.00727	0.00331	0.00362	0.00292
Fe-,Mn- oxic	-0.01846	-0.0147	-0.0083	0.0001	-0.0067
Oxidizing co	-0.00184	0.00223	0.00489	0.01237	0.00459
Residual	-0.00415	0.01124	0.0046	0.00963	0.00538
SSE-sum	-0.00053	0.02053	0.01957	0.03864	0.01486
Total digest	-0.00275	-0.0023	-0.0017	-0.0015	-0.0025
Total digest	-0.03458	-0.0247	-0.0311	-0.0268	-0.0306

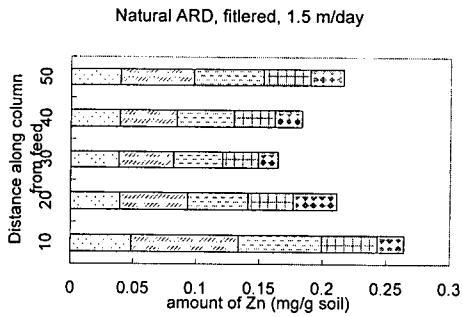
Zn	10	20	30	40	50
Initial Rinse	-0.00037	-0.0004	-0.0002	0.00015	-0.0005
Exchangeab	0.048589	0.03927	0.03838	0.03915	0.03954
Ionic-bound	0.085092	0.05409	0.04359	0.04535	0.0583
Fe-,Mn- oxic	0.065737	0.04774	0.03883	0.04495	0.05506
Oxidizing co	0.043612	0.03553	0.02812	0.03253	0.03709
Residual	0.021029	0.0344	0.01566	0.0215	0.02597
SSE-sum	0.264059	0.21103	0.16459	0.18348	0.21596
Total digest	0.001032	0.00076	0.00213	0.0024	0.00097
Total digest	0.243599	0.19107	0.15288	0.16088	0.15925

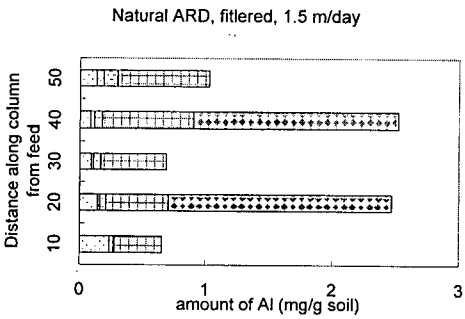
Al	10	20	30	40	50
Initial Rinse	-0.04161	-0.0237	-0.0331	-0.0138	-0.0411
Exchangeab	0.237659	0.14503	0.09218	0.08471	0.13248
Ionic-bound	0.03242	0.0163	0.01925	0.03278	0.05542
Fe-,Mn- oxic	0.010369	0.04893	0.05669	0.06207	0.11234
Oxidizing co	0.376213	0.49674	0.52521	0.72572	0.72997
Residual	-2.57786	1.76421	-0.5125	1.61947	-0.1563
SSE-sum	-1.9212	2.47121	0.18085	2.52475	0.87392
Total digest	-0.22324	-0.2162	-0.2086	-0.211	-0.2088
Total digest	-3.80646	-5.469	-5.6433	-4.0831	-4.7655





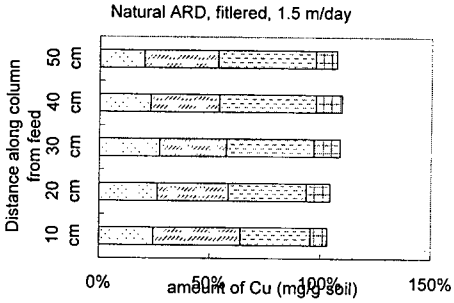




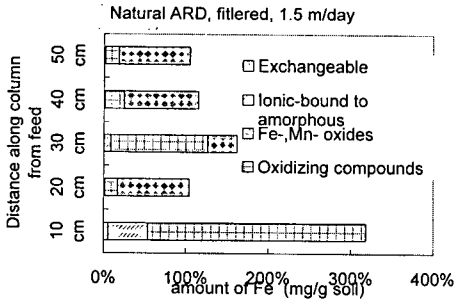


PTB5,6Av((minus background from treated clinop, %)

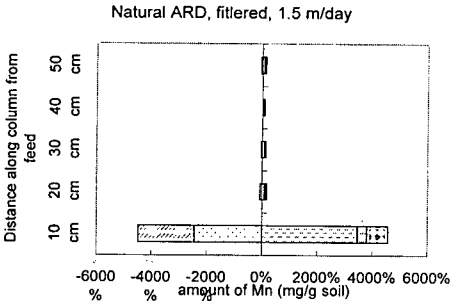
Cu	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchange	25%	26%	27%	23%	20%	24.36%
Ionic-boun	39%	32%	30%	31%	33%	33.25%
Fe-,Mn- ox	31%	35%	39%	44%	44%	38.70%
Oxidizing c	8%	11%	12%	12%	10%	10.30%
Residual	-3%	-4%	-9%	-9%	-7%	-6.61%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total diges	1%	1%	1%	1%	0%	
Total diges	61%	28%	23%	17%	21%	



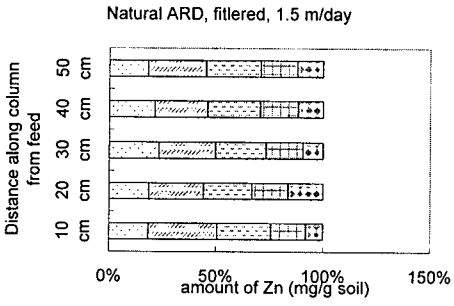
Fe	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchange	6%	0%	1%	0%	0%	1.25%
Ionic-boun	48%	2%	8%	1%	2%	12.23%
Fe-,Mn- ox	-60%	-5%	-62%	-15%	-5%	-29.44%
Oxidizing c	264%	16%	118%	24%	16%	87.57%
Residual	-158%	87%	36%	90%	87%	28.38%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total diges	-5%	-2%	-1%	0%	-2%	
Total diges	61%	-49%	-36%	40%	-19%	



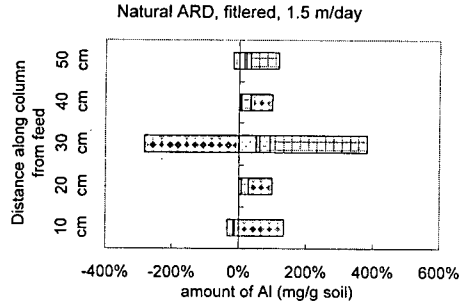
Mn	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchange	-2434%	71%	77%	33%	58%	-438.94%
Ionic-boun	-2045%	35%	17%	9%	20%	-392.80%
Fe-,Mn- ox	3458%	-72%	-43%	0%	-45%	659.76%
Oxidizing c	345%	11%	25%	32%	31%	88.76%
Residual	777%	55%	24%	25%	36%	183.22%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total diges	0%	0%	0%	0%	0%	
Total diges	-4%	-3%	-4%	-3%	-4%	



Zn	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchange	18%	19%	23%	21%	18%	20.00%
Ionic-boun	32%	26%	26%	25%	27%	27.21%
Fe-,Mn- ox	25%	23%	24%	24%	25%	24.22%
Oxidizing c	17%	17%	17%	18%	17%	17.07%
Residual	8%	16%	10%	12%	12%	11.50%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total diges	0%	0%	0%	0%	0%	
Total diges	24%	20%	17%	16%	16%	

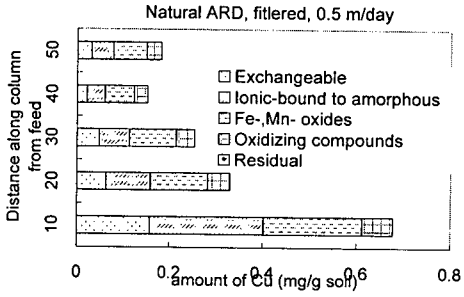


Al	10 cm	20 cm	30 cm	40 cm	50 cm	
Exchange	-12%	6%	51%	3%	15%	12.60%
Ionic-boun	-2%	1%	11%	1%	6%	3.45%
Fe-,Mn- ox	-1%	2%	31%	2%	13%	9.62%
Oxidizing c	-20%	20%	290%	29%	84%	80.64%
Residual	134%	71%	-283%	64%	-18%	-6.31%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total diges	-23%	-21%	-21%	-21%	-22%	
Total diges	153%	-131%	-122%	38%	-80%	

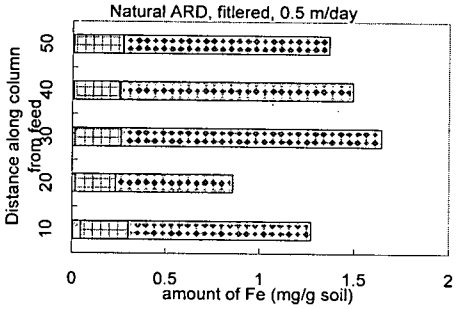


PTB8,9A (minus background from treated clinop)

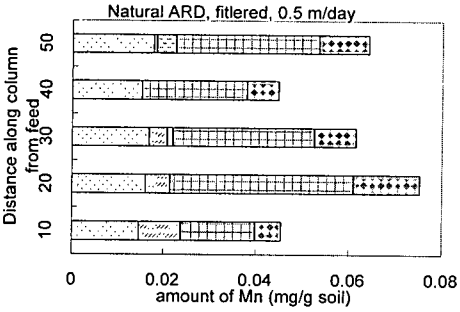
Cu	10	20	30	40	50
Initial Rin	0.00699	0.00346	0.00386	0.00416	0.00405
Exchang	0.15774	0.06259	0.04767	0.02148	0.03047
Ionic-bou	0.24456	0.0961	0.06578	0.03855	0.04734
Fe-,Mn-	0.21066	0.12414	0.10112	0.06289	0.07252
Oxidizing	0.06549	0.04754	0.03951	0.02924	0.03152
Residual	-0.0174	-0.0264	-0.0278	-0.0328	-0.032
SSE-sum	0.66106	0.304	0.22625	0.1194	0.14985
Total dig	0.01977	0.008	0.00918	0.01356	0.00888
Total dig	0.56365	0.23326	0.15976	0.07944	0.12873



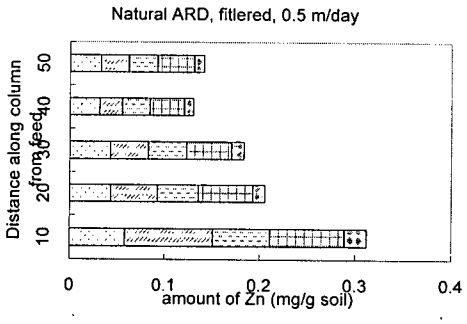
Fe	10	20	30	40	50
Initial Rin	-0.0356	-0.0257	-0.0241	-0.0144	-0.0169
Exchang	0.0045	0.00065	0.00048	0.00034	0.00039
Ionic-bou	0.04236	0.0153	0.01192	0.00705	0.00838
Fe-,Mn-	-0.0452	-0.0937	-0.0628	-0.1379	-0.1156
Oxidizing	0.25478	0.21761	0.24833	0.24858	0.26298
Residual	0.97436	0.6277	1.38579	1.23842	1.09767
SSE-sum	1.23079	0.76757	1.58369	1.35647	1.25378
Total dig	-0.0576	-0.039	-0.0282	0.00492	-0.0218
Total dig	-0.1085	-0.8881	-0.815	-0.6323	-1.5885



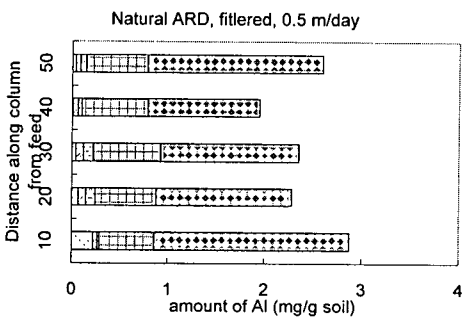
Mn	10	20	30	40	50
Initial Rin	-0.0005	-0.0007	-0.0003	0.00041	9.3E-06
Exchang	0.01461	0.01607	0.01677	0.01514	0.01772
Ionic-bou	0.0092	0.00529	0.00397	3.9E-05	0.00067
Fe-,Mn-	-0.0196	-0.0028	0.00123	-0.0017	0.00422
Oxidizing	0.0161	0.03975	0.03061	0.02285	0.0309
Residual	0.00564	0.01421	0.00905	0.00689	0.01082
SSE-sum	0.02593	0.07255	0.06162	0.0432	0.06433
Total dig	-0.0012	-0.002	-0.0012	0.00032	-0.0005
Total dig	-0.033	-0.0269	-0.0245	-0.0176	-0.0172



Zn	10	20	30	40	50
Initial Rin	0.00038	5.6E-05	0.00037	0.00208	0.00127
Exchang	0.05831	0.04337	0.04287	0.03129	0.03284
Ionic-bou	0.09307	0.04963	0.04037	0.02393	0.02945
Fe-,Mn-	0.05982	0.04309	0.04012	0.02925	0.03049
Oxidizing	0.07757	0.05721	0.0472	0.0365	0.03847
Residual	0.02355	0.01308	0.01327	0.0096	0.01056
SSE-sum	0.31232	0.20638	0.18382	0.13057	0.1418
Total dig	0.00246	0.00127	0.00179	0.00804	0.00569
Total dig	0.24084	0.12885	0.11083	0.07251	0.0988



Al	10	20	30	40	50
Initial Rin	-0.0461	-0.0383	-0.036	-0.0256	-0.0315
Exchang	0.22369	0.06805	0.04008	0.01032	0.03457
Ionic-bou	0.04327	0.07832	0.08128	0.05451	0.05206
Fe-,Mn-	0.02505	0.09988	0.10067	0.03725	0.06164
Oxidizing	0.56737	0.6355	0.7042	0.68943	0.63604
Residual	2.0202	1.40501	1.43158	1.16029	1.81861
SSE-sum	2.87957	2.28676	2.3578	1.95179	2.60292
Total dig	-0.2195	-0.1912	-0.1839	-0.1507	-0.1275
Total dig	-8.0965	-6.2068	-5.5936	-6.1936	-5.5158



PTB8,9A (minus background from treated clinop, %)

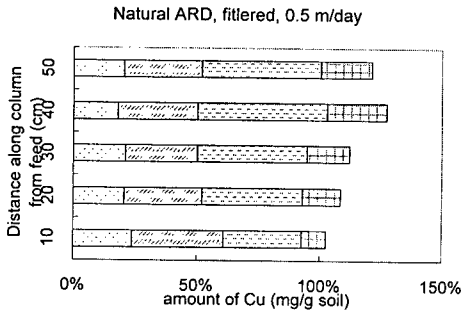
Cu	10	20	30	40	50	average
Exchang	23.86%	20.59%	21.07%	17.99%	20.33%	20.77%
Ionic-bou	37.00%	31.61%	29.07%	32.28%	31.59%	32.31%
Fe-,Mn-	31.87%	40.84%	44.69%	52.67%	48.40%	43.69%
Oxidizing	9.91%	15.64%	17.46%	24.49%	21.03%	17.71%
Residual	-2.63%	-8.68%	-12.30%	-27.43%	-21.35%	-14.48%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	0.0197668	0.0079994	0.0091819	0.0135597	0.0088786	
Total dig	0.5636475	0.2332584	0.1597617	0.0794426	0.1287287	

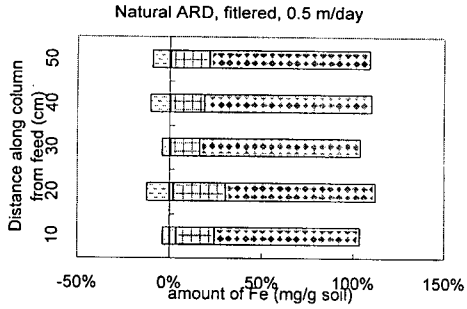
Fe	10	20	30	40	50	
Exchang	0.37%	0.08%	0.03%	0.03%	0.03%	0.11%
Ionic-bou	3.44%	1.99%	0.75%	0.52%	0.67%	1.48%
Fe-,Mn-	-3.67%	-12.21%	-3.97%	-10.17%	-9.22%	-7.85%
Oxidizing	20.70%	28.35%	15.68%	18.33%	20.98%	20.81%
Residual	79.17%	81.78%	87.50%	91.30%	87.55%	85.46%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	-0.057591	-0.039003	-0.028198	0.0049247	-0.021807	
Total dig	-0.108538	-0.888113	-0.815005	-0.632276	-1.5885	

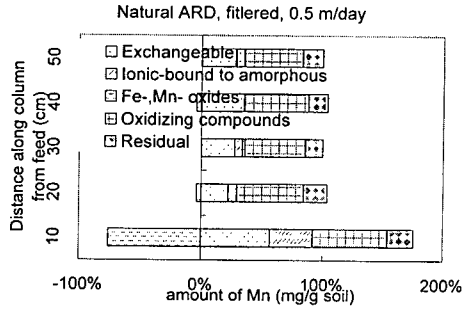
Mn	10	20	30	40	50	
Exchang	56.36%	22.15%	27.21%	35.05%	27.55%	33.66%
Ionic-bou	35.49%	7.29%	6.43%	0.09%	1.04%	10.07%
Fe-,Mn-	-75.71%	-3.82%	2.00%	-3.97%	6.56%	-14.99%
Oxidizing	62.10%	54.79%	49.68%	52.88%	48.04%	53.50%
Residual	21.76%	19.59%	14.68%	15.94%	16.82%	17.76%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	-0.001244	-0.001972	-0.001172	0.0003168	-0.000453	
Total dig	-0.032952	-0.026938	-0.024541	-0.017631	-0.017244	

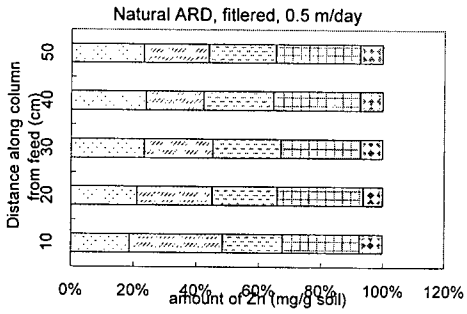
Zn	10	20	30	40	50	
Exchang	18.67%	21.01%	23.32%	23.96%	23.16%	22.02%
Ionic-bou	29.80%	24.05%	21.96%	18.33%	20.77%	22.98%
Fe-,Mn-	19.15%	20.88%	21.82%	22.40%	21.50%	21.15%
Oxidizing	24.84%	27.72%	25.68%	27.95%	27.13%	26.66%
Residual	7.54%	6.34%	7.22%	7.35%	7.45%	7.18%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	0.0024645	0.0012735	0.0017892	0.0080412	0.0056939	
Total dig	0.2408432	0.1288501	0.1108304	0.072512	0.0988008	

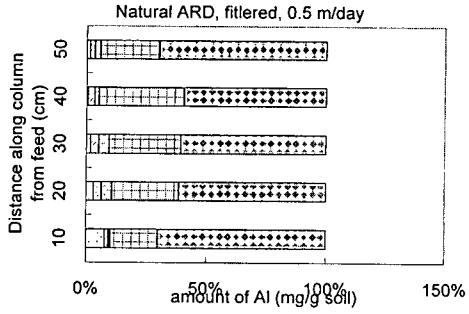
Al	10	20	30	40	50	
Exchang	7.77%	2.98%	1.70%	0.53%	1.33%	2.86%
Ionic-bou	1.50%	3.42%	3.45%	2.79%	2.00%	2.63%
Fe-,Mn-	0.87%	4.37%	4.27%	1.91%	2.37%	2.76%
Oxidizing	19.70%	27.79%	29.87%	35.32%	24.44%	27.42%
Residual	70.16%	61.44%	60.72%	59.45%	69.87%	64.33%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	-0.219501	-0.19124	-0.183948	-0.150693	-0.12747	
Total dig	-8.096537	-6.206812	-5.593581	-6.19364	-5.515756	











PTB11,1: (minus background from treated clinop)

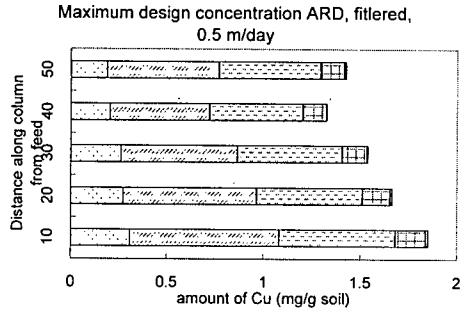
Cu	10	20	30	40	50
Initial Rin	0.03935	0.01593	0.01364	0.00409	0.00872
Exchang	0.30723	0.27471	0.26199	0.20286	0.18932
Ionic-bou	0.77372	0.68973	0.60317	0.518	0.58136
Fe-,Mn-	0.60065	0.54662	0.53967	0.48195	0.52343
Oxidizing	0.15673	0.14261	0.12924	0.12114	0.12233
Residual	0.01349	0.01104	0.00636	0.00325	0.00968
SSE-sum	1.85182	1.66471	1.54044	1.3272	1.42611
Total dig	0.11337	0.056	0.03658	0.01895	0.02185
Total dig	2.51903	2.22643	2.15126	1.83776	2.13888

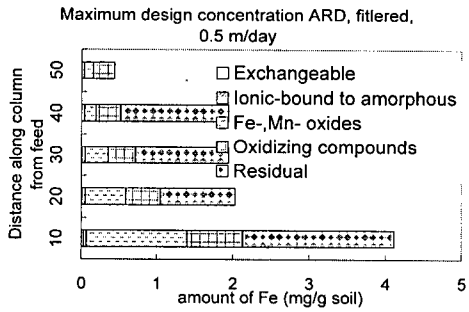
Fe	10	20	30	40	50
Initial Rin	-0.0349	-0.0355	-0.0352	-0.0346	-0.0355
Exchang	0.0297	0.00919	0.00472	0.00072	0.00012
Ionic-bou	0.03807	0.04398	0.04342	0.04002	0.03411
Fe-,Mn-	1.33334	0.53743	0.30675	0.15136	0.12207
Oxidizing	0.73194	0.45807	0.36199	0.32795	0.28348
Residual	1.98379	0.98348	1.22965	1.42821	-1.5486
SSE-sum	4.11684	2.03215	1.94652	1.94826	-1.1089
Total dig	-0.0587	-0.0617	-0.0625	-0.0582	-0.061
Total dig	-0.5801	-0.8533	-1.036	-2.1469	-1.2462

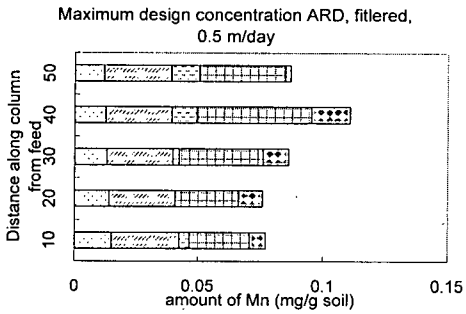
Mn	10	20	30	40	50
Initial Rin	0.00088	-0.0004	-0.0004	-0.0011	-0.0006
Exchang	0.01514	0.014	0.01323	0.01261	0.01192
Ionic-bou	0.02729	0.02673	0.02665	0.02671	0.02724
Fe-,Mn-	0.00414	-0.0013	0.00244	0.01014	0.01148
Oxidizing	0.02421	0.02555	0.03386	0.0459	0.03419
Residual	0.00644	0.00975	0.0103	0.01559	0.00221
SSE-sum	0.07721	0.07471	0.08648	0.11094	0.08704
Total dig	0.00271	0.00016	-0.0011	-0.0023	-0.0019
Total dig	-0.0354	-0.0054	0.00253	0.01356	0.03142

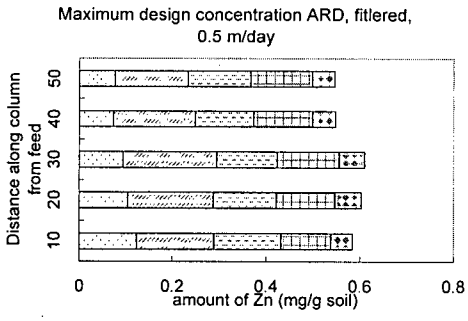
Zn	10	20	30	40	50
Initial Rin	0.00436	0.00125	0.00108	-0.0003	0.00033
Exchang	0.12328	0.10451	0.094	0.0734	0.07652
Ionic-bou	0.16639	0.18334	0.20126	0.17633	0.15756
Fe-,Mn-	0.1427	0.13478	0.12926	0.12427	0.13322
Oxidizing	0.10587	0.12446	0.13196	0.12525	0.13121
Residual	0.04655	0.05604	0.05427	0.05005	0.04833
SSE-sum	0.58478	0.60313	0.61075	0.5493	0.54684
Total dig	0.01477	0.00686	0.00418	0.00187	0.00246
Total dig	0.81287	0.59061	0.53851	0.55264	0.58436

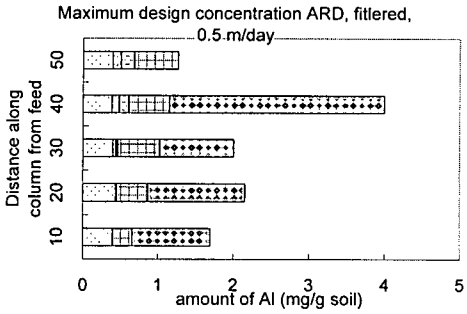
Al	10	20	30	40	50
Initial Rin	-0.0378	-0.0434	-0.0422	-0.0426	-0.042
Exchang	0.39861	0.43606	0.40257	0.38468	0.39763
Ionic-bou	0.00545	0.01407	0.04261	0.09837	0.10979
Fe-,Mn-	-0.085	-0.0324	0.02473	0.12875	0.17961
Oxidizing	0.25777	0.41776	0.55556	0.54212	0.58735
Residual	1.0397	1.29232	0.98647	2.84751	-1.3824
SSE-sum	1.61658	2.12777	2.01194	4.00143	-0.108
Total dig	-0.2054	-0.2241	-0.2257	-0.2234	-0.2255
Total dig	-10.272	-8.8246	-8.2314	-6.7756	-6.1529











PTB11,1: (minus background from treated clinop,%)

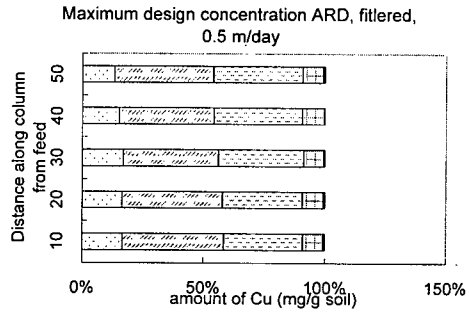
Cu	10	20	30	40	50	
Exchang	16.59%	16.50%	17.01%	15.28%	13.28%	15.73%
Ionic-bou	41.78%	41.43%	39.16%	39.03%	40.77%	40.43%
Fe-,Mn- c	32.44%	32.84%	35.03%	36.31%	36.70%	34.66%
Oxidizing	8.46%	8.57%	8.39%	9.13%	8.58%	8.62%
Residual	0.73%	0.66%	0.41%	0.25%	0.68%	0.55%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0.11337	0.056	0.03658	0.01895	0.021848	
Total dige	2.51903	2.22643	2.15126	1.83776	2.138884	

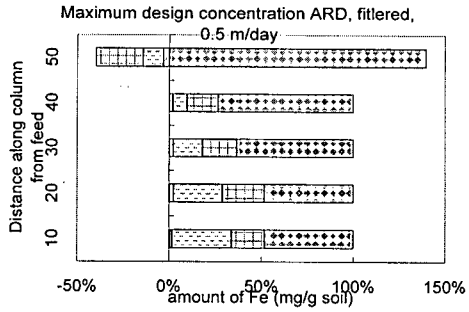
Fe	10	20	30	40	50	
Exchang	0.72%	0.45%	0.24%	0.04%	-0.01%	0.29%
Ionic-bou	0.92%	2.16%	2.23%	2.05%	-3.08%	0.86%
Fe-,Mn- c	32.39%	26.45%	15.76%	7.77%	-11.01%	14.27%
Oxidizing	17.78%	22.54%	18.60%	16.83%	-25.57%	10.04%
Residual	48.19%	48.40%	63.17%	73.31%	139.66%	74.54%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	-0.0587	-0.0617	-0.0625	-0.0582	-0.06095	
Total dige	-0.5801	-0.8533	-1.036	-2.1469	-1.2462	

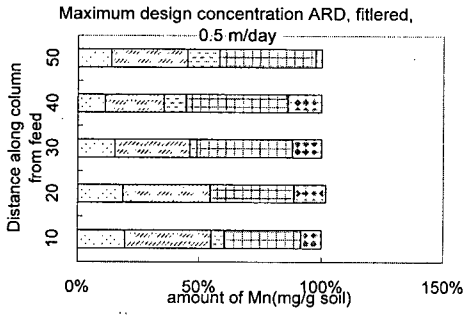
Mn	10	20	30	40	50	
Exchang	19.60%	18.75%	15.30%	11.36%	13.69%	15.74%
Ionic-bou	35.35%	35.78%	30.81%	24.08%	31.30%	31.46%
Fe-,Mn- c	5.36%	-1.79%	2.82%	9.14%	13.19%	5.74%
Oxidizing	31.35%	34.20%	39.16%	41.37%	39.28%	37.07%
Residual	8.34%	13.06%	11.91%	14.05%	2.54%	9.98%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0%	0%	0%	0%	0%	
Total dige	-0.0354	-0.0054	0.00253	0.01356	0.031425	

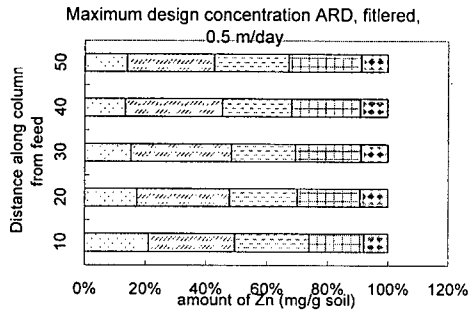
Zn	10	20	30	40	50	
Exchang	21.08%	17.33%	15.39%	13.36%	13.99%	16.23%
Ionic-bou	28.45%	30.40%	32.95%	32.10%	28.81%	30.54%
Fe-,Mn- c	24.40%	22.35%	21.16%	22.62%	24.36%	22.98%
Oxidizing	18.10%	20.64%	21.61%	22.80%	23.99%	21.43%
Residual	7.96%	9.29%	8.89%	9.11%	8.84%	8.82%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0.01477	0.00686	0.00418	0.00187	0.002458	
Total dige	0.81287	0.59061	0.53851	0.55264	0.584359	

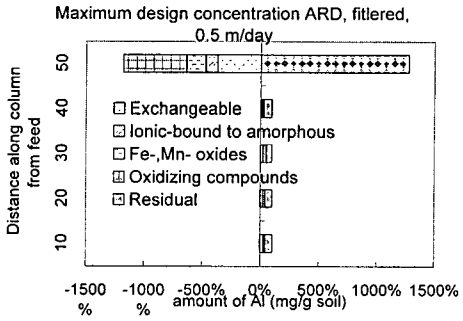
Al	10	20	30	40	50	
Exchang	24.66%	20.49%	20.01%	9.61%	-368.11%	-58.67%
Ionic-bou	0.34%	0.66%	2.12%	2.46%	-101.64%	-19.21%
Fe-,Mn- c	-5.26%	-1.52%	1.23%	3.22%	-166.27%	-33.72%
Oxidizing	15.95%	19.63%	27.61%	13.55%	-543.74%	-93.40%
Residual	64.32%	60.74%	49.03%	71.16%	1279.76%	305.00%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	-0.2054	-0.2241	-0.2257	-0.2234	-0.22547	
Total dige	-10.272	-8.8246	-8.2314	-6.7756	-6.15289	











PTB13,1 (minus background from treated clinop)

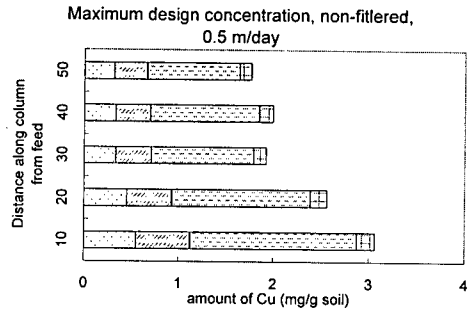
Cu	10	20	30	40	50
Initial Rin	0.07325	0.04518	0.01646	0.0212	0.01359
Exchang	0.55055	0.45318	0.3351	0.33602	0.31668
Ionic-bou	0.57455	0.47781	0.37654	0.36591	0.34995
Fe-,Mn-	1.75032	1.45926	1.07928	1.14413	0.97784
Oxidizing	0.18945	0.17521	0.13599	0.15001	0.12619
Residual	-0.0071	-0.0046	-0.0161	-0.0135	-0.0166
SSE-sum	3.0578	2.56084	1.91082	1.98257	1.75411
Total dig	0.16655	0.11318	0.04101	0.04624	0.03771
Total dig	2.88758	2.69461	2.17133	1.93933	1.96373

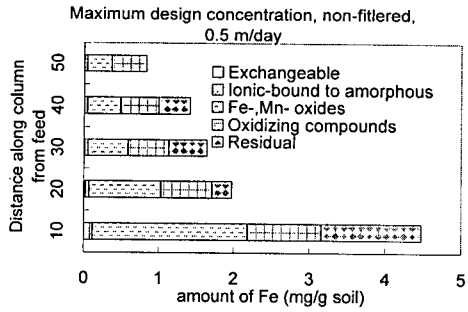
Fe	10	20	30	40	50
Initial Rin	-0.0327	-0.0362	-0.0355	-0.0356	-0.0353
Exchang	0.08296	0.02	0.00649	0.00545	0.00234
Ionic-bou	0.03709	0.0484	0.04677	0.03943	0.03911
Fe-,Mn-	2.06789	0.96182	0.53693	0.44238	0.32722
Oxidizing	0.97326	0.68295	0.54457	0.50656	0.46509
Residual	1.31679	0.26315	0.51186	0.42664	-0.3132
SSE-sum	4.47798	1.97632	1.64662	1.42046	0.52059
Total dig	-0.0598	-0.0595	-0.0601	-0.0618	-0.0617
Total dig	-2.6166	-4.5265	-4.8062	-5.1083	-5.0743

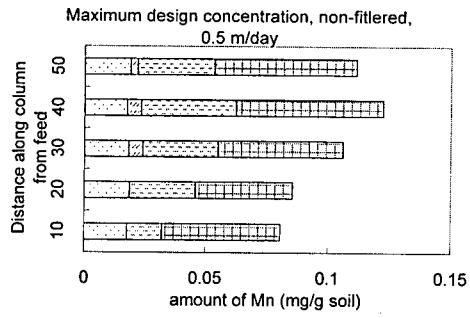
Mn	10	20	30	40	50
Initial Rin	0.00313	0.00208	0.00026	0.00064	0.00013
Exchang	0.01773	0.01862	0.01832	0.01758	0.0188
Ionic-bou	-0.0004	-0.0012	0.00584	0.00583	0.00305
Fe-,Mn-	0.01435	0.02733	0.03094	0.03907	0.03164
Oxidizing	0.04872	0.03985	0.05118	0.06013	0.05818
Residual	-0.015	-0.0195	-0.0137	-0.0152	-0.017
SSE-sum	0.06542	0.06511	0.09255	0.10738	0.09465
Total dig	0.00676	0.00491	0.0002	0.00061	0.00071
Total dig	-0.0466	-0.0212	-0.0163	-0.0107	0.00732

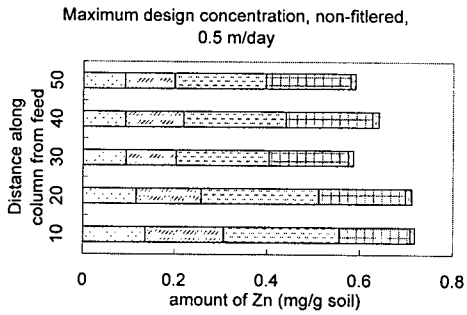
Zn	10	20	30	40	50
Initial Rin	0.01053	0.00687	0.00264	0.00311	0.002
Exchang	0.13562	0.1162	0.09362	0.09218	0.09083
Ionic-bou	0.17138	0.14171	0.10929	0.1268	0.109
Fe-,Mn-	0.24988	0.25422	0.20239	0.22201	0.19785
Oxidizing	0.15181	0.18607	0.16988	0.18608	0.18162
Residual	0.00988	0.01369	0.01137	0.01467	0.01129
SSE-sum	0.71858	0.71188	0.58654	0.64175	0.59059
Total dig	0.02704	0.01935	0.0081	0.00831	0.00744
Total dig	0.68804	0.66641	0.52459	0.53779	0.53149

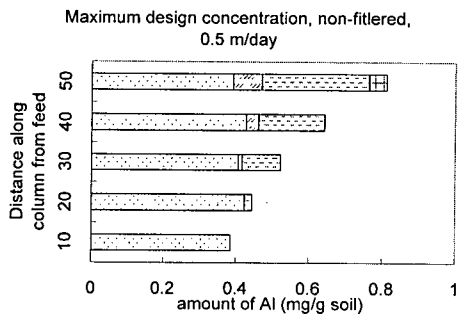
Al	10	20	30	40	50
Initial Rin	-0.0242	-0.0213	-0.0222	-0.0197	-0.0166
Exchang	0.38575	0.42369	0.40605	0.42749	0.39173
Ionic-bou	-0.0042	-0.0027	0.01113	0.03474	0.07921
Fe-,Mn-	-0.0408	0.02149	0.10657	0.1819	0.29336
Oxidizing	-0.2394	-0.1219	-0.0357	-0.0274	0.04846
Residual	-0.8832	-0.7146	-0.3871	-1.1048	-2.2523
SSE-sum	-0.7818	-0.394	0.10092	-0.4881	-1.4395
Total dig	-0.1904	-0.2099	-0.2245	-0.2261	-0.2257
Total dig	-9.9159	-9.5472	-10.013	-10.01	-9.7866











PTB13,1· (minus background from treated clinop,%)

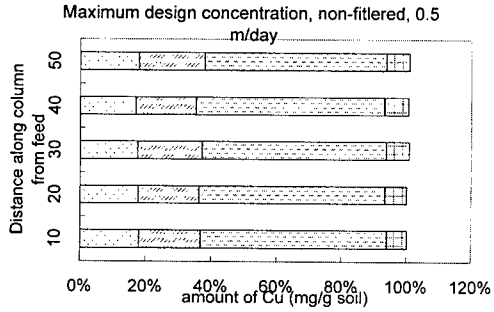
Cu	10	20	30	40	50	
Exchang	18.00%	17.70%	17.54%	16.95%	18.05%	17.65%
Ionic-bou	18.79%	18.66%	19.71%	18.46%	19.95%	19.11%
Fe-,Mn- c	57.24%	56.98%	56.48%	57.71%	55.75%	56.83%
Oxidizing	6.20%	6.84%	7.12%	7.57%	7.19%	6.98%
Residual	-0.23%	-0.18%	-0.84%	-0.68%	-0.94%	-0.58%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0.1665532	0.1131813	0.0410064	0.0462385	0.0377106	
Total dige	2.88758	2.6946095	2.1713262	1.9393327	1.9637335	

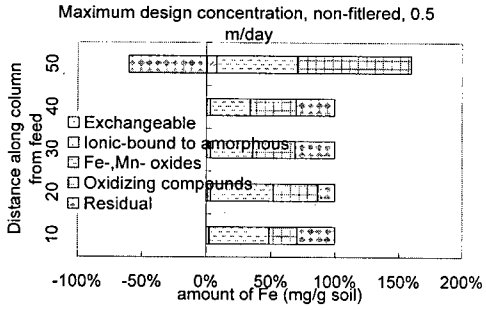
Fe	10	20	30	40	50	
Exchang	1.85%	1.01%	0.39%	0.38%	0.45%	0.82%
Ionic-bou	0.83%	2.45%	2.84%	2.78%	7.51%	3.28%
Fe-,Mn- c	46.18%	48.67%	32.61%	31.14%	62.85%	44.29%
Oxidizing	21.73%	34.56%	33.07%	35.66%	89.34%	42.87%
Residual	29.41%	13.32%	31.09%	30.04%	-60.15%	8.74%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	-0.059778	-0.0595433	-0.0601186	-0.061831	-0.06172	
Total dige	-2.616595	-4.5264788	-4.8062025	-5.108261	-5.0743	

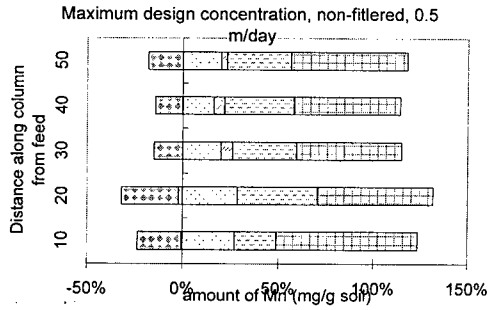
Mn	10	20	30	40	50	
Exchang	27.10%	28.60%	19.80%	16.37%	19.87%	22.35%
Ionic-bou	-0.59%	-1.89%	6.31%	5.43%	3.23%	2.50%
Fe-,Mn- c	21.93%	41.98%	33.43%	36.39%	33.42%	33.43%
Oxidizing	74.48%	61.20%	55.30%	56.00%	61.47%	61.69%
Residual	-22.93%	-29.89%	-14.84%	-14.19%	-17.98%	-19.97%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0.0067595	0.0049073	0.0001984	0.0006102	0.0007118	
Total dige	-0.0466	-0.0211588	-0.0163333	-0.010736	0.0073248	

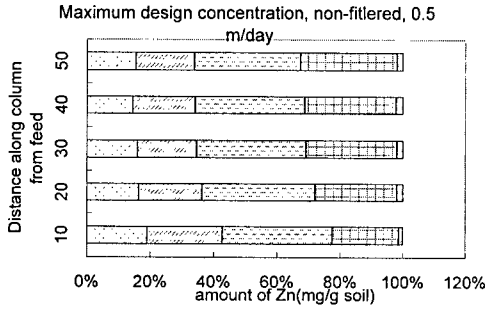
Zn	10	20	30	40	50	
Exchang	18.87%	16.32%	15.96%	14.36%	15.38%	16.18%
Ionic-bou	23.85%	19.91%	18.63%	19.76%	18.46%	20.12%
Fe-,Mn- c	34.77%	35.71%	34.51%	34.59%	33.50%	34.62%
Oxidizing	21.13%	26.14%	28.96%	29.00%	30.75%	27.19%
Residual	1.38%	1.92%	1.94%	2.29%	1.91%	1.89%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	0.0270402	0.0193537	0.008103	0.0083074	0.007439	
Total dige	0.6880392	0.666409	0.5245932	0.5377892	0.5314886	

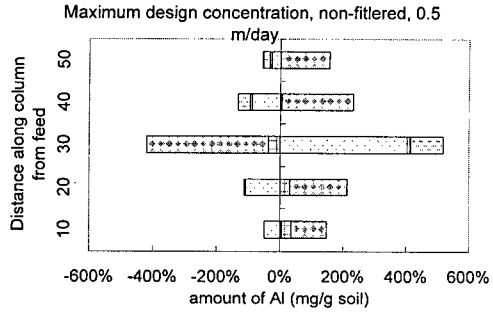
Al	10	20	30	40	50	
Exchang	-49.34%	-107.53%	402.34%	-87.58%	-27.21%	26.13%
Ionic-bou	0.53%	0.70%	11.03%	-7.12%	-5.50%	-0.07%
Fe-,Mn- c	5.21%	-5.45%	105.59%	-37.27%	-20.38%	9.54%
Oxidizing	30.62%	30.93%	-35.41%	5.62%	-3.37%	5.68%
Residual	112.98%	181.35%	-383.55%	226.35%	156.46%	58.72%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dige	-0.19039	-0.2099385	-0.2245478	-0.226115	-0.225708	
Total dige	-9.91591	-9.5472325	-10.01261	-10.01045	-9.786556	











PTB15 (minus background from treated clinop)

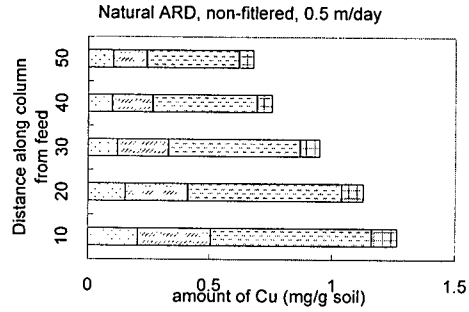
Cu	10	20	30	40	50
Initial Rin	0.02436	0.01487	0.00697	0.00209	0.00092
Exchang	0.20392	0.15328	0.12025	0.10034	0.10329
Ionic-bou	0.30177	0.25822	0.21105	0.16581	0.13918
Fe-,Mn-	0.65568	0.62826	0.53835	0.42723	0.37751
Oxidizing	0.10353	0.08801	0.08141	0.06152	0.0593
Residual	-0.0158	-0.0195	-0.0214	-0.02805	-0.0257
SSE-sum	1.24913	1.1083	0.92963	0.72685	0.65354
Total dig	0.05326	0.03587	0.02649	0.00611	0.00244
Total dig	1.51282	2.13053	1.95996	1.27692	1.14972

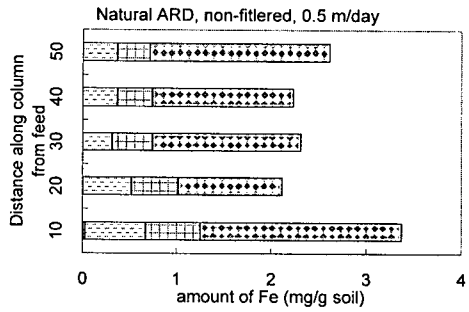
Fe	10	20	30	40	50
Initial Rin	-0.0363	-0.0339	-0.0354	-0.03025	-0.0316
Exchang	0.01002	0.00283	0.00117	0.00085	0.00071
Ionic-bou	0.01784	-0.0077	-0.0076	-0.00818	-0.0084
Fe-,Mn-	0.64448	0.52022	0.31352	0.36702	0.36412
Oxidizing	0.58211	0.49427	0.42844	0.37648	0.34988
Residual	2.12122	1.10499	1.57606	1.4935	1.90249
SSE-sum	3.37567	2.1146	2.31156	2.22967	2.60879
Total dig	-0.0624	-0.0622	-0.0628	-0.05015	-0.0377
Total dig	-4.4281	0.72342	1.41814	1.1079	0.3865

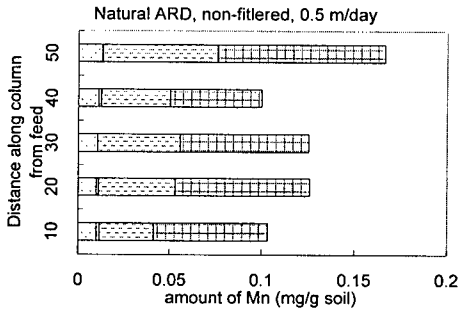
Mn	10	20	30	40	50
Initial Rin	0.00159	0.00088	5.9E-05	-0.00081	-0.001
Exchang	0.01005	0.00992	0.01061	0.01112	0.01304
Ionic-bou	0.00163	0.00136	-7E-05	0.00138	0.00014
Fe-,Mn-	0.02967	0.04193	0.04519	0.03784	0.06287
Oxidizing	0.06228	0.07286	0.06976	0.04971	0.09053
Residual	-0.0083	-0.0109	-0.0087	-0.01332	-0.0064
SSE-sum	0.09532	0.11514	0.11681	0.08674	0.16017
Total dig	0.00266	0.00184	0.00102	-0.0022	-0.0029
Total dig	-0.0285	0.01489	0.02801	0.03703	0.02278

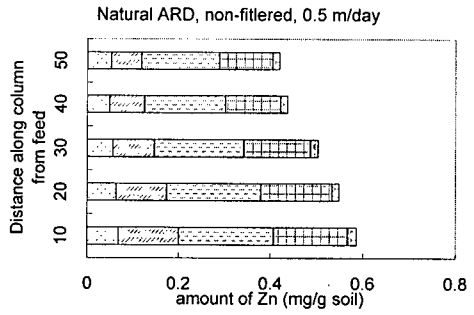
Zn	10	20	30	40	50
Initial Rin	0.00514	0.00335	0.00183	0.0003	-0.0002
Exchang	0.06857	0.06301	0.05655	0.04888	0.05262
Ionic-bou	0.13255	0.11159	0.09037	0.07699	0.06647
Fe-,Mn-	0.20615	0.2051	0.19511	0.17634	0.16994
Oxidizing	0.16032	0.15363	0.14486	0.11965	0.11513
Residual	0.01937	0.0154	0.01658	0.01575	0.01533
SSE-sum	0.58696	0.54872	0.50346	0.43762	0.41948
Total dig	0.01275	0.01018	0.00877	0.00245	0.00087
Total dig	0.5399	0.66728	0.68268	0.56327	0.52522

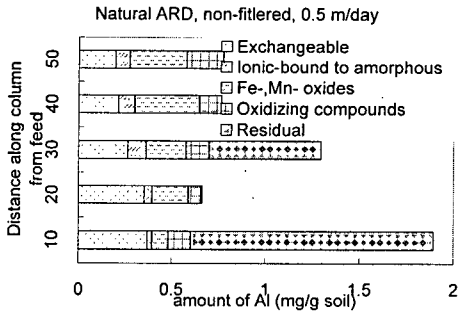
Al	10	20	30	40	50
Initial Rin	-0.0628	-0.0647	-0.0652	-0.06245	-0.0626
Exchang	0.37064	0.35465	0.26582	0.21403	0.19815
Ionic-bou	0.02619	0.04256	0.09812	0.08736	0.07778
Fe-,Mn-	0.08824	0.1945	0.21388	0.34847	0.30353
Oxidizing	0.1192	0.06767	0.12444	0.11908	0.19807
Residual	1.2921	0.00726	0.59539	-0.08445	-0.9216
SSE-sum	1.89637	0.66664	1.29765	0.6845	-0.1441
Total dig	-0.2191	-0.2201	-0.2205	-0.20715	-0.1962
Total dig	-6.7245	2.07819	2.06591	3.28051	1.22651





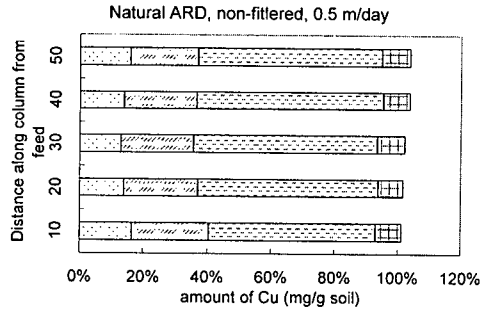




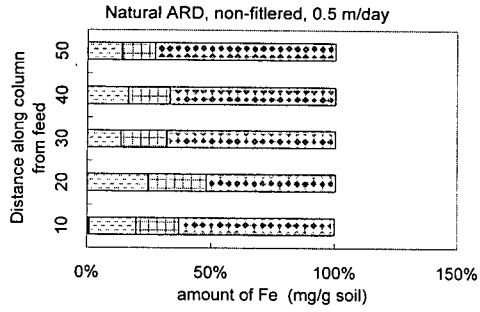


PTB15 (minus background from treated clinop,%)

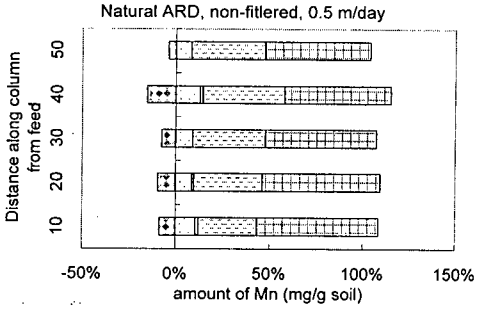
Cu	10	20	30	40	50	
Exchang	16.32%	13.83%	12.94%	13.80%	15.80%	14.54%
Ionic-bou	24.16%	23.30%	22.70%	22.81%	21.30%	22.85%
Fe-,Mn- c	52.49%	56.69%	57.91%	58.78%	57.76%	56.73%
Oxidizing	8.29%	7.94%	8.76%	8.46%	9.07%	8.50%
Residual	-1.26%	-1.76%	-2.31%	-3.86%	-3.94%	-2.62%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	0.053262	0.035868	0.026491	0.0061068	0.00243567	
Total dig	1.512815	2.130532	1.959961	1.2769204	1.14971653	



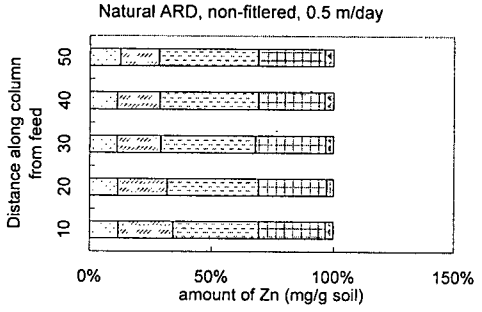
Fe	10	20	30	40	50	
Exchang	0.30%	0.13%	0.05%	0.04%	0.03%	0.11%
Ionic-bou	0.53%	-0.36%	-0.33%	-0.37%	-0.32%	-0.17%
Fe-,Mn- c	19.09%	24.60%	13.56%	16.46%	13.96%	17.53%
Oxidizing	17.24%	23.37%	18.53%	16.89%	13.41%	17.89%
Residual	62.84%	52.26%	68.18%	66.98%	72.93%	64.64%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	-0.06239	-0.06224	-0.06282	-0.050154	-0.0376747	
Total dig	-4.428105	0.723422	1.418137	1.1078986	0.386505	



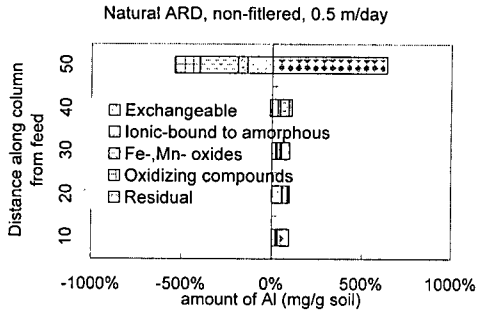
Mn	10	20	30	40	50	
Exchang	10.55%	8.61%	9.09%	12.82%	8.14%	9.84%
Ionic-bou	1.71%	1.18%	-0.06%	1.59%	0.09%	0.90%
Fe-,Mn- c	31.13%	36.42%	38.69%	43.63%	39.25%	37.82%
Oxidizing	65.34%	63.28%	59.72%	57.31%	56.52%	60.44%
Residual	-8.73%	-9.49%	-7.44%	-15.36%	-4.00%	-9.00%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	0.002665	0.001843	0.001024	-0.002202	-0.0028864	
Total dig	-0.028498	0.014894	0.028006	0.0370342	0.02277578	



Zn	10	20	30	40	50	
Exchang	11.68%	11.48%	11.23%	11.17%	12.54%	11.62%
Ionic-bou	22.58%	20.34%	17.95%	17.59%	15.84%	18.86%
Fe-,Mn- c	35.12%	37.38%	38.75%	40.29%	40.51%	38.41%
Oxidizing	27.31%	28.00%	28.77%	27.34%	27.45%	27.77%
Residual	3.30%	2.81%	3.29%	3.60%	3.65%	3.33%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	0.012755	0.010178	0.008773	0.0024527	0.00086785	
Total dig	0.539901	0.667283	0.682679	0.5632702	0.52522093	



Al	10	20	30	40	50	
Exchang	19.54%	53.20%	20.48%	31.27%	-137.54%	-2.61%
Ionic-bou	1.38%	6.38%	7.56%	12.76%	-53.99%	-5.18%
Fe-,Mn- c	4.65%	29.18%	16.48%	50.91%	-210.69%	-21.89%
Oxidizing	6.29%	10.15%	9.59%	17.40%	-137.48%	-18.81%
Residual	68.14%	1.09%	45.88%	-12.34%	639.70%	148.49%
SSE-sum	100%	100%	100%	100%	100%	100.00%
Total dig	-0.219083	-0.22007	-0.220515	-0.207145	-0.196235	
Total dig	-6.724524	2.078195	2.065912	3.2805104	1.22651133	



PTB17 (minus background from treated clinop)

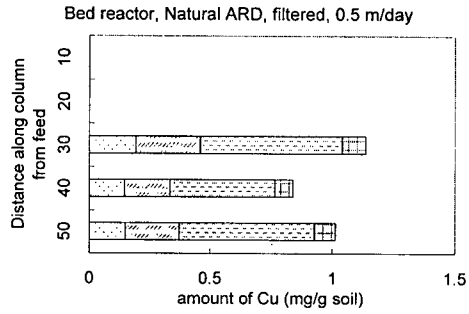
Cu	10	20	30	40	50
Initial Rinse			0.01788	0.0035	0.01172
Exchangeable			0.19144	0.14575	0.1494
Ionic-bound to amorphous			0.26721	0.18873	0.22389
Fe-,Mn- oxides			0.58198	0.43098	0.55523
Oxidizing compounds			0.09678	0.07548	0.08566
Residual			-0.0231	-0.0273	-0.0236
SSE-sum			1.11433	0.81363	0.99057
Total digestion initial rinse			0.04061	0.01316	0.02897
Total digestion			1.93881	1.50925	1.57757

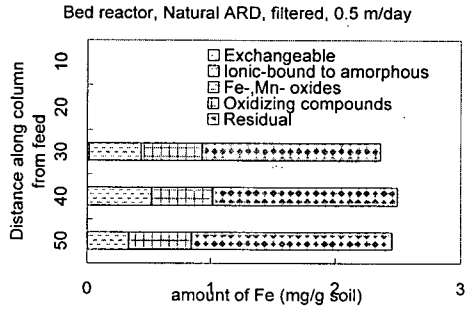
Fe	10	20	30	40	50
Initial Rinse			-0.0362	-0.0335	-0.0364
Exchangeable			0.01388	0.00218	0.00203
Ionic-bound to amorphous			-0.006	-0.008	-0.0071
Fe-,Mn- oxides			0.42383	0.51903	0.33456
Oxidizing compounds			0.49251	0.49513	0.5102
Residual			1.43042	1.48357	1.60614
SSE-sum			2.35469	2.49191	2.4458
Total digestion initial rinse			-0.061	-0.0553	-0.0629
Total digestion			-0.4447	0.57193	0.35355

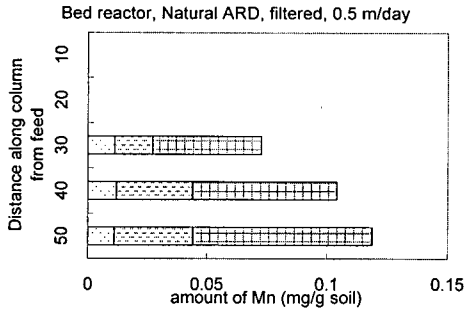
Mn	10	20	30	40	50
Initial Rinse			0.00168	-0.0006	0.00093
Exchangeable			0.01117	0.01197	0.01113
Ionic-bound to amorphous			-0.0009	-0.0002	-0.0007
Fe-,Mn- oxides			0.01618	0.03203	0.0331
Oxidizing compounds			0.04556	0.06029	0.07476
Residual			-0.0219	-0.0166	-0.0162
SSE-sum			0.05015	0.08757	0.10212
Total digestion initial rinse			0.00309	-0.0012	0.00166
Total digestion			-0.0152	0.01972	0.02335

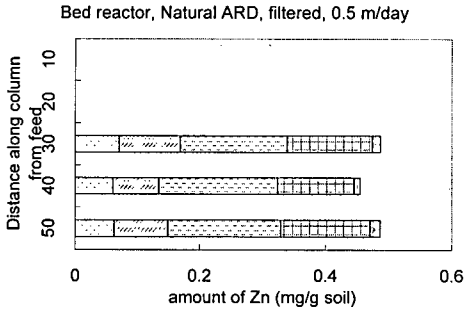
Zn	10	20	30	40	50
Initial Rinse			0.00384	0.00075	0.00263
Exchangeable			0.0705	0.06044	0.06252
Ionic-bound to amorphous			0.09842	0.07397	0.0868
Fe-,Mn- oxides			0.17058	0.19002	0.18009
Oxidizing compounds			0.13505	0.12078	0.14155
Residual			0.01331	0.00994	0.01637
SSE-sum			0.48786	0.45515	0.48734
Total digestion initial rinse			0.01117	0.00352	0.00791
Total digestion			0.57583	0.53812	0.61102

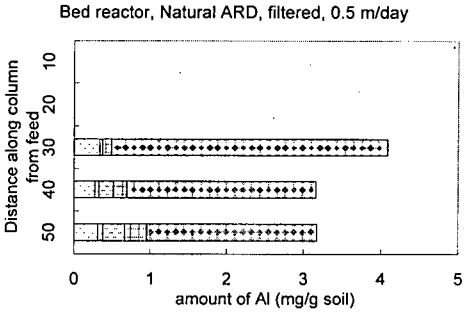
Al	10	20	30	40	50
Initial Rinse			-0.0624	-0.0642	-0.0645
Exchangeable			0.33613	0.27487	0.31305
Ionic-bound to amorphous			-0.0163	0.05322	0.06754
Fe-,Mn- oxides			0.04074	0.19103	0.28595
Oxidizing compounds			0.11644	0.17436	0.29059
Residual			3.5992	2.46929	2.21896
SSE-sum			4.0762	3.16277	3.17608
Total digestion initial rinse			-0.2025	-0.2076	-0.205
Total digestion			2.78128	1.43972	4.44362











PTB17 (minus background from treated clinop,%)

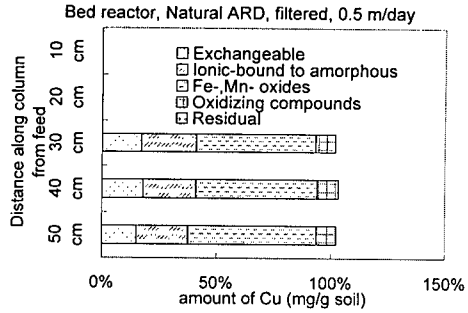
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeable			17.18%	17.91%	15.08%	16.73%
Ionic-bound to amorphous			23.98%	23.20%	22.60%	23.26%
Fe-,Mn- oxides			52.23%	52.97%	56.05%	53.75%
Oxidizing compounds			8.69%	9.28%	8.65%	8.87%
Residual			-2.07%	-3.36%	-2.38%	-2.60%
SSE-sum			100%	100%	100%	100.00%
Total digestion initial rinse			0.04061	0.013158	0.02897	
Total digestion			1.93881	1.509248	1.57757	

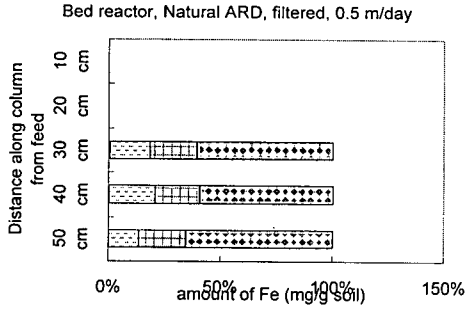
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeable			0.59%	0.09%	0.08%	0.25%
Ionic-bound to amorphous			-0.25%	-0.32%	-0.29%	-0.29%
Fe-,Mn- oxides			18.00%	20.83%	13.68%	17.50%
Oxidizing compounds			20.92%	19.87%	20.86%	20.55%
Residual			60.75%	59.54%	65.67%	61.98%
SSE-sum			100.00%	100.00%	100.00%	100.00%
Total digestion initial rinse			-0.06101	-0.05526	-0.06287	
Total digestion			-0.44467	0.571929	0.35355	

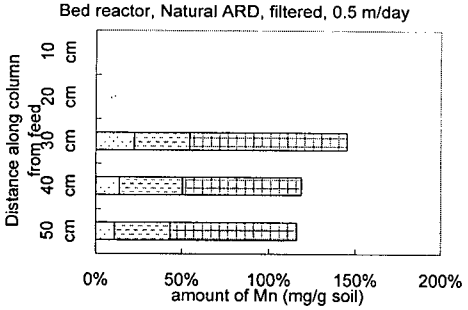
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeable			22.27%	13.67%	10.90%	15.61%
Ionic-bound to amorphous			-1.76%	-0.18%	-0.66%	-0.87%
Fe-,Mn- oxides			32.26%	36.58%	32.42%	33.75%
Oxidizing compounds			90.85%	68.85%	73.21%	77.64%
Residual			-43.62%	-18.92%	-15.86%	-26.13%
SSE-sum			100.00%	100.00%	100.00%	100.00%
Total digestion initial rinse			0.00309	-0.00118	0.00166	
Total digestion			-0.01519	0.019716	0.02335	

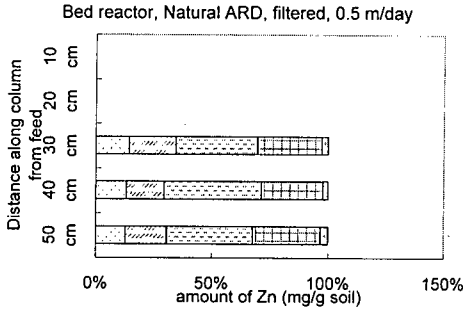
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeable			14.45%	13.28%	12.83%	13.52%
Ionic-bound to amorphous			20.17%	16.25%	17.81%	18.08%
Fe-,Mn- oxides			34.96%	41.75%	36.95%	37.89%
Oxidizing compounds			27.68%	26.54%	29.05%	27.75%
Residual			2.73%	2.18%	3.36%	2.76%
SSE-sum			100%	100%	100%	100.00%
Total digestion initial rinse			0.01117	0.003521	0.00791	
Total digestion			0.57583	0.538119	0.61102	

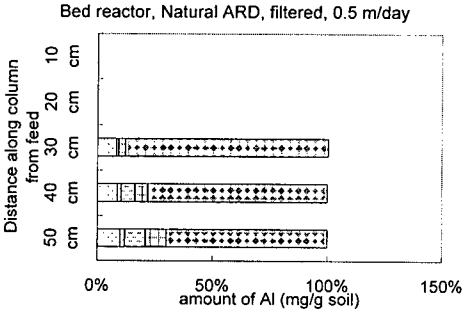
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeable			8.25%	8.69%	9.86%	8.93%
Ionic-bound to amorphous			-0.40%	1.68%	2.13%	1.14%
Fe-,Mn- oxides			1.00%	6.04%	9.00%	5.35%
Oxidizing compounds			2.86%	5.51%	9.15%	5.84%
Residual			88.30%	78.07%	69.86%	78.75%
SSE-sum			100.00%	100.00%	100.00%	100.00%
Total digestion initial rinse			-0.20246	-0.20758	-0.205	
Total digestion			2.78128	1.439725	4.44362	











PTB18 (minus background from treated clinop)

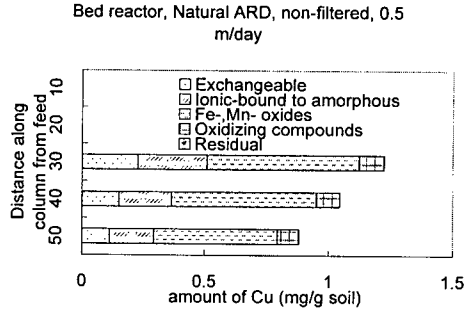
Cu	10	20	30	40	50
Initial Rinse			0.02095	0.01261	0.00646
Exchangeable			0.22772	0.151	0.11352
Ionic-bound to amorphous			0.28246	0.21528	0.18031
Fe-,Mn- oxides			0.61444	0.58612	0.502
Oxidizing compounds			0.10064	0.09404	0.08683
Residual			-0.023	-0.0211	-0.0213
SSE-sum			1.2023	1.02536	0.8614
Total digestion initial rinse			0.05305	0.0282	0.01527
Total digestion			2.47418	1.90827	2.3248

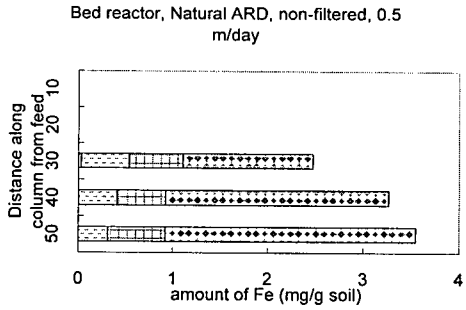
Fe	10	20	30	40	50
Initial Rinse			-0.0353	-0.0364	-0.0363
Exchangeable			0.02879	0.00232	0.00077
Ionic-bound to amorphous			-0.0062	-0.0066	-0.008
Fe-,Mn- oxides			0.50888	0.41012	0.3145
Oxidizing compounds			0.57056	0.514	0.60708
Residual			1.36894	2.34154	2.63033
SSE-sum			2.47094	3.26137	3.54466
Total digestion initial rinse			-0.0596	-0.0604	-0.061
Total digestion			1.17863	0.70039	-0.0704

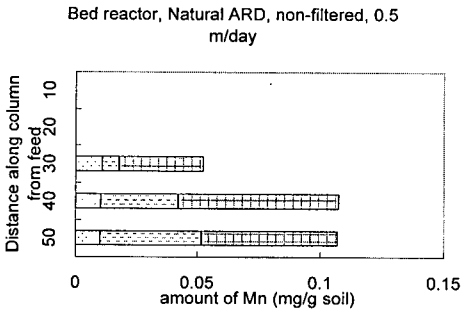
Mn	10	20	30	40	50
Initial Rinse			0.00186	0.00087	0.00021
Exchangeable			0.01101	0.01037	0.01003
Ionic-bound to amorphous			-0.0031	-0.0009	-0.0014
Fe-,Mn- oxides			0.00688	0.03182	0.04174
Oxidizing compounds			0.03454	0.06535	0.05539
Residual			-0.017	-0.0145	-0.013
SSE-sum			0.03237	0.09213	0.09282
Total digestion initial rinse			0.00474	0.0011	-0.0003
Total digestion			-0.0061	0.02796	0.03248

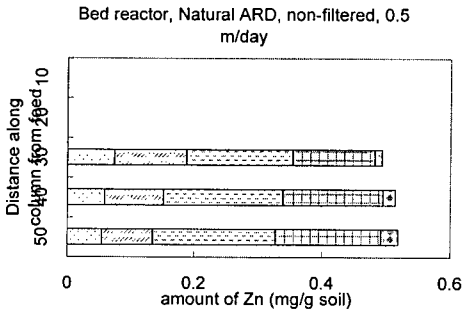
Zn	10	20	30	40	50
Initial Rinse			0.00502	0.00264	0.00189
Exchangeable			0.07384	0.05871	0.05415
Ionic-bound to amorphous			0.11443	0.09318	0.0809
Fe-,Mn- oxides			0.16627	0.1877	0.1923
Oxidizing compounds			0.12832	0.15576	0.16479
Residual			0.01155	0.01966	0.02707
SSE-sum			0.49441	0.51501	0.51923
Total digestion initial rinse			0.01545	0.00692	0.00444
Total digestion			0.64274	0.65132	0.61223

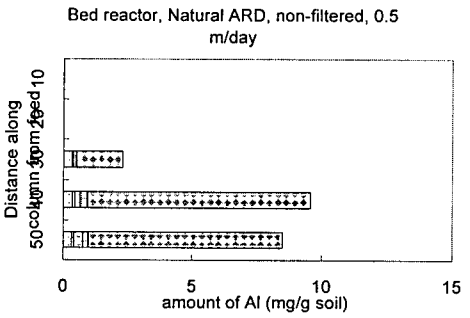
Al	10	20	30	40	50
Initial Rinse			-0.0611	-0.0638	-0.0473
Exchangeable			0.33166	0.34947	0.32327
Ionic-bound to amorphous			0.01741	0.10797	0.09887
Fe-,Mn- oxides			0.03317	0.19568	0.33453
Oxidizing compounds			0.11532	0.29212	0.22568
Residual			1.82549	8.63229	7.52215
SSE-sum			2.32305	9.57754	8.5045
Total digestion initial rinse			-0.1872	-0.2148	-0.2082
Total digestion			4.15109	6.15303	2.82531





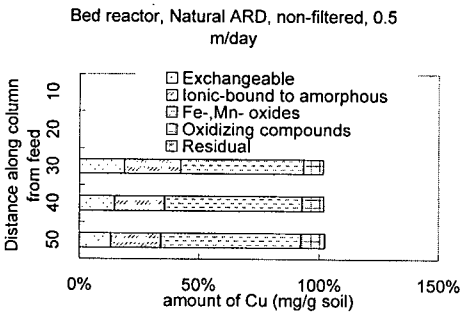




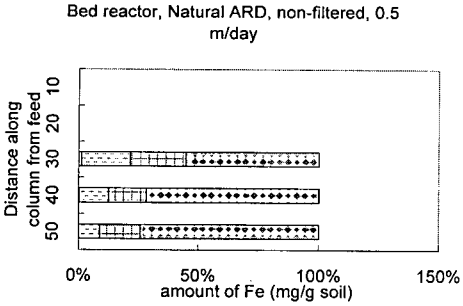


PTB18 (minus background from treated clinop,%)

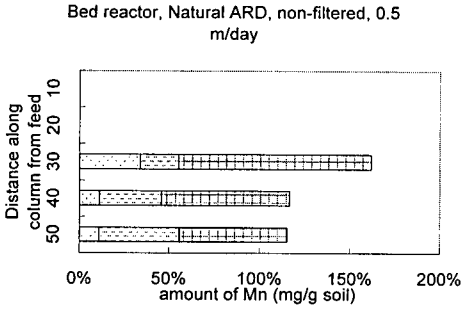
Cu	10	20	30	40	50	
Exchangeable			18.94%	14.73%	13.18%	15.62%
Ionic-bound to amorphous			23.49%	21.00%	20.93%	21.81%
Fe-,Mn- oxides			51.11%	57.16%	58.28%	55.52%
Oxidizing compounds			8.37%	9.17%	10.08%	9.21%
Residual			-1.91%	-2.06%	-2.47%	-2.15%
SSE-sum			100%	100%	100%	100.00%
Total digestion initial rinse			0.053047	0.028197	0.015268	
Total digestion			2.474181	1.908272	2.324797	



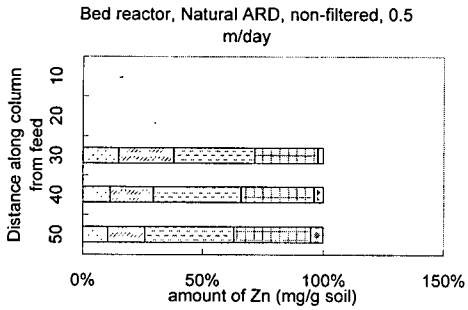
Fe	10	20	30	40	50	
Exchangeable			1.17%	0.07%	0.02%	0.42%
Ionic-bound to amorphous			-0.25%	-0.20%	-0.23%	-0.23%
Fe-,Mn- oxides			20.59%	12.58%	8.87%	14.01%
Oxidizing compounds			23.09%	15.76%	17.13%	18.66%
Residual			55.40%	71.80%	74.21%	67.13%
SSE-sum			100.00%	100.00%	100.00%	100.00%
Total digestion initial rinse			-0.05959	-0.06036	-0.06103	
Total digestion			1.17863	0.700392	-0.07036	



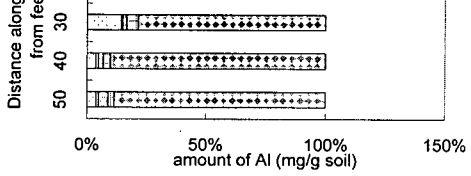
Mn	10	20	30	40	50	
Exchangeable			34.02%	11.26%	10.80%	18.69%
Ionic-bound to amorphous			-9.58%	-1.02%	-1.46%	-4.02%
Fe-,Mn- oxides			21.26%	34.54%	44.97%	33.59%
Oxidizing compounds			106.71%	70.94%	59.67%	79.10%
Residual			-52.41%	-15.71%	-13.98%	-27.37%
SSE-sum			100.00%	100.00%	100.00%	100.00%
Total digestion initial rinse			0.004744	0.001099	-0.00031	
Total digestion			-0.00614	0.027959	0.03248	



Zn	10	20	30	40	50	
Exchangeable			14.93%	11.40%	10.43%	12.25%
Ionic-bound to amorphous			23.14%	18.09%	15.58%	18.94%
Fe-,Mn- oxides			33.63%	36.45%	37.04%	35.70%
Oxidizing compounds			25.96%	30.24%	31.74%	29.31%
Residual			2.34%	3.82%	5.21%	3.79%
SSE-sum			100.00%	100.00%	100.00%	100.00%
Total digestion initial rinse			0.01545	0.006922	0.004444	
Total digestion			0.642742	0.651323	0.612228	



Al	10	20	30	40	50	
Exchangeable			14.28%	3.65%	3.80%	7.24%
Ionic-bound to amorphous			0.75%	1.13%	1.16%	1.01%
Fe-,Mn- oxides			1.43%	2.04%	3.93%	2.47%
Oxidizing compounds			4.96%	3.05%	2.65%	3.56%
Residual			78.58%	90.13%	88.45%	85.72%
SSE-sum			100.00%	100.00%	100.00%	100.00%
Total digestion initial rinse			-0.18722	-0.21479	-0.20819	
Total digestion			4.151089	6.153032	2.825313	



Appendix I. Results of water sample analyses from Critical Path Analysis column leaching cells

Cell ID CPA8

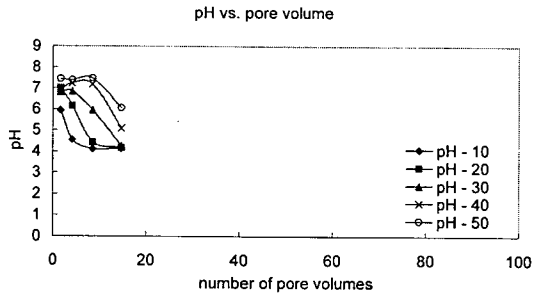
wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.66675 m/day

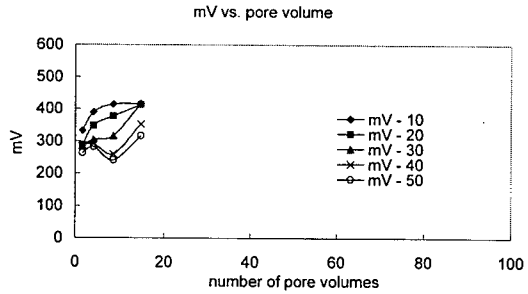
initial concentration of metals, Co		
[Cu]o	37.991	mg/L
[Fe]o	0.323	mg/L
[Mn]o	3.475	mg/L
[Zn]o	19.2104	mg/L
[Al]o	23.17	mg/L
pH	3.27	
redox pot	560.5	mV
EC	2.31	mS/cm

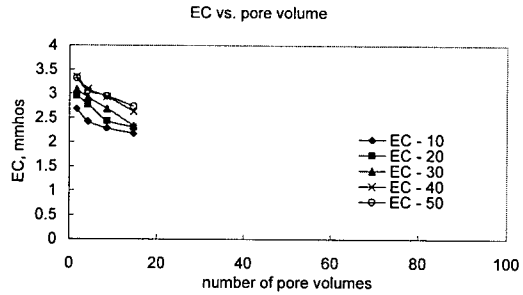
# of pore volumes passed through column:
14.6691 pore volumes

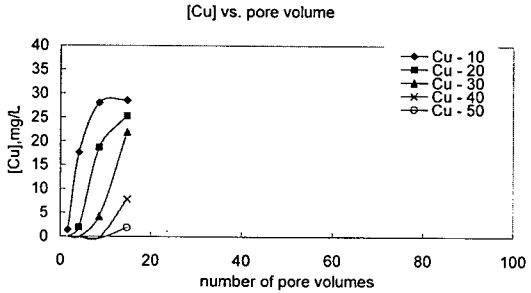
			time used	Flowrate				10cm								20cm								30cm		
Date	Time	vol effl (m	hh:mm:ss (min)	L/day	m/day	pv/day	#pore vol	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	
1 Apr 15, 2	9:00a	533.17	21:00:00	1260.00	0.60934	0.45485	1.88199	1.64674	5.95	332	2.68	1.406	0.081	4.519	6.2444	0.01	7	288.2	2.95	-0.081	0.18	0.474	0.0112	0.06	6.81	283.2
2 Apr 16,2(	9:00a	811.68	21:15:39	1275.65	0.91625	0.68395	2.82992	4.15368	4.55	389.4	2.42	17.678	0.055	4.087	14.4855	6.83	6.15	347.7	2.77	1.909	0.009	3.469	6.8382	0.04	6.84	304.5
3 Apr 18,2(	3:40p	1431.62	74:49:25	3218.83	1.28092	0.95616	7.91244	8.57535	4.12	414.8	2.28	28.071	0.06	4.447	18.2853	18.64	4.44	376.6	2.43	18.703	0.027	4.773	15.1944	8.8	5.95	315.5
4 Apr 21,2(	9:00a	1972.98	61:47:20	3707.33	0.76634	0.57205	2.36691	**14.6691**	4.14	415	2.17	28.585	0.084	4.183	17.7778	19.96	4.17	412.9	2.3	25.285	0.077	4.191	16.3964	16.77	4.24	416.3

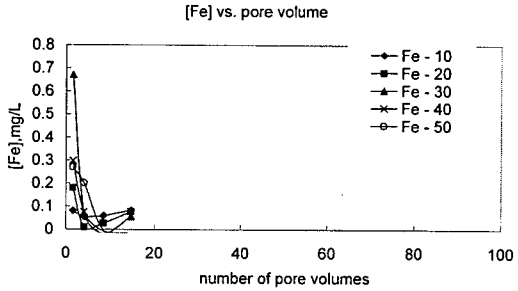
						40cm									50cm											
EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5	DO
3.09	-0.086	0.671	0.049	-0.0147	0.43	6.95	283.8	3.35	-0.069	0.298	0.106	-0.0194	0.11	7.44	261.8	3.32	-0.082	0.27	0.103	-0.0139	0.07	463.8	7.86102	15.301	6.7
2.92	-0.081	0.071	1.336	0.5197	-0.11	7.23	290.8	3.09	-0.089	0.076	0.108	-0.0324	-0.12	7.38	281.5	3.05	-0.097	0.201	0.078	-0.0048	0.03	483.5	8.19492	15.5749	4.5
2.68	4.197	-0.02	4.647	10.2901	0	7.18	259.6	2.93	-0.255	-0.006	1.977	0.7589	-0.38	7.47	239.8	2.94	-0.375	-0.005	0.677	-0.0329	-0.54	441.8	7.48814	14.9581	6.6
2.33	21.902	0.056	4.261	16.0449	14.39	5.1	352.6	2.63	7.862	-0.018	4.182	10.8207	1.38	6.06	316	2.73	1.853	-0.018	3.283	6.2302	-0.23	518	8.77966	14.8397	7

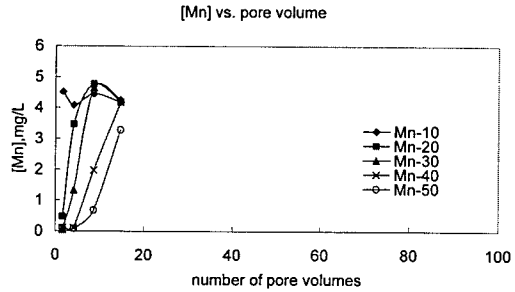

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

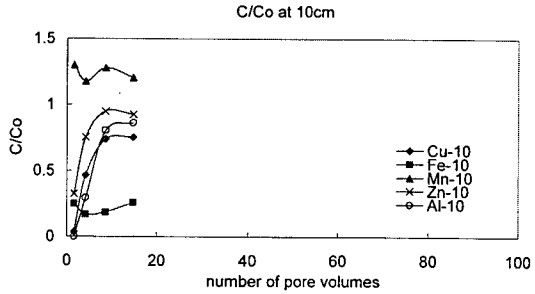

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

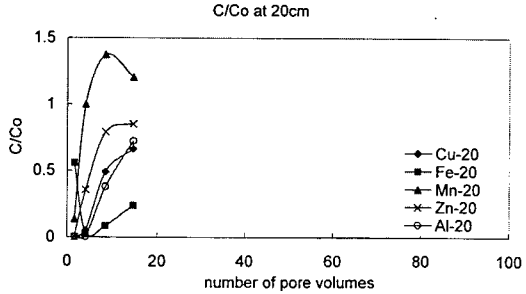

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

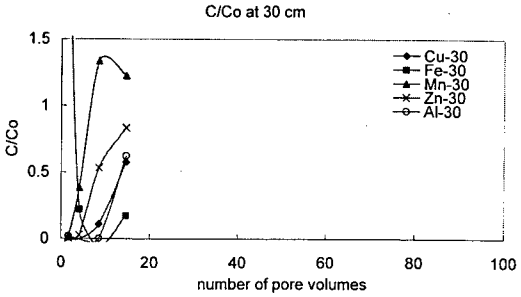

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

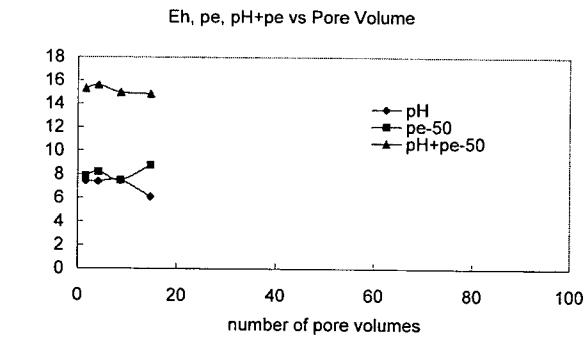

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

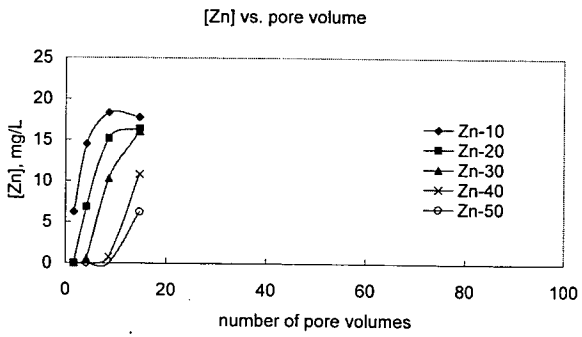

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

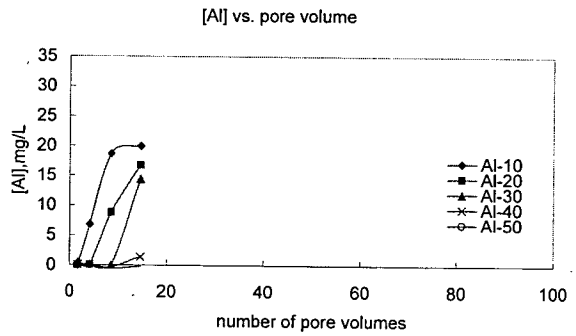

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

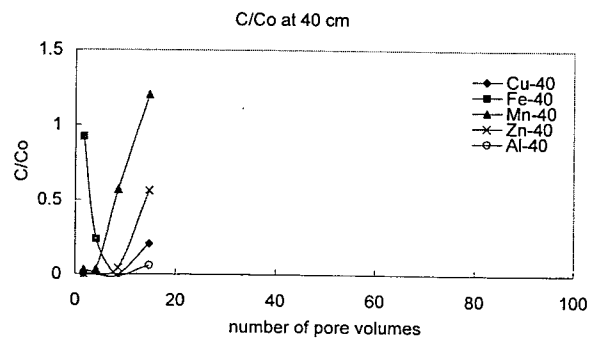

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

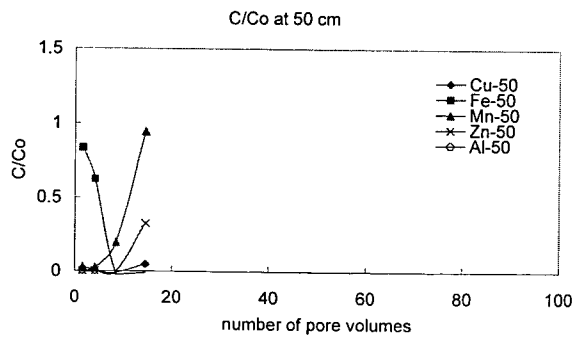

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
number of pore volumes
pH
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
35
30
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID CPA7

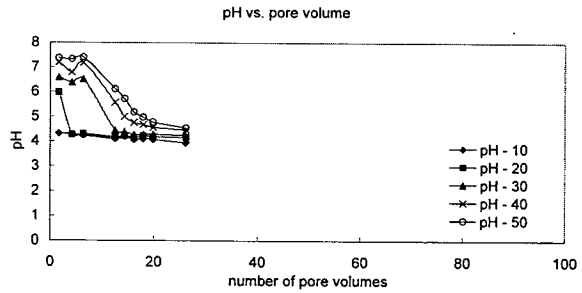
wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.54593 m/day

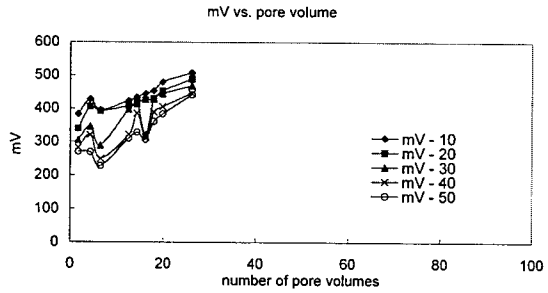
initial concentration of metals, Co	
[Cu]o	37.991 mg/L
[Fe]o	0.323 mg/L
[Mn]o	3.475 mg/L
[Zn]o	19.2104 mg/L
[Al]o	23.17 mg/L
pH	3.27
redox pot	560.5 mV
EC	2.31 mS/cm

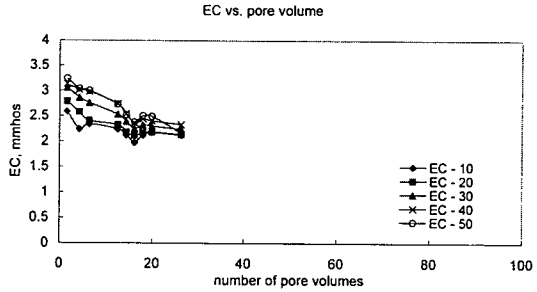
# of pore volumes passed through column:
26.17 pore volumes

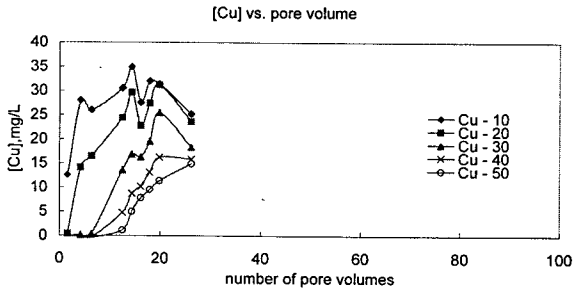
			time used		Flowrate				10cm								20cm								30cm	
Date	Time	vol effl (m	hh:mm:ss	(min)	L/day	m/day	pv/day	#pore vol	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	
1 Apr 15, 2	9:00a	533.35	21:00:00	1260.00	0.60954	0.455	1.88262	1.64729	4.32	383.3	2.59	12.595	0.002	4.594	12.3466	4.34	5.99	339.3	2.79	0.388	0.045	2.911	3.4705	0.07	6.58	
2 Apr 16,2	9:00a	833.77	21:15:39	1275.65	0.94119	0.70257	2.90694	4.22246	4.28	426.9	2.24	28.05	0.114	3.756	16.0278	18.42	4.27	405.6	2.58	14.124	0.023	4.31	12.2368	3.9	6.38	
3 Apr 18,2	3:40p	704.74	74:49:25	3218.83	0.63055	0.47069	3.89504	6.39911	4.23	394.4	2.34	26.025	0.056	4.155	15.5264	16.78	4.29	391.7	2.41	16.469	0.033	4.208	12.5509	10.36	6.52	
4 Apr 21,2	9:00a	1974.03	61:47:20	3707.33	0.76675	0.57235	2.36817	12.4961	4.1	423.2	2.24	30.567	0.121	4.276	18.3789	19.53	4.17	408.1	2.32	24.465	0.078	4.133	15.7277	15.55	4.43	
5 Apr 22,2	9:32a	584.32	20:35:08	1235.13	0.68124	0.50852	2.10406	14.3008	4.19	433.9	2.12	34.975	0.12	4.625	20.9769	18.53	4.22	419.4	2.18	29.689	0.068	4.507	17.8778	16.37	4.38	
6 Apr 23,2	9:05a	582.27	18:40:45	1120.75	0.74813	0.55845	2.31067	16.0992	4.07	444.6	1.971	27.614	0.127	4.144	17.1653	26.04	4.13	425.1	2.11	22.822	0.061	3.692	15.0975	22.38	4.27	
7 Apr 24,2	8:50a	579.02	18:55:16	1135.27	0.73444	0.54824	2.26839	17.8875	4.1	453	2.12	32.076	0.158	3.223	19.2515	26.14	4.22	428.8	2.17	27.461	0.078	3.238	17.2236	23.13	4.27	
8 Apr 25,2	9:00a	623.5	19:55:16	1195.27	0.75116	0.56072	2.32003	19.8132	4.07	479.6	2.17	31.421	0.191	3.824	20.5129	26.18	4.18	452.9	2.18	31.236	0.049	3.878	19.2078	24.04	4.28	
9 Apr 28,2	9:35a	2057.34	68:39:13	4119.22	0.71921	0.53686	2.22133	**26.1675**	3.93	507	2.12	25.235	0.286	4.095	15.8807	26.14	4.15	488	2.13	23.651	0.119	3.917	13.436	24.8	4.23	

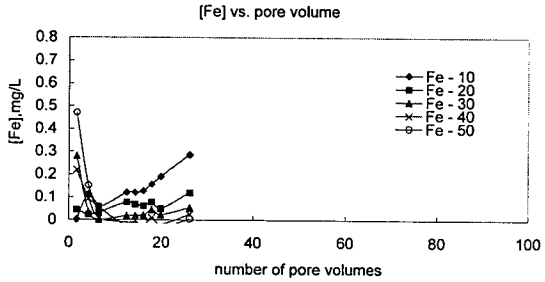
40cm								50cm																			
mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5	DO	
305.6	3.06	-0.079	0.281	0.136	-0.0211	0.19	7.19	282.2	3.13	-0.084	0.219	0.059	-0.0146	0.04	7.37	270	3.24	-0.082	0.47	0.074	-0.0036	0.33	472	8	15.37	6	
345.3	2.86	0.168	0.034	2.267	2.5544	0.01	6.79	319.9	3.02	-0.1	0.092	0.366	-0.0031	-0.06	7.33	268.7	3.04	-0.096	0.151	0.078	-0.013	-0.05	470.7	7.97797	15.308	4.5	
288.9	2.76	0.287	0.001	3.375	4.1158	-0.2	7.17	249.3	2.98	-0.363	0.008	1.532	0.0822	-0.36	7.41	227.4	3	-0.41	0.059	0.399	-0.017	-0.4	429.4	7.27797	14.688	8	
397.5	2.53	13.623	0.018	4.251	11.4175	6.39	5.57	321.3	2.74	4.747	-0.01	3.993	7.6925	0.41	6.11	309.9	2.73	1.106	-0.026	3.415	5.2427	-0.17	511.9	8.67627	14.7863	7.5	
414.3	2.39	16.862	0.019	4.493	13.0208	8.17	4.99	385.6	2.54	8.748	-0.011	4.293	9.4468	1.72	5.72	328	2.52	4.977	-0.005	4.098	7.9168	0.32	530	8.98305	14.7031	7.9	
320	2.25	16.341	0.021	3.829	11.7074	13.1	4.75	312.4	2.36	10.27	-0.026	3.721	9.1475	4.67	5.18	306.3	2.38	7.865	-0.037	4.065	8.3546	1.83	508.3	8.61525	13.7953	6.9	
428.5	2.32	19.54	0.044	3.237	14.2689	14.61	4.68	388.7	2.44	13.179	0.01	3.028	11.5305	6.28	4.97	360.1	2.5	9.534	-0.021	3.225	9.5987	2.86	562.1	9.52712	14.4971	7.7	
444.2	2.3	25.501	0.023	3.871	16.2504	16.92	4.56	404.8	2.4	16.196	-0.019	3.799	12.5234	9.09	4.77	383.2	2.49	11.369	-0.036	3.739	10.3185	4.72	585.2	9.91864	14.6886	7.1	
467.6	2.23	18.374	0.053	4.093	12.2698	20.52	4.45	445.7	2.33	15.893	0.024	4.102	10.7174	12.77	4.53	441.1	2.15	14.921	0.005	3.987	10.1462	10.49	643.1	10.9	15.43	6.2	

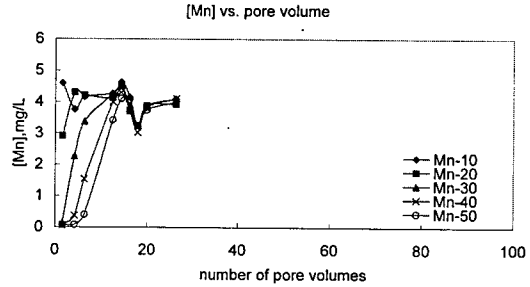

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

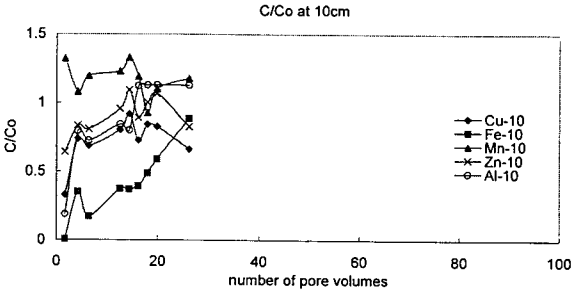

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

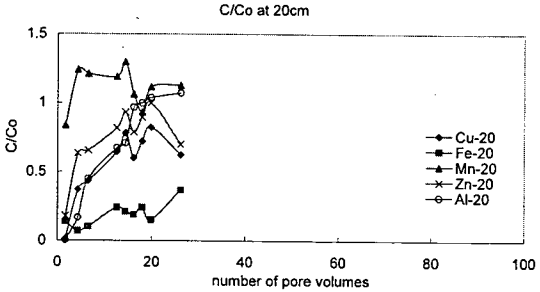

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

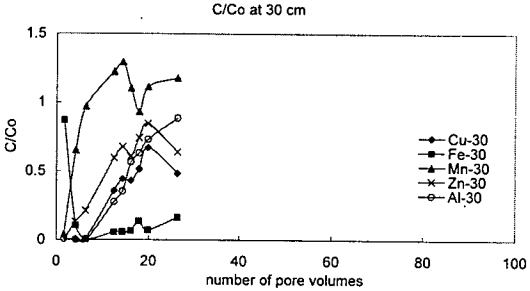

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

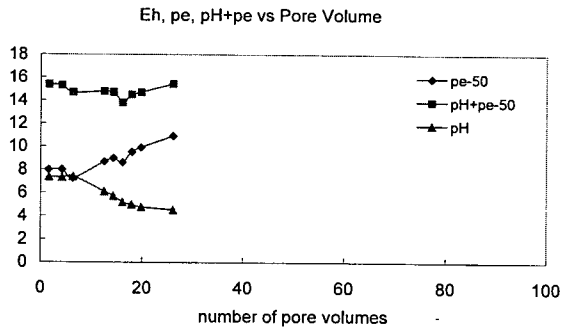

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

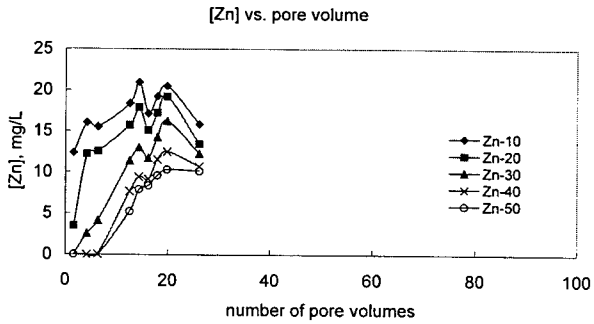

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

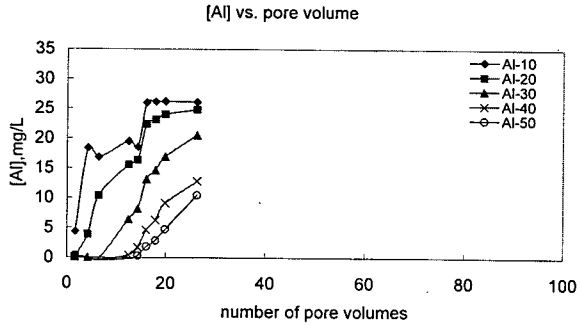

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

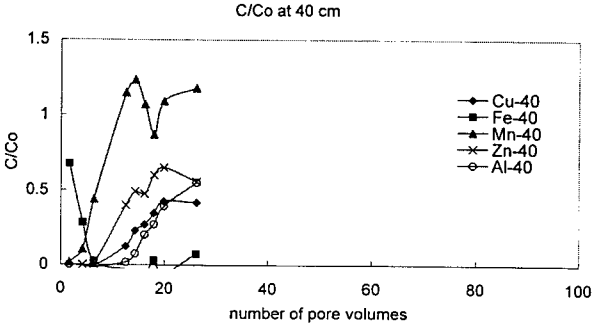

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

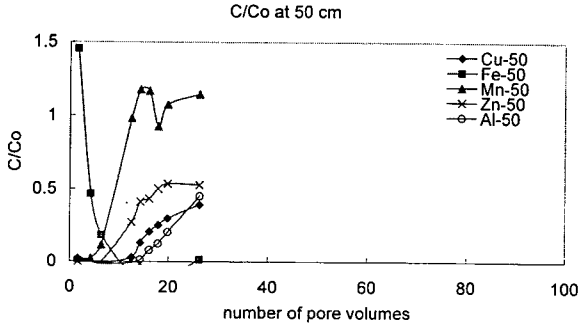

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
pe-50
pH+pe-50
pH
number of pore volumes


[Zn] vs. pore volume
[Zn], mg/L
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50
number of pore volumes


[Al] vs. pore volume
[Al],mg/L
Al-10
Al-20
Al-30
Al-40
Al-50
number of pore volumes


C/Co at 40 cm
C/Co
Cu-40
Fe-40
Mn-40
Zn-40
Al-40
number of pore volumes


C/Co at 50 cm
C/Co
Cu-50
Fe-50
Mn-50
Zn-50
Al-50
number of pore volumes

Cell ID CPA6

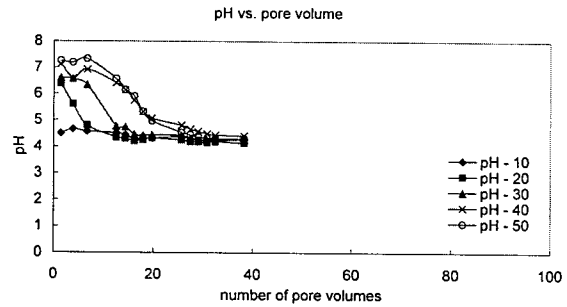
wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.52309 m/day

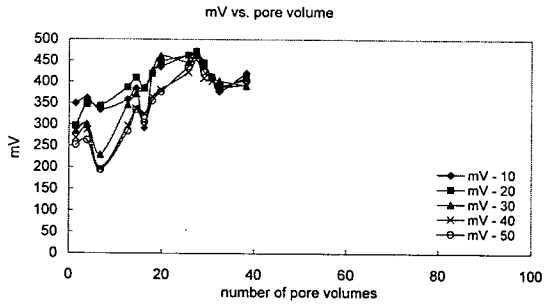
initial concentration of metals, Co		
[Cu]o	37.991	mg/L
[Fe]o	0.323	mg/L
[Mn]o	3.475	mg/L
[Zn]o	19.2104	mg/L
[Al]o	23.17	mg/L
pH	3.27	
redox pot	560.5	mV
EC	2.31	mS/cm

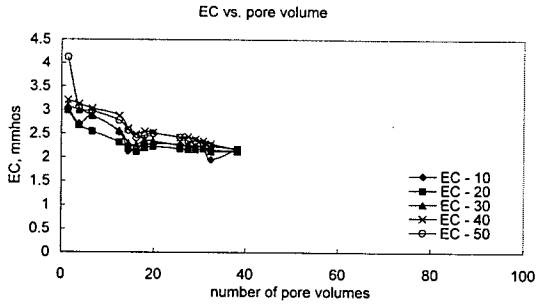
# of pore volumes passed through column:
38.21 pore volumes

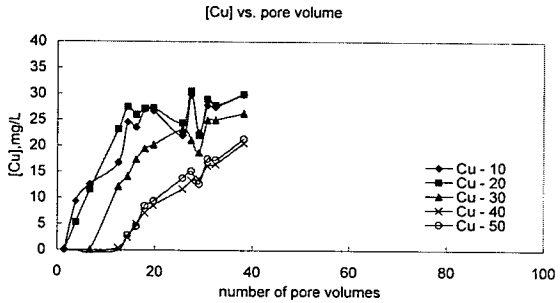
	Date	Time	vol effl (n	time used hh:mm:ss	(min)	Flowrate L/day	m/day	pv/day	#pore vol	10cm CPA6 pH	mV	EC	Cu	Fe	Mn	Zn	Al	20cm CPA6 pH	mV	EC	Cu	Fe	Mn	Zn	Al	30cm CPA6 pH
1	Apr 15, 2	9:00a	468.32	21:00:00	1260.00	0.53522	0.39953	1.65308	1.44644	4.5	349.4	3.04	0.005	0.113	1.377	1.1685	0	6.38	296.6	2.99	-0.084	0.139	0.765	0.0518	-0.09	6.61
2	Apr 16,2	9:00a	780.84	21:15:39	1275.65	0.88144	0.65797	2.7224	3.85813	4.66	361.6	2.71	9.355	0.078	3.158	8.5796	4.68	5.61	347.9	2.67	5.303	-0.06	4.254	8.7165	0.83	6.57
3	Apr 18,2	3:40p	925.89	74:49:25	3218.83	0.82843	0.61839	5.11732	6.71782	4.57	334	2.87	12.59	0.007	3.549	9.4479	6.45	4.8	343.4	2.55	11.6	-0.01	4.504	11.4459	4.27	6.33
4	Apr 21,2	9:00a	1890.29	61:47:20	3707.33	0.73423	0.54807	2.26771	12.5561	4.52	358.3	2.53	16.802	0.018	3.624	11.0218	8.17	4.35	387.7	2.32	23.22	0.04	4.325	14.916	13.3	4.76
5	Apr 22,2	9:32a	593.01	20:35:08	1235.13	0.69137	0.51608	2.13535	14.3877	4.44	384.3	2.13	24.584	0.025	4.036	15.5221	11.36	4.3	409.8	2.2	27.504	0.048	4.537	18.0734	15.06	4.74
6	Apr 23,2	9:05a	579.27	18:40:45	1120.75	0.74428	0.55558	2.29876	16.1768	4.28	291.9	2.22	23.547	0.034	3.879	15.4103	19.23	4.21	384.3	2.12	26.004	0.037	4.208	16.7021	21.87	4.45
7	Apr 24,2	8:50a	557.15	18:55:16	1135.27	0.7067	0.52753	2.18271	17.8976	4.33	423.2	2.26	27.056	0.047	4.116	17.6642	19.63	4.26	419.3	2.2	27.215	0.055	4.411	17.9833	20.96	4.42
8	Apr 25,2	9:00a	586.74	19:55:16	1195.27	0.70688	0.52766	2.18324	19.7098	4.31	435.2	2.29	26.792	0.053	3.759	17.3379	22.55	4.31	446.3	2.23	27.287	0.066	3.677	17.1529	23.12	4.44
9	Apr 28,2	9:35a	1923.89	68:39:13	4119.22	0.67256	0.50204	2.07724	25.6519	4.37	462.9	2.27	22.064	0.053	3.885	14.5632	20.12	4.25	462.5	2.18	24.454	0.053	4.049	16.3704	24.2	4.42
10	Apr 29,2	9:30a	561.65	19:56:33	1196.55	0.67592	0.50455	2.08764	27.3866	4.28	464.2	2.21	29.809	0.057	4.057	15.5942	19.61	4.18	470.7	2.16	30.556	0.066	4.295	16.0095	21.51	4.27
11	Apr 30,2	8:45a	531.93	19:55:11	1195.18	0.64089	0.4784	1.97944	29.0295	4.24	437	2.23	22.531	0.054	3.931	15.4228	18.78	4.17	443.9	2.16	22.031	0.058	4.12	15.663	20.81	4.23
12	May 1,20	9:20a	560.35	20:13:02	1213.03	0.6652	0.49655	2.05451	30.7602	4.26	408.7	2.2	27.812	0.06	3.972	17.3381	23.81	4.15	409.2	2.18	28.988	0.064	3.987	17.7585	25.33	4.23
13	May 2,20	9:15a	543.72	19:46:52	1186.87	0.65968	0.49243	2.03749	32.4395	4.26	377.6	1.952	27.482	0.072	4.116	16.3702	23.65	4.18	385.5	2.15	27.827	0.07	4.191	16.7602	26.02	4.22
14	May 5,20	9:50a	1868.19	67:08:46	4028.77	0.66775	0.49845	2.06239	**38.2096**	4.25	420.4	2.17	29.898	0.061	4.409	17.915	22.09	4.13	409.2	2.14	29.98	0.071	4.332	17.8518	24.82	4.26

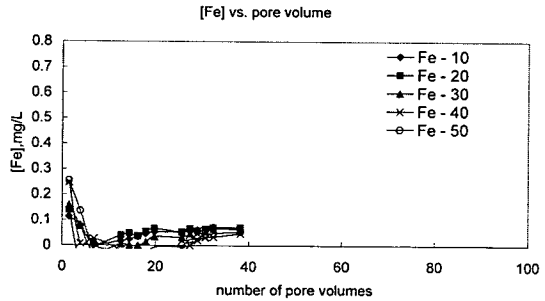
							40cm CPA6									50cm CPA6											
mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5(	DO
285.1	3.08	-0.082	0.158	0.083	-0.0571	-0.07	7.12	268.2	3.21	-0.089	0.247	0.053	-0.0532	0.04	7.25	252.1	4.12	-0.07	0.254	0.207	0.0331	0.25	454.1	7.69661	14.9466	
301.1	3	-0.078	0.077	0.918	0.1826	0.02	6.59	288.2	3.13	-0.088	0.007	0.103	-0.0242	-0.09	7.19	263.1	3.06	-0.088	0.136	0.053	-0.0093	0.17	465.1	7.88305	15.0731	
229.4	2.88	-0.006	-0.024	2.831	2.8997	-0.2	6.92	197.7	3.03	-0.4	0.027	0.507	0.0266	-0.28	7.33	193.8	2.98	-0.403	0.003	0.251	0.0085	-0.23	395.8	6.70847	14.0385	
346.1	2.56	12.185	0.006	4.697	11.172	4.03	6.41	296.9	2.88	0.425	-0.019	2.918	3.4056	-0.11	6.57	284.1	2.78	-0.127	-0.022	3.257	3.8538	-0.27	486.1	8.23898	14.809	
371.9	2.29	14.124	0	4.854	12.7379	4.71	6.13	337.1	2.6	2.475	-0.028	3.616	6.1233	-0.07	6.15	334.5	2.57	2.823	-0.035	4.328	7.3411	-0.07	536.5	9.09322	15.2432	
385.4	2.26	17.4	0	4.563	13.5392	11.46	5.75	324.5	2.49	5.013	-0.052	4.197	7.4452	0.61	5.9	305.1	2.41	4.57	-0.051	3.982	7.4117	0.27	507.1	8.59492	14.4949	
426	2.36	19.497	0.014	4.178	14.2405	11.27	5.31	364.5	2.55	7.119	-0.041	3.271	9.0554	1.47	5.32	355.6	2.46	8.476	-0.038	3.178	10.047	1.51	557.6	9.45085	14.7708	
461.1	2.34	20.244	0.035	3.526	14.2027	14.38	5.06	380.9	2.52	8.601	-0.007	4.045	9.4361	2.53	4.97	376.3	2.5	9.414	-0.008	3.832	9.8812	3.15	578.3	9.80169	14.7717	
446.4	2.25	23.208	0.032	4.083	13.8585	17	4.8	422.4	2.42	11.725	-0.005	4.395	10.3441	6.03	4.53	436	2.42	13.821	0.001	4.163	10.7605	9.01	638	10.8136	15.3436	
473	2.26	21.138	0.047	4.191	14.0756	16.89	4.66	452.5	2.43	13.368	0.001	4.522	10.9983	6.42	4.44	462.6	2.34	15.185	0.024	4.293	11.6828	10.33	664.6	11.2644	15.7044	
445.2	2.23	18.75	0.062	3.949	14.3432	18.72	4.57	408.6	2.38	13.655	0.02	4.193	12.2872	8.02	4.35	423.9	2.34	12.674	0.029	4.08	13.2634	12.26	625.9	10.6085	14.9585	
411.5	2.23	24.966	0.058	4.005	15.7974	22.7	4.48	401.2	2.34	16.207	0.032	4.155	13.4021	11.58	4.32	410.8	2.3	17.573	0.042	4.004	13.5929	15.56	612.8	10.3864	14.7064	
401.5	2.13	25.007	0.066	4.149	15.5009	23.73	4.43	387.8	2.28	16.498	0.033	4.174	13.1569	13.72	4.3	390	2.24	17.317	0.047	4.181	13.2404	17.35	592	10.0339	14.3339	
390.9	2.13	26.287	0.063	4.296	16.3601	22.54	4.4	392.3	2.17	20.566	0.047	4.285	14.402	16.76	4.29	404.4	2.17	21.381	0.054	4.254	14.3416	17.84	606.4	10.278	14.568	

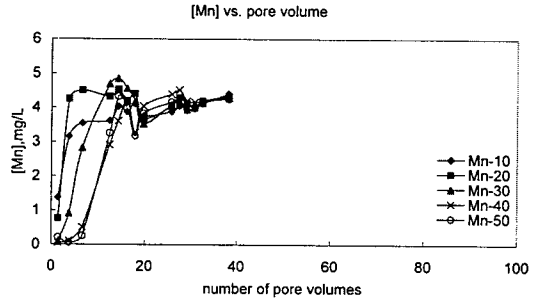

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

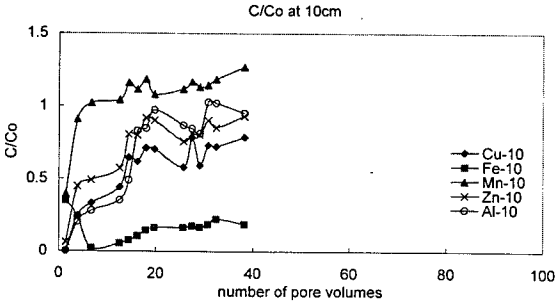

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

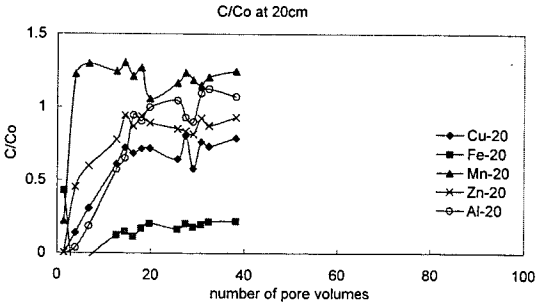

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

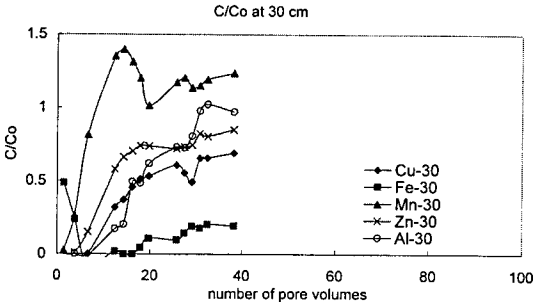

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

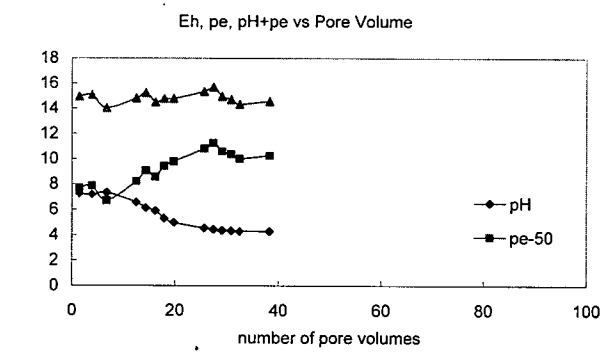

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

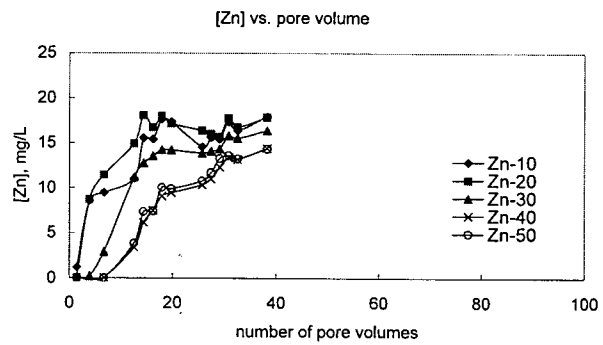

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

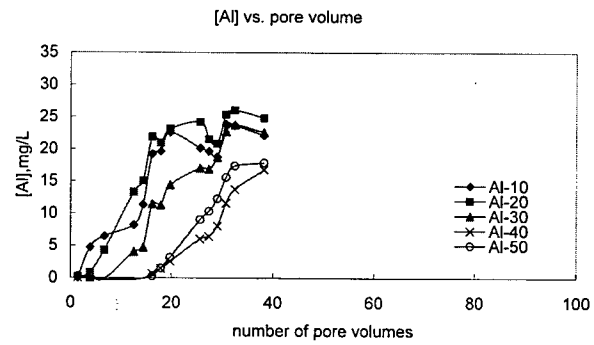

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

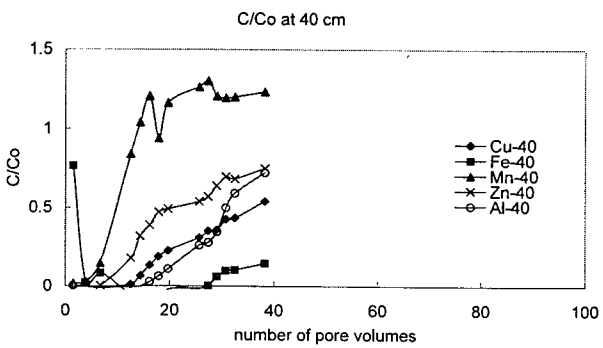

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

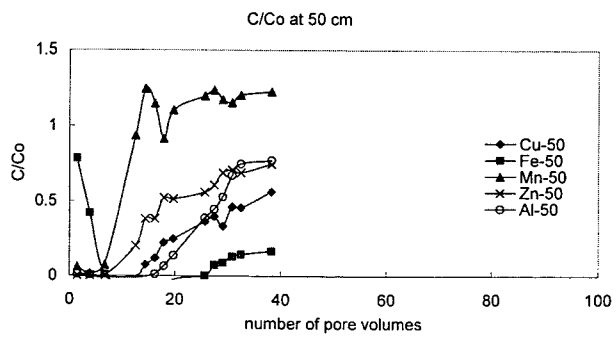

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
number of pore volumes
pH
pe-50


[Zn] vs. pore volume
[Zn], mg/L
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
35
30
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID PTB5

wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.52037 m/day

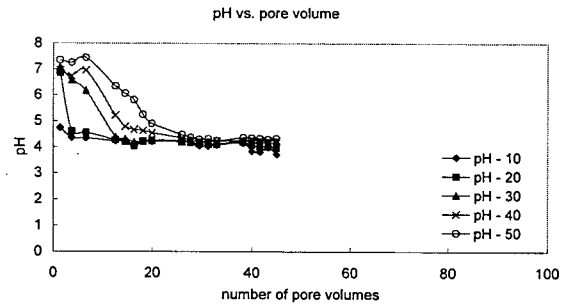
initial concentration of metals, Co

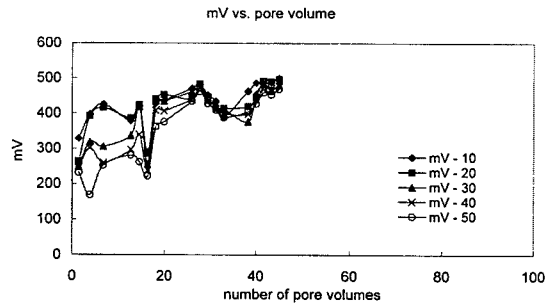
[Cu]o	37.991	mg/L
[Fe]o	0.323	mg/L
[Mn]o	3.475	mg/L
[Zn]o	19.2104	mg/L
[Al]o	23.17	mg/L
pH	3.27	
redox po:	560.5	mV
EC	2.31	mS/cm

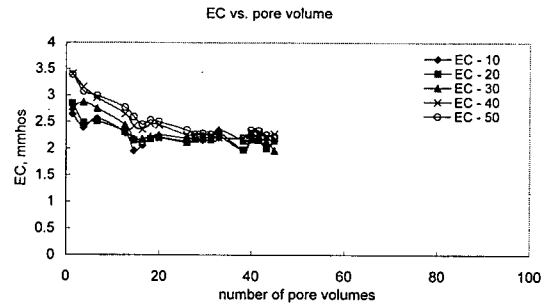
# of pore volumes passed through column:
44.92 pore volumes

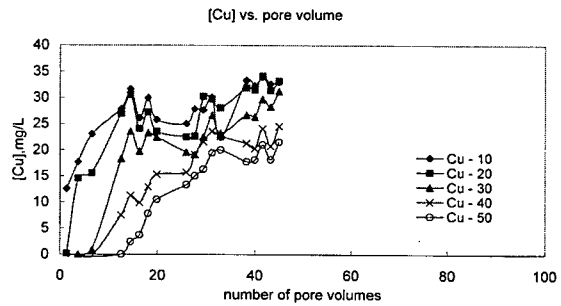
	Date	Time	vol effl (n	time used hh:mm:s	(min)	Flowrate L/day	m/day	pv/day	#pore vol	10cm pH	mV	EC	Cu	Fe	Mn	Zn	Al	20cm pH	mV	EC	Cu	Fe	Mn	Zn	Al	30cm pH
1	Apr 15, 2	9:00a	444.6	21:00:00	1260.00	0.50811	0.37929	1.56935	1.37318	4.74	328	2.64	12.58	-0.015	4.452	12.2909	3.26	6.85	264.1	2.85	0.178	0.022	2.242	1.8993	-0.01	7.09
2	Apr 16,2	9:00a	770.51	21:15:39	1275.65	0.86978	0.64926	2.68638	3.75297	4.36	396.8	2.39	17.666	-0.075	3.921	14.2965	13.4	4.6	392.8	2.48	14.559	-0.014	4.506	13.4245	6.91	6.57
3	Apr 18,2	3:40p	930.44	74:49:25	3218.83	0.8325	0.62143	5.14246	6.6267	4.34	425.8	2.56	23.02	0.041	4.256	14.9209	15.73	4.56	415.7	2.51	15.564	0.007	4.561	12.1732	8.22	6.17
4	Apr 21,2	9:00a	1926.27	61:47:20	3707.33	0.7482	0.55851	2.31088	12.5761	4.23	377.9	2.29	27.896	0.079	4.11	17.8512	17.02	4.27	386.1	2.31	26.953	0.076	4.236	17.3602	17.11	4.39
5	Apr 22,2	9:32a	609.56	20:35:08	1235.13	0.71067	0.53049	2.19495	14.4588	4.25	420.3	1.953	31.643	0.085	3.863	17.6616	15.92	4.2	424.5	2.15	30.531	0.068	3.938	17.4402	16.13	4.31
6	Apr 23,2	9:05a	589.55	18:40:45	1120.75	0.75749	0.56544	2.33956	16.2797	4.1	288.2	2.06	26.112	0.076	4.009	16.1443	22.76	4.03	289.2	2.11	24.1	0.067	3.965	15.9766	22.55	4.19
7	Apr 24,2	8:50a	567.91	18:55:16	1135.27	0.72035	0.53772	2.22486	18.0337	4.2	427.1	2.18	29.991	0.091	3.936	17.4564	22.98	4.22	441	2.18	27.251	0.066	4.124	16.33	22.21	4.23
8	Apr 25,2	9:00a	596.9	19:55:16	1195.27	0.71912	0.5368	2.22105	19.8773	4.22	435.7	2.21	25.799	0.127	3.501	17.1897	23.19	4.26	452.9	2.2	23.522	0.094	3.484	15.8853	23.24	4.25
9	Apr 28,2	9:35a	1963.05	68:39:13	4119.22	0.68625	0.51226	2.11952	25.9403	4.23	471.2	2.13	25.032	0.126	3.888	16.5993	22.96	4.24	440.5	2.11	22.468	0.06	3.976	14.4743	23.54	4.2
10	Apr 29,2	9:30a	570.45	19:56:33	1196.55	0.68651	0.51246	2.12035	27.7022	4.18	483.7	2.17	27.85	0.153	3.808	16.4011	19.95	4.17	483.2	2.17	22.625	0.072	3.813	15.4951	19.25	4.25
11	Apr 30,2	8:45a	555.69	19:11:55	1151.92	0.69466	0.51854	2.14552	29.4185	4.05	452	2.16	27.633	0.164	4.039	17.7836	22.62	4.13	446.2	2.18	30.242	0.093	3.955	17.0797	23.93	4.2
12	May 1,20	9:20a	577.45	20:13:02	1213.03	0.68549	0.5117	2.11721	31.202	4.03	434.2	2.16	30.087	0.17	3.941	17.9071	26.19	4.09	414.9	2.16	29.748	0.088	3.886	17.2961	25.92	4.15
13	May 2,20	9:15a	561.03	19:46:52	1186.87	0.68069	0.50811	2.10235	32.9348	4.08	391.8	2.23	22.391	0.089	3.88	13.0929	16.59	4.1	413.8	2.3	28.081	0.091	4.181	15.5671	25.41	4.11
14	May 5,20	9:50a	1711.13	67:08:46	4028.77	0.61161	0.45654	1.889	38.2198	4.15	463	1.97	33.332	0.364	4.205	18.4026	26.06	4.19	418.9	1.971	31.878	0.13	4.054	17.9146	26.7	4.25
15	May 6,20	10:00a	557.77	20:15:05	1215.08	0.66102	0.49343	2.0416	39.9425	3.84	486.9	2.25	32.304	0.295	3.66	18.1811	26.32	4.08	447.1	2.17	31.474	0.12	3.803	17.661	27.16	4.18
16	May 7,20	9:10a	522.31	18:50:37	1130.62	0.66524	0.49658	2.05463	41.5557	3.82	486.8	2.2	33.977	0.4	4.148	16.9489	24.21	4.02	492	2.15	34.131	0.191	4.134	17.3257	25.77	4.19
17	May 8,20	8:50a	538.2	19:35:05	1175.08	0.65953	0.49232	2.03703	43.218	3.99	488	2.17	32.639	0.376	4.142	16.6272	31.89	4.02	489.4	1.995	31.405	0.193	4.143	17.3719	32.87	4.17
18	May 9,20	9:00a	550.13	20:17:14	1217.23	0.65081	0.48581	2.01008	**44.9171**	3.72	499.5	2.15	33.015	0.257	3.382	17.5356	28.4	3.97	497.5	2.14	33.159	0.178	3.554	18.3831	32.19	4.16

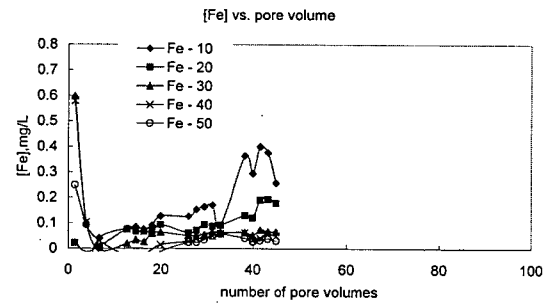
40cm								50cm																			
mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5	DO
249	2.78	-0.076	0.598	0.094	-0.0243	0.41	6.95	246.2	3.41	-0.071	0.58	0.056	-0.0386	0.44	7.34	231.8	3.39	-0.074	0.248	0.097	-0.0484	0.14	433.8	7.35254	14.6925	
318.2	2.87	-0.005	0.099	2.545	1.9433	0	6.74	301.9	3.16	-0.083	0.104	0.341	-0.027	0	7.25	168.5	3.07	-0.087	0.093	0.129	-0.0115	0.04	370.5	6.27966	13.5297	
305.9	2.75	0.866	-0.008	3.976	5.316	-0.09	6.95	259.8	2.95	-0.364	0.03	1.649	0.3343	-0.39	7.44	252.1	2.99	-0.425	-0.016	0.384	-0.1517	-0.33	454.1	7.69661	15.1366	
336.9	2.44	18.329	0.019	4.305	14.1973	8.21	5.21	296.1	2.65	7.572	-0.028	4.1	8.852	1.19	6.34	280.7	2.77	0.068	-0.03	3.291	4.3283	-0.22	482.7	8.18136	14.5214	
419	2.18	23.56	0.034	4.221	16.2926	11.25	4.79	339.5	2.42	11.241	-0.017	3.921	10.867	3.26	6.06	261.7	2.59	2.407	-0.035	3.6	7.1108	-0.06	463.7	7.85932	13.9193	
254.7	2.18	19.714	0.027	3.956	13.8597	17.61	4.67	238.1	2.36	9.899	-0.025	3.516	8.6126	4.59	5.81	221.9	2.45	3.732	-0.04	3.618	6.9078	0.27	423.9	7.18475	12.9947	
439.4	2.22	23.259	0.06	4.075	14.9156	19.1	4.63	408.5	2.46	12.896	-0.004	4.204	9.9764	6.52	5.24	361.7	2.53	7.804	-0.043	4.13	8.4689	1.65	563.7	9.55424	14.7942	
434.3	2.25	22.425	0.064	3.518	16.3082	20.01	4.54	406.8	2.44	15.265	0.015	3.539	11.3747	9.75	4.9	375.5	2.5	10.487	-0.012	3.831	10.4865	3.63	577.5	9.78814	14.6881	
461.7	2.19	19.548	0.05	4.004	13.1708	20.42	4.35	440.2	2.25	15.704	0.028	4.113	11.3767	15.2	4.47	434.3	2.34	13.337	0.024	4.13	10.6098	10.16	636.3	10.7847	15.2547	
475.3	2.19	19.114	0.052	3.755	14.2567	16.55	4.26	473.3	2.26	19.07	0.038	3.893	14.0571	14.39	4.36	462.3	2.26	15.015	0.024	3.932	12.1805	10.47	664.3	11.2593	15.6193	
444.7	2.24	22.438	0.055	3.898	16.8197	20.49	4.22	434.2	2.25	21.534	0.045	3.876	14.7683	17.89	4.29	428.1	2.28	16.279	0.034	4.059	13.1441	13.56	630.1	10.6797	14.9697	
417.2	2.19	26.632	0.066	3.86	15.8119	22.75	4.19	423.5	2.25	23.517	0.049	4.05	15.0192	19.29	4.31	409.7	2.26	19.414	0.049	3.843	14.0966	17.15	611.7	10.3678	14.6778	
411.3	2.35	23.174	0.063	3.981	14.2142	21.31	4.23	399.1	2.2	22.607	0.059	4.116	14.6056	21.22	4.24	388.2	2.21	19.986	0.057	4.149	13.7607	18.82	590.2	10.0034	14.2434	
376	2.15	26.678	0.063	4.071	16.3746	22.04	4.26	398.5	2.2	21.237	0.062	4.296	14.2177	16.23	4.36	404.7	2.19	17.763	0.04	4.099	13.1461	13.9	606.7	10.2831	14.6431	
455.4	2.17	26.345	0.052	4.122	15.6438	22.16	4.29	437.6	2.32	20.248	0.032	3.906	13.8719	15.29	4.34	427.1	2.34	18.106	0.027	4.213	12.6612	14.66	629.1	10.6627	15.0027	
483.5	2.17	29.684	0.074	4.279	15.0585	21.73	4.25	467.6	2.3	24.058	0.041	4.371	13.534	15.86	4.32	459.5	2.33	20.982	0.031	4.253	12.4676	13.46	661.5	11.2119	15.5319	
466.5	2.14	28.274	0.066	4.1	16.1821	27.31	4.24	470.2	2.22	20.789	0.053	4.097	14.8507	20.11	4.29	453.8	2.25	18.149	0.038	4.103	14.164	17.8	655.8	11.1153	15.4053	
481.2	1.962	31.213	0.066	3.541	16.8292	30.33	4.25	475.7	2.27	24.538	0.05	3.515	14.3193	23.22	4.32	469	2.22	21.489	0.03	3.63	13.1041	20.2	671	11.3729	15.6929	

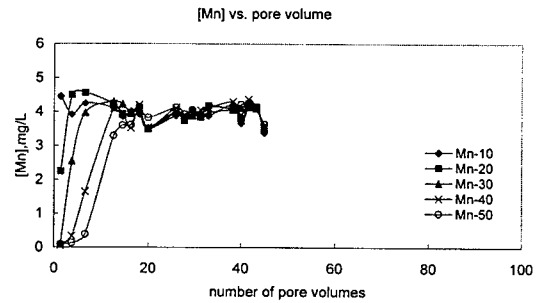

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

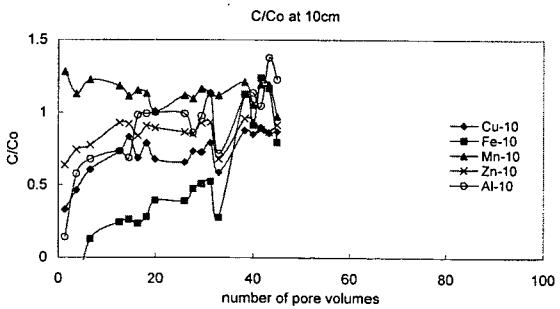

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

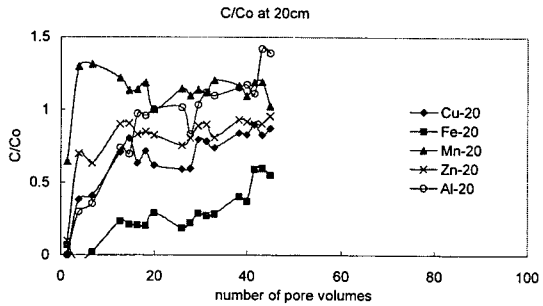

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

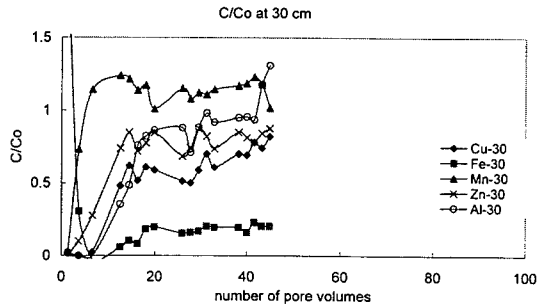

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

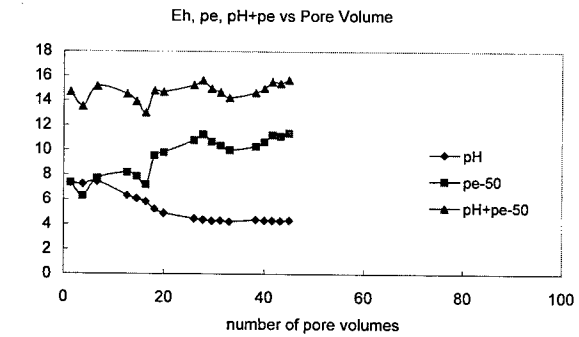

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

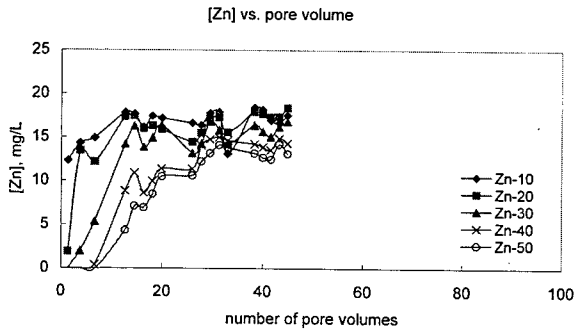

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

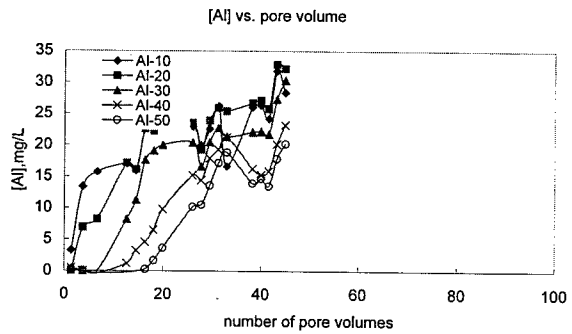

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

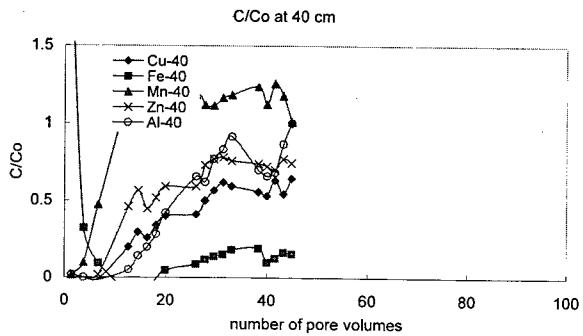

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

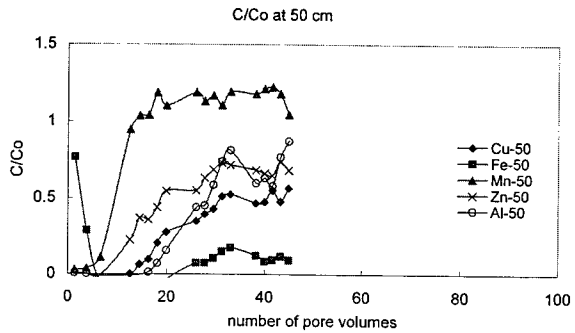

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
number of pore volumes
pH
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
35
30
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID CPA4

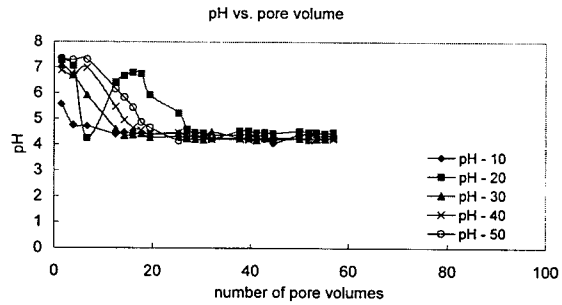
wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.50956 m/day

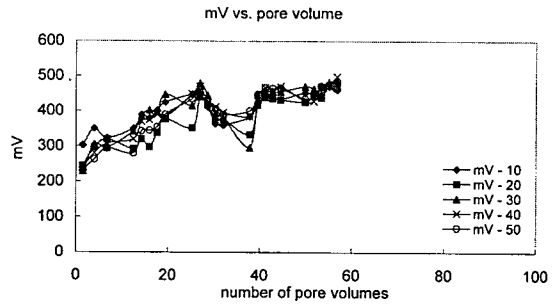
initial concentration of metals, Co		
[Cu]o	37.991	mg/L
[Fe]o	0.323	mg/L
[Mn]o	3.475	mg/L
[Zn]o	19.2104	mg/L
[Al]o	23.17	mg/L
pH	3.27	
redox pot	560.5	mV
EC	2.31	mS/cm

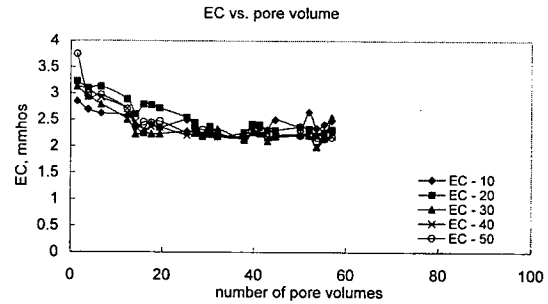
# of pore volumes passed through column:
56.84 pore volumes

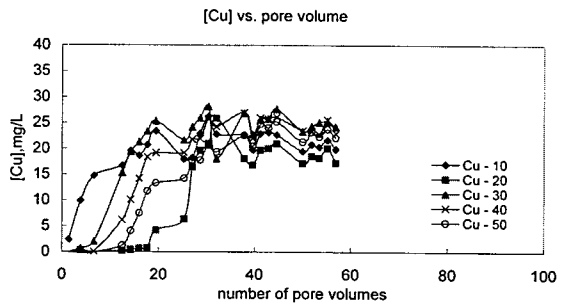
	Date	Time	time used vol effl (n	hh:mm:s:	(min)	Flowrate L/day	m/day	pv/day	#pore vol	10cm pH	mV	EC	Cu	Fe	Mn	Zn	Al	20cm pH	mV	EC	Cu	Fe	Mn	Zn	Al	30cm pH
1	Apr 15, 2	9:00a	463.83	21:00:00	1260.00	0.53009	0.3957	1.63723	1.43258	5.56	302.3	2.85	2.36	-0.018	1.862	4.0129	0.06	7.29	244.3	3.23	-0.036	0.328	0.285	0.098	0.18	7.11
2	Apr 16,2	9:00a	782.16	21:15:39	1275.65	0.88293	0.65908	2.727	3.84834	4.75	349.8	2.69	9.893	-0.055	3.515	9.3322	4.12	7.07	296.1	3.1	0.318	0.088	0.55	0.8085	0.05	6.71
3	Apr 18,2	3:40p	899.5	74:49:25	3218.83	0.80481	0.60077	4.97146	6.62652	4.71	322.7	2.62	14.742	0.012	4.049	9.8497	7.81	4.25	319.1	3.13	-0.032	0.027	0.259	0.0108	-0.57	5.92
4	Apr 21,2	9:00a	1866.93	61:47:20	3707.33	0.72515	0.5413	2.23969	12.3927	4.4	350.9	2.57	16.748	0.001	3.664	12.6102	8.12	6.42	291.8	2.89	0.201	-0.017	1.651	2.0921	-0.21	4.61
5	Apr 22,2	9:32a	574.97	20:35:08	1235.13	0.67034	0.50038	2.07039	14.1685	4.48	389.9	2.36	19.573	0.037	3.696	12.6771	9.41	6.67	320.4	2.6	0.428	-0.022	1.951	2.5985	-0.13	4.36
6	Apr 23,2	9:05a	571.41	18:40:45	1120.75	0.73418	0.54804	2.26757	15.9334	4.42	380.6	2.26	18.647	0.034	3.479	12.2927	15.26	6.81	297.6	2.79	0.678	-0.026	1.776	2.1963	0.19	4.37
7	Apr 24,2	8:50a	549.49	18:55:16	1135.27	0.69699	0.52028	2.1527	17.6305	4.44	401.4	2.41	20.769	0.017	3.762	13.6941	14.46	6.76	337.9	2.78	0.799	-0.039	2.003	2.7435	-0.01	4.43
8	Apr 25,2	9:00a	572.6	19:55:16	1195.27	0.68984	0.51494	2.13063	19.399	4.4	424.8	2.35	23.416	0.036	3.704	15.4936	16.47	5.92	377.5	2.72	4.217	-0.047	2.225	4.6107	0.17	4.27
9	Apr 28,2	9:35a	1898.83	68:39:13	4119.22	0.66379	0.4955	2.05018	25.2637	4.43	448.8	2.5	17.963	0.041	3.401	12.8257	19.09	5.23	352.3	2.54	6.385	0.001	2.199	5.4777	1.39	4.31
10	Apr 29,2	9:30a	551.71	19:56:33	1196.55	0.66396	0.49562	2.0507	26.9677	4.41	454.1	2.37	18.264	0.032	3.598	13.2317	15.46	4.59	440.1	2.44	16.417	0.01	3.009	10.8696	8.98	4.24
11	Apr 30,2	8:45a	535.2	19:11:55	1151.92	0.66905	0.49942	2.06641	28.6207	4.3	412	2.18	22.96	0.044	3.825	15.251	14.53	4.46	417.9	2.18	19.597	0.035	3.385	12.5329	11.89	4.21
12	May 1,20	9:20a	554.7	20:13:02	1213.03	0.65849	0.49154	2.03379	30.334	4.34	364	2.27	26.233	0.037	4.2	13.9745	18.97	4.44	376.4	2.37	20.96	0.024	3.668	11.4024	15.6	4.2
13	May 2,20	9:15a	538.48	19:46:52	1186.87	0.65333	0.48769	2.01785	31.9971	4.37	360.5	2.18	22.841	0.041	4.077	14.0257	16.42	4.23	375.7	2.19	25.916	0.063	4.031	15.4425	21.59	4.49
14	May 5,20	9:50a	1873	67:08:46	4028.77	0.66947	0.49973	2.0677	37.782	4.38	384.7	2.21	22.55	0.037	4.091	13.6823	15.62	4.53	332.9	2.26	18.058	0.029	3.647	11.657	13.17	4.25
15	May 6,20	10:00a	567.53	20:15:05	1215.08	0.67258	0.50206	2.07732	39.5349	4.4	438.4	2.39	19.775	0.01	3.417	12.3505	15.16	4.53	417.2	2.42	16.812	-0.007	3.173	10.4408	12.57	4.27
16	May 7,20	9:10a	529.02	18:50:37	1130.62	0.67378	0.50296	2.08103	41.1688	4.33	447.4	2.38	22.887	0.034	3.933	13.5017	14.45	4.46	438.5	2.4	19.672	0.023	3.666	12.5141	12.57	4.19
17	May 8,20	8:50a	545.72	19:35:05	1175.08	0.66875	0.4992	2.06549	42.8543	4.34	437.3	2.31	23.12	0.024	4.152	13.6211	17.33	4.48	436	2.29	20.016	0.023	3.808	12.2454	15.08	4.26
18	May 9,20	9:00a	555.02	20:17:14	1217.23	0.65659	0.49013	2.02795	44.5685	4.06	433.9	2.5	22.674	0.037	3.709	13.6067	16.48	4.44	432.2	2.3	20.936	0.029	3.482	12.614	15.19	4.21
19	May 12,2	8:25a	1736.83	66:52:30	4012.50	0.62331	0.46528	1.92515	49.9329	4.39	452.4	2.38	19.479	0.003	3.771	13.1184	16.15	4.52	426	2.36	17.161	0.002	3.643	11.7698	14.17	4.24
20	May 13,2	11:00a	613.91	22:19:47	1339.78	0.65983	0.49254	2.03794	51.829	4.39	449.7	2.65	20.796	0.036	4.045	13.5017	16.75	4.48	443.9	2.33	18.527	0.023	3.872	12.2414	13.92	4.23
21	May 14,2	9:05a	514.55	18:15:24	1095.4	0.67642	0.50493	2.08918	53.4182	4.34	467.7	2.34	20.318	-0.011	3.8	13.4542	20.33	4.47	438.3	2.2	18.199	-0.014	3.677	11.7109	17.77	4.23
22	May 15,2	8:55a	552.67	19:25:12	1165.2	0.68301	0.50984	2.10954	55.1252	4.34	470.8	2.41	21.66	0.026	4.373	14.5391	19.07	4.42	472.7	2.26	20.063	0.019	4.36	13.4495	17	4.23
23	May 16,2	9:15a	555.42	19:47:06	1187.1	0.67375	0.50293	2.08092	**56.8406**	4.35	462.1	2.48	19.884	0.005	3.575	12.5737	17.33	4.48	466.2	2.31	17.272	-0.007	3.393	11.392	15.11	4.29

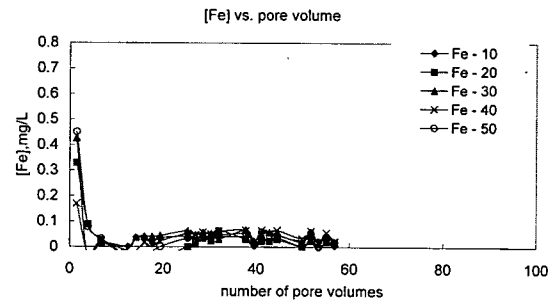
							40cm																					50cm										
mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5	DO
229.8	3.13	-0.079	0.426	0.156	-0.0131	0.23	6.88	241.2	3.14	-0.049	0.17	0.104	-0.0425	0.05	7.35	230.1	3.75	-0.053	0.45	0.101	-0.0224	0.14	432.1	7.32373	14.6737	
304.9	2.94	0.705	-0.067	2.02	2.3325	0.02	6.67	279.5	3.07	-0.078	-0.027	0.272	-0.0057	-0.1	7.29	261.9	2.95	-0.089	0.078	0.052	-0.024	-0.03	463.9	7.86271	15.1527	
295.9	2.79	1.981	-0.03	3.709	4.7275	-0.42	6.99	307.8	2.92	0.093	0.018	2.009	0.4928	-0.65	7.31	293.8	2.97	-0.055	0.033	0.827	-0.0263	-0.71	495.8	8.40339	15.7134	
342.9	2.5	15.334	-0.008	4.186	13.1053	6.32	5.47	319.9	2.71	6.21	-0.043	4.56	10.7921	0.92	6.16	280	2.7	1.253	-0.04	3.559	6.425	-0.2	482	8.16949	14.3295	
387	2.23	19.425	0.037	3.967	13.2384	10.36	4.95	369.9	2.46	10.182	-0.017	4.07	10.3943	2.47	5.83	342.7	2.37	4.063	-0.039	3.623	7.3633	0.3	544.7	9.2322	15.0622	
403.1	2.26	21.328	0.042	4.116	14.6973	18.14	4.65	375.8	2.32	14.191	0.015	4.435	12.021	6.16	5.44	344.8	2.45	7.498	-0.031	4.178	9.2264	1.83	546.8	9.2678	14.7078	
397.6	2.23	23.381	0.04	4.268	16.2618	18.16	4.56	389.9	2.37	18.372	-0.001	4.698	14.125	9.53	4.86	354.6	2.44	11.752	-0.019	4.163	11.0669	3.67	556.6	9.4339	14.2939	
448	2.23	25.317	0.044	3.999	16.9738	20.26	4.41	381.7	2.36	19.182	0.022	3.865	14.0881	12.47	4.66	390	2.47	13.346	0.001	3.818	11.7439	6.04	592	10.0339	14.6939	
416	2.28	21.654	0.063	3.786	16.2457	27.17	4.46	448.3	2.21	19.238	0.053	3.677	14.143	22.03	4.15	435.3	2.26	14.224	0.035	3.725	12.0797	14.4	637.3	10.8017	14.9517	
479.6	2.25	24.16	0.047	3.792	16.0731	18.39	4.23	470.3	2.26	21.791	0.048	3.864	14.427	15.8	4.32	462.2	2.33	17.629	0.032	3.962	12.6493	11.55	664.2	11.2576	15.5776	
444.1	2.21	25.948	0.058	4.102	15.738	20.03	4.23	425.6	2.24	21.953	0.058	4.24	14.5871	17.1	4.3	429.8	2.31	17.765	0.036	4.173	12.8418	13.24	631.8	10.7085	15.0085	
396.1	2.23	28.177	0.052	4.344	14.8647	25.63	4.2	411.9	2.23	25.762	0.049	4.156	14.4453	24.16	4.28	405.9	2.29	20.678	0.042	4.186	12.8826	18.95	607.9	10.3034	14.5834	
381.2	2.33	18.069	0.032	3.548	11.5927	13.54	4.21	396.3	2.18	24.241	0.06	4.105	14.9878	21.45	4.27	390.4	2.24	19.353	0.046	4.291	13.3001	17.31	592.4	10.0407	14.3107	
296.3	2.12	26.862	0.066	4.2	15.6798	22.22	4.21	384.7	2.15	26.943	0.066	4.371	15.4602	22.42	4.24	400.4	2.15	22.594	0.052	4.15	14.1737	20.11	602.4	10.2102	14.4502	
446.2	2.27	22.747	0.024	3.507	13.4294	20.03	4.2	433.9	2.29	22.015	0.021	3.51	13.0237	20.26	4.24	447.4	2.28	20.464	0.017	3.535	12.3246	18.31	649.4	11.0068	15.2468	
455.3	2.25	25.682	0.051	3.763	14.9405	19.32	4.16	467.2	2.28	25.951	0.066	3.933	14.4859	18.52	4.2	466.7	2.26	24.768	0.059	4.21	14.0219	17.88	668.7	11.3339	15.5339	
454.7	2.1	25.763	0.057	3.973	14.7789	25.46	4.24	457.1	2.17	25.752	0.054	4.321	14.4915	24.08	4.22	464.9	2.19	24.006	0.046	4.316	14.112	23.31	666.9	11.3034	15.5234	
455.5	2.2	27.665	0.049	3.499	14.4492	21.06	4.18	470.3	2.18	26.09	0.065	3.626	14.6006	24.07	4.27	465.3	2.18	25.199	0.044	3.38	14.2294	22.11	667.3	11.3102	15.5802	
470.1	2.23	23.34	0.02	3.625	14.7926	26.4	4.24	428.8	2.23	23.467	0.033	3.697	14.3586	26.57	4.24	435.6	2.2	21.311	0.025	3.637	13.9077	26.28	637.6	10.8068	15.0468	
463.5	2.21	24.349	0.058	4.077	14.6483	22.17	4.19	428.4	2.23	23.264	0.062	3.895	14.4963	19.64	4.19	443.2	2.2	23.233	0.052	4.117	14.2382	18.2	645.2	10.9356	15.1256	
448.6	1.989	25.088	0.013	3.752	14.1816	27.35	4.21	467.5	1.998	22.703	0.02	3.768	13.931	28.79	4.23	471.5	2.1	22.292	0.019	3.917	13.2828	28.25	673.5	11.4153	15.6453	
483.1	2.16	25.268	0.043	4.267	15.9004	26.66	4.24	472	2.15	25.518	0.055	4.342	15.7195	27.48	4.23	475.4	2.14	23.737	0.038	4.416	15.3306	25.44	677.4	11.4814	15.7114	
485.1	2.55	24.249	0.021	3.593	13.8961	24.37	4.23	498.8	2.19	22.91	0.021	3.373	13.7244	23.7	4.29	486.4	2.17	22.088	0.018	3.414	12.8198	22.99	688.4	11.6678	15.9578	

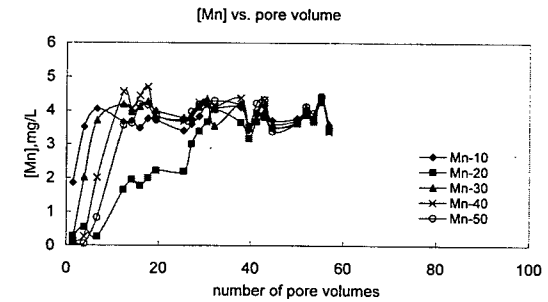

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

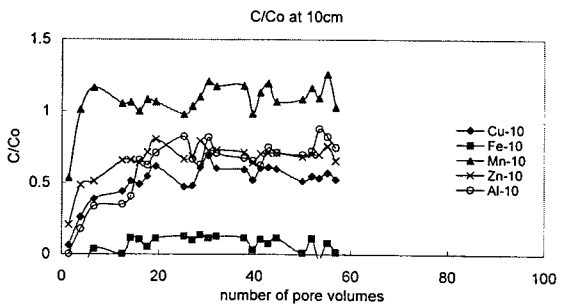

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

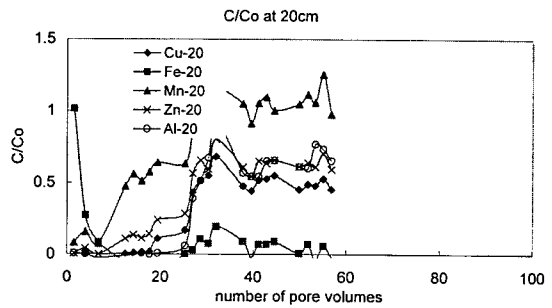

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

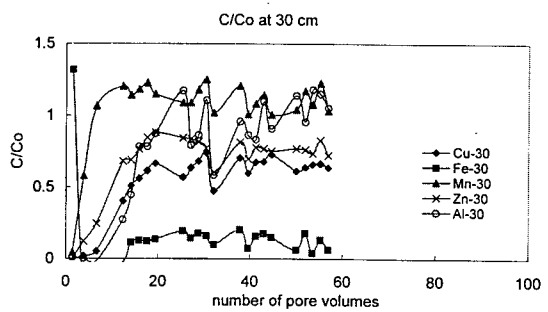

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

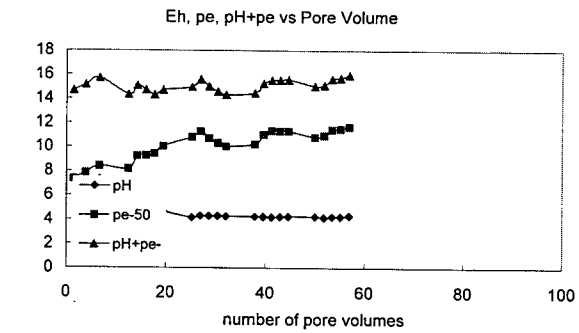

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

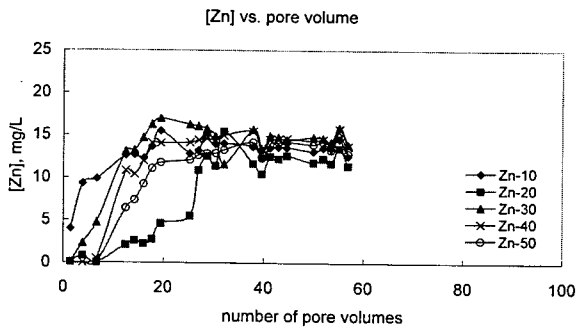

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

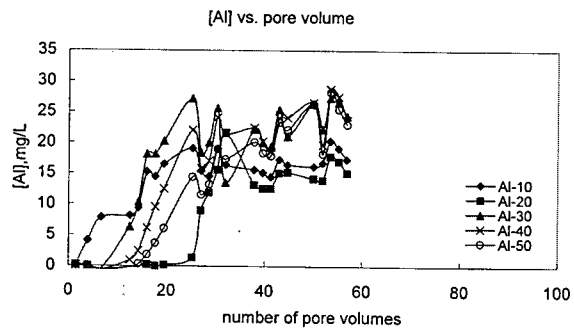

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

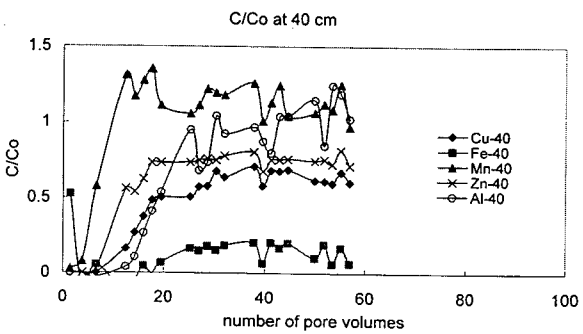

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

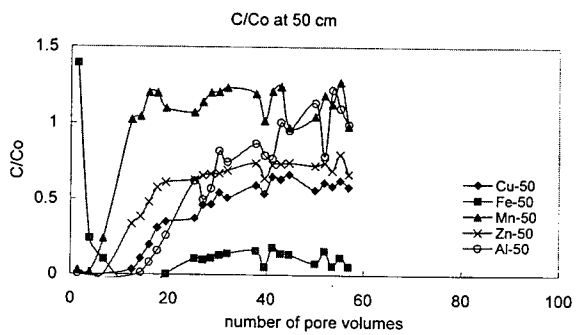

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
pH
pe-50
pH+pe-
number of pore volumes


[Zn] vs. pore volume
[Zn], mg/L
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50
number of pore volumes


[Al] vs. pore volume
[Al],mg/L
Al-10
Al-20
Al-30
Al-40
Al-50
number of pore volumes


C/Co at 40 cm
C/Co
Cu-40
Fe-40
Mn-40
Zn-40
Al-40
number of pore volumes


C/Co at 50 cm
C/Co
Cu-50
Fe-50
Mn-50
Zn-50
Al-50
number of pore volumes

Cell ID CPA3

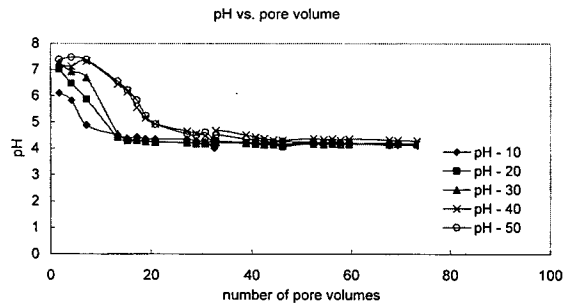
wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.52396 m/day

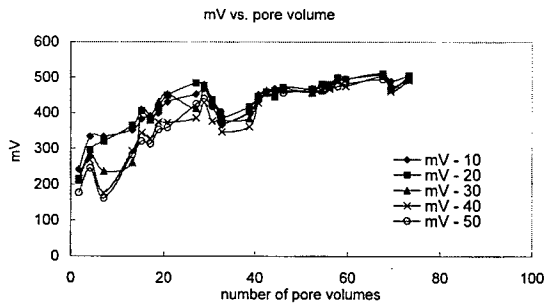
initial concentration of metals, Co		
[Cu]o	37.991	mg/L
[Fe]o	0.323	mg/L
[Mn]o	3.475	mg/L
[Zn]o	19.2104	mg/L
[Al]o	23.17	mg/L
pH	3.27	
redox pot	560.5	mV
EC	2.31	mS/cm

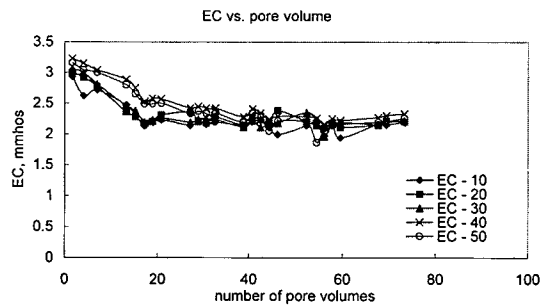
# of pore volumes passed through column:
73.27 pore volumes

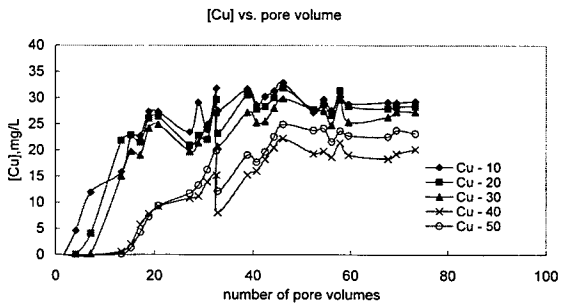
			time used		Flowrate				10cm									20cm								30cm
	Date	Time	vol effl (n	hh:mm:s	(min)	L/day	m/day	pv/day	#pore vol	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH
1	Apr 15, 2	9:00a	545.44	21:00:00	1260.00	0.62336	0.46532	1.9253	1.68464	6.1	241.2	2.93	-0.089	0.087	0.784	0.0231	0.03	7.01	215.4	3	-0.092	0.316	0.217	-0.0424	0.14	7.25
2	Apr 16,2	9:00a	783.89	21:15:39	1275.65	0.88488	0.66054	2.73303	4.10574	5.83	334.3	2.62	4.607	-0.031	4.541	10.114	0.37	6.47	296.5	2.92	0.039	0.023	2.513	2.3075	-0.01	6.92
3	Apr 18,2	3:40p	967.87	74:49:25	3218.83	0.86599	0.64643	5.34934	7.09509	4.88	334.1	2.71	11.929	0.002	4.596	10.2986	4.21	5.87	320.7	2.77	4.081	-0.008	4.562	7.4891	0.19	6.7
4	Apr 21,2	9:00a	2008.23	61:47:20	3707.33	0.78004	0.58227	2.4092	13.2977	4.5	352	2.47	15.804	0.022	3.968	11.4398	7.4	4.41	365.2	2.36	21.858	0.043	4.394	18.5196	11.64	4.55
5	Apr 22,2	9:32a	635.95	20:35:08	1235.13	0.74143	0.55345	2.28997	15.2619	4.39	383	2.3	22.818	0.035	3.898	13.4832	11.29	4.28	406	2.28	22.829	0.049	3.921	14.911	13.5	4.33
6	Apr 23,2	9:05a	613.33	18:40:45	1120.75	0.78804	0.58824	2.43392	17.1562	4.43	391.1	2.13	22.696	0.042	4.178	15.9975	20.24	4.28	378.7	2.17	21.477	0.069	4.389	16.0385	21.35	4.34
7	Apr 24,2	8:50a	563.07	18:55:16	1135.27	0.71421	0.53313	2.2059	18.8953	4.35	399.4	2.19	27.352	0.021	3.955	17.5045	18.88	4.26	414.7	2.2	26.101	0.049	4.378	17.2683	20.05	4.26
8	Apr 25,2	9:00a	615.04	19:55:16	1195.27	0.74097	0.55311	2.28855	20.7949	4.35	431	2.23	27.306	0.043	4.147	19.3332	21.54	4.26	448.8	2.31	26.44	0.06	4.177	19.3696	21.67	4.23
9	Apr 28,2	9:35a	2036.89	68:39:13	4119.22	0.71206	0.53153	2.19925	27.086	4.34	452.9	2.14	23.444	0.049	3.817	15.5548	28.37	4.2	484.4	2.35	20.868	0.067	3.927	14.9158	26.52	4.22
10	Apr 29,2	9:30a	584.22	19:56:33	1196.55	0.70309	0.52483	2.17154	28.8904	4.29	468.2	2.22	29.087	0.037	4.047	16.8397	20.89	4.19	477.5	2.2	22.807	0.041	3.991	15.6628	19.94	4.18
11	Apr 30,2	8:45a	573.49	19:11:55	1151.917	0.71691	0.53515	2.21425	30.6616	4.24	419.8	2.16	23.935	0.049	4.276	15.7152	20.86	4.19	437.6	2.18	21.977	0.056	4.097	14.7996	19.39	4.17
12	May 1,20	9:20a	593.92	20:13:02	1213.033	0.70505	0.52629	2.17759	32.496	4.01	373.3	2.2	31.78	0.052	4.374	16.9733	25.93	4.15	393.6	2.27	29.665	0.059	4.364	16.4046	25.06	4.32
13	May 2,20	9:15a	86.19	19:46:52	1186.867	0.10457	0.07806	0.32298	32.7622	4.25	366.9	2.2	27.537	0.055	4.582	16.5916	22.38	4.25	384.1	2.28	23.192	0.057	4.216	14.396	18.95	4.23
14	May 5,20	9:50a	1964.65	67:08:46	4028.77	0.70222	0.52419	2.16887	38.8302	4.22	400.9	2.14	31.644	0.058	4.182	17.9093	25.75	4.2	417.7	2.15	30.551	0.065	4.501	17.6444	25.95	4.19
15	May 6,20	10:00a	611.02	20:15:05	1215.083	0.72412	0.54053	2.23651	40.7174	4.22	451.6	2.2	28.606	0.018	3.643	15.3094	24.13	4.15	445.8	2.27	27.823	0.023	3.753	15.1298	24.01	4.17
16	May 7,20	9:10a	567.38	18:50:37	1130.617	0.72264	0.53943	2.23193	42.4698	4.17	460.7	2.23	30.205	0.073	4.038	17.5319	22.77	4.15	458.5	2.23	28.373	0.065	3.786	16.955	24.11	4.14
17	May 8,20	8:50a	585.38	19:35:05	1175.083	0.71735	0.53548	2.2156	44.2778	4.2	467.8	2.12	31.322	0.05	4.251	17.5607	28.51	4.17	445	2.18	30.014	0.071	4.042	17.6388	29.34	4.15
18	May 9,20	9:00a	596.34	20:17:14	1217.233	0.70548	0.52661	2.17892	46.1196	4.17	463.4	1.992	32.884	0.037	3.867	17.1557	25.55	4.07	471.7	2.38	31.853	0.034	3.752	16.9061	26.74	4.15
19	May 12,2	8:25a	1998.76	66:52:30	4012.50	0.71731	0.53545	2.21548	52.2929	4.22	460.6	2.14	27.226	0.032	3.687	16.5504	27.59	4.22	467.5	2.2	27.788	0.034	3.896	16.8987	28.74	4.16
20	May 13,2	11:00a	683.97	22:19:47	1339.783	0.73513	0.54875	2.27051	54.4054	4.2	480.5	2.22	29.674	0.079	4.166	16.7449	30.44	4.16	480.8	2.14	28.682	0.062	4.069	16.1974	28.14	4.15
21	May 14,2	9:05a	533.32	18:15:24	1095.4	0.7011	0.52334	2.16539	56.0526	4.23	476.9	1.971	27.579	0.034	3.781	16.2045	26.22	4.18	480.2	2.1	26.67	0.015	3.58	15.8235	28.18	4.17
22	May 15,2	8:55a	560.62	19:25:12	1165.2	0.69284	0.51718	2.13988	57.7842	4.16	494.8	2.14	30.218	0.069	4.52	17.5524	26.3	4.15	498.8	2.18	31.388	0.053	4.396	17.2701	27.68	4.15
23	May 16,2	9:15a	569.54	19:47:06	1187.1	0.69087	0.51571	2.13382	59.5432	4.2	496.1	1.939	28.772	0.041	3.789	15.8618	26.37	4.18	494.5	2.11	28.38	0.021	3.61	15.5481	28.99	4.16
24	May 20,2	9:00a	2618.97	91:50:20	5510.33	0.68441	0.51089	2.11385	67.6321	4.12	506.7	2.16	29.097	0.087	3.925	16.2626	24.52	4.14	510.8	2.15	27.881	0.048	3.688	15.5289	24.79	4.16
25	May 21,2	9:10a	563.94	19:41:13	1181.217	0.68749	0.51319	2.12337	69.3739	4.13	489.3	2.15	29.042	0.103	3.937	17.0923	24.03	4.16	464.7	2.21	28.271	0.06	3.76	17.1953	24.39	4.18
26	May 23,2	9:45a	1262.37	44:00:32	2640.53	0.68843	0.51389	2.12626	**73.2728**	4.11	504.4	2.19	29.273	0.092	4.01	15.8063	23.02	4.13	505.6	2.2	28.36	0.065	3.594	15.248	25.24	4.15

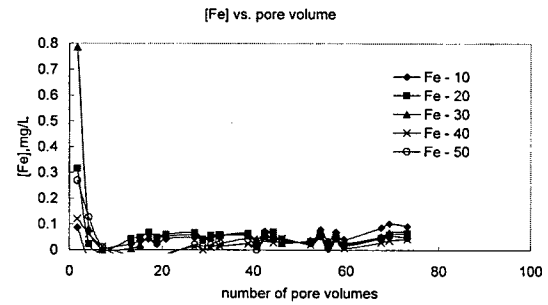
							40cm								50cm											
mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5	DO
212.1	3.06	-0.082	0.786	0.081	-0.0034	0.51	7.21	215.7	3.23	-0.077	0.121	0.098	-0.0431	0.03	7.38	176.5	3.16	-0.077	0.269	0.077	-0.0165	0.1	378.5	6.41525	13.7953	
283.3	3	-0.092	0.082	0.941	0.195	0.08	7.12	268.7	3.15	-0.09	0.062	0.095	-0.022	0.03	7.47	245.5	3.04	-0.08	0.127	0.079	-0.0021	0.02	447.5	7.58475	15.0547	
236.7	2.81	0.213	0.002	3.276	2.4235	-0.59	7.33	176.5	3.04	-0.06	0.014	0.645	-0.0839	-0.66	7.38	161.1	3	-0.078	0.011	0.298	-0.0729	-0.7	363.1	6.15424	13.5342	
261	2.46	15.075	0.005	4.724	15.887	5.92	6.45	293.9	2.89	0.577	-0.023	2.353	3.6334	-0.15	6.55	283.7	2.8	0.106	-0.036	2.635	3.4436	-0.23	485.7	8.2322	14.7822	
409.5	2.38	19.808	0.019	4.275	14.2273	10.31	6.16	344	2.75	2.051	-0.023	2.558	4.4291	0.07	6.21	320.8	2.65	1.326	-0.034	3.155	4.6655	-0.02	522.8	8.86102	15.071	
391.5	2.2	19.011	0.052	4.306	14.7824	17.7	5.54	327.8	2.53	5.764	-0.021	3.214	6.5277	1.17	5.83	312.8	2.49	4.264	-0.03	3.358	6.4892	0.59	514.8	8.72542	14.5554	
431.1	2.23	24.145	0.046	4.451	16.6447	18.21	5.15	373.6	2.58	7.696	-0.051	3.431	8.0396	1.88	5.24	352.8	2.49	7.196	-0.028	4.448	9.0463	1.68	554.8	9.40339	14.6434	
452.6	2.26	24.924	0.053	4.172	18.5102	20.98	4.92	372.3	2.57	9.168	-0.017	3.294	9.0773	3	4.91	358.5	2.5	9.307	-0.02	3.935	9.9112	3.02	560.5	9.5	14.41	
412.7	2.19	19.723	0.058	3.835	13.6135	24.25	4.65	385.8	2.42	10.77	0.013	3.272	8.6557	8.86	4.54	425.1	2.33	11.723	0.02	3.979	10.2768	11.43	627.1	10.6288	15.1688	
479.2	2.24	21.377	0.041	4.172	14.9843	19.23	4.57	428.5	2.45	11.158	0	3.38	9.5438	8.53	4.49	440.2	2.37	13.253	0.014	3.978	11.2121	10.97	642.2	10.8847	15.3747	
433.2	2.25	24.945	0.049	4.33	15.6579	20.45	4.48	376.7	2.42	13.915	0.01	3.761	10.1798	9.58	4.6	418.6	2.33	16.22	0.02	4.41	12.11	12.32	620.6	10.5186	15.1186	
403.1	2.22	27.201	0.056	4.252	15.4741	23.68	4.22	382	2.4	15.178	0.019	4.081	10.9793	12.44	4.31	402.7	2.26	19.811	0.034	4.589	13.1085	17.06	604.7	10.2492	14.5592	
380.5	2.24	20.681	0.058	4.314	13.5506	18.79	4.67	346.9	2.42	7.992	0.014	3.645	8.1445	5.7	4.51	369.5	2.34	12.102	0.025	4.596	11.5751	9.19	571.5	9.68644	14.1964	
384.6	2.11	27.239	0.056	4.237	16.2852	23.45	4.5	361.6	2.28	15.256	0.023	3.784	11.4676	12.16	4.35	402.4	2.19	19.02	0.042	4.419	13.5455	15.93	604.4	10.2441	14.5941	
448.5	2.22	25.284	0.042	3.738	14.3985	22.89	4.42	428.7	2.41	16.001	0.008	3.119	10.83	12.78	4.33	436.6	2.34	17.652	0.002	3.751	12.2738	14.79	638.6	10.8237	15.1537	
463.4	2.11	25.5	0.06	3.702	16.8393	23.31	4.37	455.3	2.34	18.269	0.044	3.453	13.3822	14.78	4.27	455.6	2.3	19.645	0.046	3.853	14.6647	16.67	657.6	11.1458	15.4158	
463.5	2.16	28.052	0.044	4.338	16.5943	28.74	4.31	463.3	2.24	20.457	0.029	3.83	13.6617	19.18	4.23	462.4	2.05	22.547	0.045	4.141	15.0363	24.66	664.4	11.261	15.491	
470.2	2.18	29.867	0.027	3.611	15.3779	23.08	4.31	462.6	2.29	22.189	0.045	3.413	13.1597	17.92	4.26	456.7	2.21	24.916	0.042	3.59	14.5387	21.7	658.7	11.1644	15.4244	
456.9	2.35	27.67	0.037	4.104	16.7358	30.1	4.37	458.3	2.28	19.328	0.021	3.622	12.7234	19.87	4.24	467.1	2.18	23.742	0.026	3.79	14.9743	25.73	669.1	11.3407	15.5807	
463.6	2.19	27.512	0.063	4.161	15.7242	27.3	4.33	469.3	2.26	19.733	0.051	3.846	12.3438	18.21	4.22	473.7	1.865	24.16	0.053	4.33	14.3795	23.98	675.7	11.4525	15.6725	
473.2	1.962	24.793	0.012	3.49	15.3547	27.56	4.36	467.3	2.16	18.655	-0.008	3.553	12.4219	20.34	4.24	473.1	2.1	21.557	0.014	3.809	13.8172	26.05	675.1	11.4424	15.6824	
500.5	2.16	29.635	0.053	4.4	16.5923	28.24	4.31	493.8	2.25	21.338	0.04	4.286	13.7357	19.84	4.21	474.5	2.15	23.631	0.045	4.535	15.6128	25.37	676.5	11.4661	15.6761	
495.9	2.19	25.352	0.026	3.686	14.915	28.26	4.36	475.5	2.22	19.07	0.007	3.226	11.7752	18.55	4.18	481.9	2.16	22.721	0.016	3.599	13.2704	23.78	683.9	11.5915	15.7715	
507.7	2.15	26.301	0.051	3.646	15.4922	25.38	4.32	502.3	2.27	18.324	0.029	3.449	12.4358	17.8	4.2	494.8	2.19	22.507	0.046	3.648	14.1141	20.51	696.8	11.8102	16.0102	
473	2.19	27.329	0.068	3.789	15.9438	24.56	4.3	459.5	2.3	19.234	0.037	3.701	12.9451	15.86	4.19	470.9	2.2	23.758	0.055	3.784	14.6478	21.1	672.9	11.4051	15.5951	
496.2	2.22	27.258	0.073	3.516	14.4017	26.98	4.28	491.4	2.33	20.075	0.042	3.426	11.7689	17.98	4.18	494.3	2.26	23.122	0.048	3.501	13.6373	23.09	696.3	11.8017	15.9817	

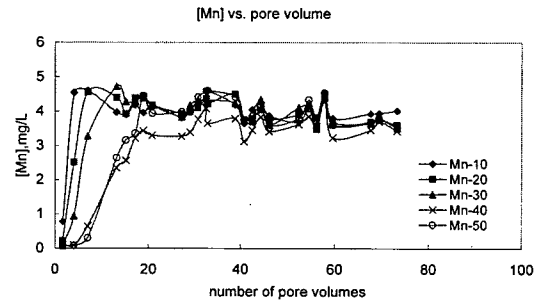

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

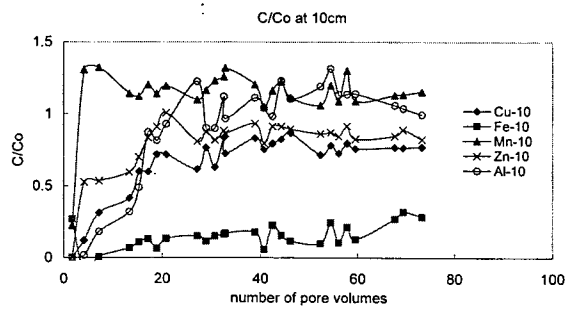

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

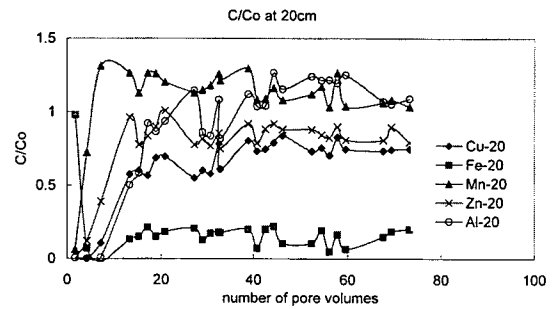

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

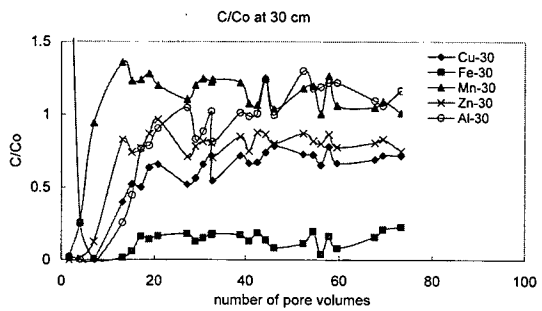

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

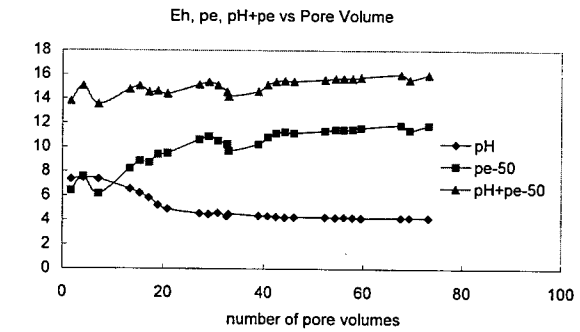

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

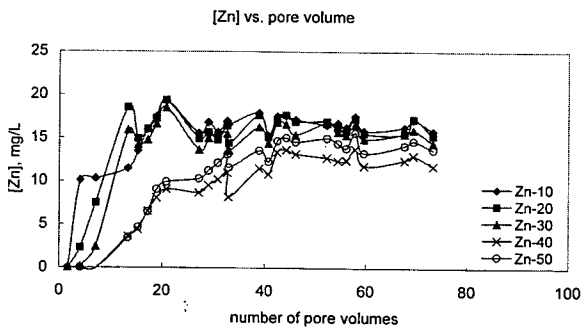

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

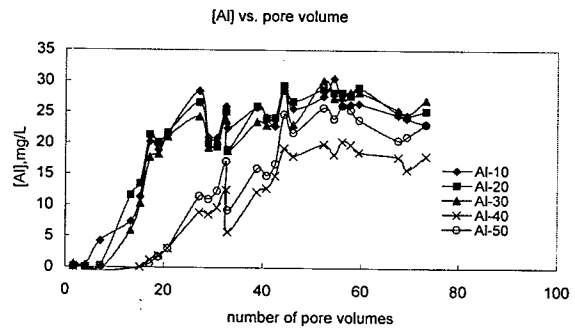

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

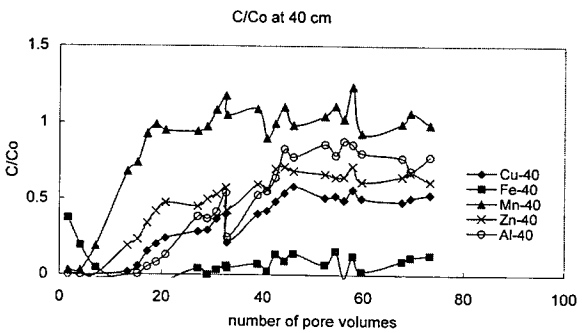

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

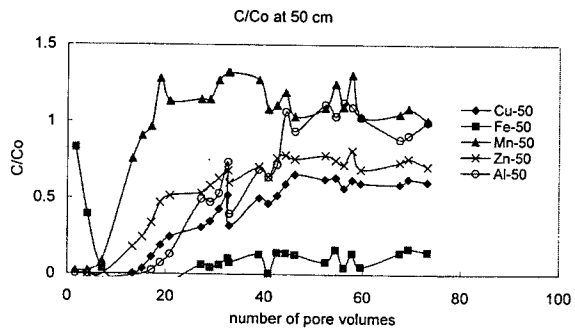

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
18
16
14
12
10
8
6
4
2
0
0
20
40
60
80
100
number of pore volumes
pH
pe-50
pH+pe-50


[Zn] vs. pore volume
[Zn], mg/L
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50


[Al] vs. pore volume
[Al],mg/L
35
30
25
20
15
10
5
0
0
20
40
60
80
100
number of pore volumes
Al-10
Al-20
Al-30
Al-40
Al-50


C/Co at 40 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-40
Fe-40
Mn-40
Zn-40
Al-40


C/Co at 50 cm
C/Co
1.5
1
0.5
0
0
20
40
60
80
100
number of pore volumes
Cu-50
Fe-50
Mn-50
Zn-50
Al-50

Cell ID CPA2

wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.51337 m/day

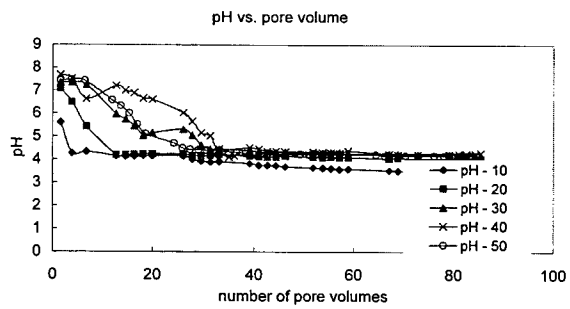
initial concentration of metals, Co

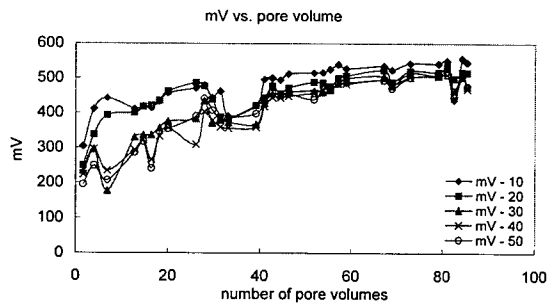
[Cu]o	37.991	mg/L
[Fe]o	0.323	mg/L
[Mn]o	3.475	mg/L
[Zn]o	19.2104	mg/L
[Al]o	23.17	mg/L
pH	3.27	
redox pot	560.5	mV
EC	2.31	mS/cm

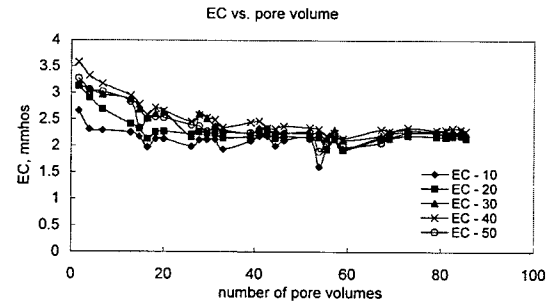
# of pore volumes passed through column:
85.40 pore volumes

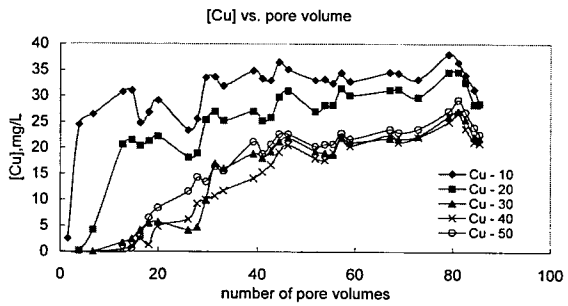
			time used		Flowrate				10cm								20cm								30cm
Date	Time	vol effl (n	hh:mm:ss	(min)	L/day	m/day	pv/day	#pore vol	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH
1 Apr 15, 2	9:00a	515.03	21:00:00	1260.00	0.58861	0.43937	1.81796	1.59071	5.61	304.2	2.66	2.521	-0.039	4.845	7.3164	0.2	7.08	249.7	3.13	-0.076	0.286	0.119	-0.0223	0.23	7.35
2 Apr 16,2(	9:00a	752.08	21:15:39	1275.65	0.84898	0.63373	2.62213	3.91357	4.27	410.9	2.31	24.467	0.051	4.488	17.0135	14.5	6.49	337.7	2.91	0.133	0.084	1.869	1.7226	0.01	7.35
3 Apr 18,2(	3:40p	932.25	74:49:25	3218.83	0.83412	0.62264	4.49931	6.7929	4.33	442	2.29	26.473	0.067	4.626	15.6173	20.41	5.43	393.1	2.69	4.183	-0.013	4.26	6.414	0.63	7.25
4 Apr 21,2(	9:00a	1935.86	61:47:20	3707.33	0.75193	0.56129	2.32238	12.772	4.15	411.2	2.25	30.792	0.071	4.292	19.8331	20.63	4.19	400.5	2.41	20.65	0.038	4.398	16.2152	11.67	5.97
5 Apr 22,2(	9:32a	612.1	20:35:08	1235.13	0.71363	0.5327	2.20409	14.6625	4.13	419	2.17	31.057	0.078	4.261	19.5172	20.1	4.2	418.1	2.32	21.532	0.048	4.371	15.5723	12.29	5.76
6 Apr 23,2(	9:05a	556.51	18:40:45	1120.75	0.71503	0.53375	2.20844	16.3813	4.13	413.8	1.973	24.817	0.091	3.899	18.2286	28.28	4.21	420.4	2.13	20.385	0.047	4.121	15.0692	18.8	5.46
7 Apr 24,2(	8:50a	567.84	18:55:16	1135.27	0.72026	0.53765	2.22459	18.1351	4.16	432.5	2.13	26.806	0.08	3.973	17.6801	25.19	4.24	435.1	2.26	21.337	0.038	4.035	15.2886	16.63	5.03
8 Apr 25,2(	9:00a	596.92	19:55:16	1195.27	0.71914	0.53681	2.22112	19.9788	4.16	456.6	2.13	29.175	0.105	3.122	17.5434	26.69	4.24	461.9	2.27	22.222	0.037	3.214	14.1803	17.88	5.15
9 Apr 28,2(	9:35a	1972.88	68:39:13	4119.22	0.68968	0.51482	2.13014	26.0722	4.15	470.7	1.987	23.405	0.12	3.855	16.6244	30.4	4.23	486.4	2.22	18.17	0.048	3.765	13.3403	21.38	5.31
10 Apr 29,2(	9:30a	575.7	19:56:33	1196.55	0.69283	0.51718	2.13987	27.8503	4	479.4	2.11	25.619	0.131	3.993	16.3578	24.95	4.17	477	2.26	18.995	0.045	3.999	13.6096	16.93	5.04
11 Apr 30,2(	8:45a	555.62	19:11:55	1151.92	0.69458	0.51848	2.14525	29.5663	3.93	443	2.12	33.559	0.175	4.174	18.1438	26.55	4.16	438.5	2.24	25.43	0.044	4.305	14.5459	18.24	4.62
12 May 1,20	9:20a	576.07	20:13:02	1213.03	0.68386	0.51048	2.11215	31.3456	3.88	462.2	2.12	33.673	0.181	4.359	18.479	30.79	4.18	386.9	2.23	27.062	0.052	4.34	15.5635	21.85	4.44
13 May 2,20	9:15a	556.61	19:46:52	1186.87	0.67532	0.50411	2.08579	33.0647	3.91	391.3	1.933	31.941	0.21	4.002	20.0265	30.56	4.21	382.8	2.15	25.237	0.062	4.209	17.088	15.65	4.45
14 May 5,20	9:50a	1947.79	67:08:46	4028.77	0.6962	0.51969	2.15026	39.0806	3.82	420.8	2.09	34.855	0.245	4.162	19.1891	29.87	4.15	420.4	2.17	27.013	0.056	4.25	16.7586	22.51	4.38
15 May 6,20	10:00a	597.65	20:15:05	1215.08	0.70828	0.5287	2.18757	40.9265	3.75	496.6	2.18	33.354	0.251	3.759	17.1927	29.6	4.14	442.4	2.22	25.204	0.031	3.743	15.1578	21.97	4.35
16 May 7,20	9:10a	552.91	18:50:37	1130.62	0.70421	0.52567	2.17501	42.6342	3.75	500.5	2.18	33.025	0.274	4.112	18.224	29.23	4.12	477.5	2.22	25.909	0.045	3.936	16.2653	24.19	4.29
17 May 8,20	8:50a	571.67	19:35:05	1175.08	0.70055	0.52294	2.16371	44.3999	3.74	494.6	1.996	36.552	0.359	4.394	17.5147	27.08	4.12	454.9	2.14	29.791	0.07	4.342	15.261	28.38	4.3
18 May 9,20	9:00a	582.29	20:17:14	1217.23	0.68886	0.51421	2.12759	46.1983	3.69	512.1	2.1	35.124	0.292	3.746	17.259	26.45	4.15	471.9	2.18	31.017	0.034	3.967	17.7536	23.02	4.32
19 May 12,2	8:25a	1802.07	66:52:30	4012.50	0.64672	0.48276	1.99746	51.7641	3.65	514.8	2.13	33.104	0.293	3.721	18.197	30.42	4.11	488.3	2.15	27.028	0.031	3.938	16.5885	27.53	4.28
20 May 13,2	11:00a	630.97	22:19:47	1339.78	0.67817	0.50623	2.09457	53.7129	3.63	516.1	1.602	33.225	0.394	4.097	18.373	32.38	4.09	485.6	2.16	28.22	0.067	4.333	17.1724	29.73	4.27
21 May 14,2	9:05a	532.95	18:15:24	1095.4	0.70061	0.52298	2.16389	55.359	3.61	525.3	1.956	32.454	0.327	3.763	17.7178	27.96	4.11	475.3	1.934	28.27	0.016	3.861	15.9421	25.39	4.29
22 May 15,2	8:55a	568.37	19:25:12	1165.2	0.70241	0.52433	2.16946	57.1145	3.58	539.3	2.13	34.488	0.387	4.372	19.1586	29.15	4.1	499.2	2.13	31.509	0.07	4.508	17.731	29.4	4.31
23 May 16,2	9:15a	575.75	19:47:06	1187.1	0.69841	0.52134	2.15709	58.8927	3.59	527.9	1.939	32.84	0.284	3.563	17.4065	31.09	4.1	506.7	1.92	30.121	0.028	3.769	15.8329	31.42	4.24
24 May 20,2	9:00a	2645.74	91:50:20	5510.33	0.6914	0.51611	2.13546	67.0643	3.53	535.3	2.17	34.568	0.417	3.969	18.3067	28.33	4.04	523	2.14	31.152	0.059	3.899	17.2018	28.16	4.23
25 May 21,2	9:10a	570.84	19:41:13	1181.22	0.6959	0.51947	2.14935	68.8274	3.51	523.1	2.16	34.396	0.406	4.028	18.4554	27.36	4.08	488.5	2.14	31.302	0.07	3.963	17.6166	26.47	4.24
26 May 23,2	9:45a	1299.9	44:00:32	2640.53	0.70889	0.52916	2.18947	72.8422	3.48	542.5	2.24	33.207	0.428	3.704	17.7327	27.94	4.03	520.3	2.19	29.774	0.073	3.495	16.6353	28.48	4.22
27 May 26,2	9:05a	2015.62	66:11:46	3971.77	0.73078	0.5455	2.25708	79.0676	3.47	541.3	2.24	38.058	0.468	4.104	17.8666	31.08	4.05	516.7	2.17	34.597	0.074	4.14	17.2666	31.09	4.22
28 May 27,2	11:05a	632.71	21:37:43	1297.72	0.70208	0.52408	2.16843	81.0218	3.48	550.3	2.18	36.44	0.488	4.054	18.5285	26.25	4.06	535.2	2.16	34.621	0.118	4.3	17.0777	27.3	4.19
29 May 28,2	9:00a	488.82	22:37:43	1357.72	0.51844	0.387	1.60126	82.5316	3.45	436.7	2.23	34.03	0.46	3.999	16.6853	28.94	4.03	497.8	2.18	32.596	0.111	4.076	16.1348	30.67	4.17
30 May 29,2	9:30a	577.89	23:37:43	1417.72	0.58697	0.43816	1.81291	84.3164	3.34	555.8	2.23	31.26	0.499	3.642	17.919	25.91	3.97	516.8	2.2	28.363	0.097	3.793	17.1233	28.68	4.16
31 May 30,2	9:00a	350.57	19:26:09	1166.15	0.4329	0.32314	1.33703	**85.3992**	3.4	545	2.19	28.331	0.467	3.505	15.9264	27.61	4.04	515.1	2.14	28.595	0.077	3.837	15.289	29.25	4.16

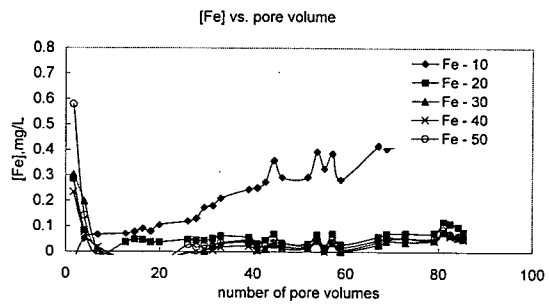
							40cm									50cm											
mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5	DO
234.1	3.15	-0.085	0.303	0.151	-0.0078	0.15	7.39	223.8	3.58	-0.071	0.234	0.113	-0.0109	0.06	7.42	195.2	3.27	-0.082	0.579	0.084	-0.016	0.37	397.2	6.7322	14.1522	
295.6	3.06	-0.09	0.198	0.112	-0.0291	-0.02	6.71	295.8	3.33	-0.093	0.076	0.096	-0.0186	-0.13	7.48	248.8	3.06	-0.087	0.142	0.087	-0.0305	0.2	450.8	7.64068	15.1207	
177.1	2.97	-0.006	0.012	0.891	0.1896	-0.3	6.76	234	3.17	-0.069	0.018	0.238	-0.0086	-0.44	7.43	207	3.02	-0.093	0.003	0.112	-0.0033	-0.44	409	6.9322	14.3622	
330.2	2.88	1.73	-0.021	2.355	3.7297	0.09	6.47	294.3	2.95	0.43	-0.037	2.286	2.5639	-0.19	6.58	286.3	2.83	-0.145	-0.036	2.401	2.2269	-0.21	488.3	8.27627	14.8563	
335.8	2.69	2.459	-0.026	2.485	4.4713	0.43	6.21	321.9	2.78	1.117	-0.043	2.521	3.4868	0.11	6.34	317.5	2.33	0.614	-0.039	3.037	4.0438	-0.08	519.5	8.80508	15.1451	
336.7	2.52	4.087	-0.027	2.497	4.8866	0.55	6.06	265.7	2.59	2.507	-0.042	2.706	4.7702	0.09	6.01	240.7	2.51	2.848	-0.036	3.443	6.0728	0.28	442.7	7.50339	13.5134	
356.3	2.61	5.525	-0.052	2.768	5.7426	1.21	6.37	332.5	2.72	1.336	-0.044	2.568	4.0112	-0.03	5.52	345.7	2.54	6.532	-0.045	4.017	9.0967	1.09	547.7	9.28305	14.8031	
375.7	2.63	5.735	-0.042	2.445	5.7787	1.27	5.66	356.8	2.66	4.875	-0.041	2.563	5.9205	0.48	5.12	353.8	2.53	8.435	-0.049	3.209	8.7552	1.99	555.8	9.42034	14.5403	
383.4	2.18	4.173	-0.001	2.85	4.5674	1.28	5.4	309.6	2.45	6.243	-0.006	3.07	6.6755	1.52	4.7	390.1	2.39	11.627	0.027	3.872	9.8317	7.56	592.1	10.0356	14.7356	
434.7	2.6	4.758	-0.006	2.935	5.1293	1.7	4.78	403.2	2.58	9.305	-0.009	3.499	8.833	3.53	4.5	440.9	2.37	14.325	0.017	4.166	11.5011	8.55	642.9	10.8966	15.3966	
370.3	2.52	9.902	0.002	3.611	8.0724	5.96	4.69	378.8	2.53	10.019	0.01	3.777	8.9882	4.64	4.44	407.4	2.27	13.45	0.025	4.373	11.6123	10.45	609.4	10.3288	14.7688	
379.8	2.36	16.997	0.022	4.133	11.3948	13.43	4.65	359.7	2.49	10.764	0.005	4.078	9.7087	6.01	4.41	379.9	2.34	16.414	0.023	4.398	12.0912	13.5	581.9	9.86271	14.2727	
372.7	2.3	16.052	0.031	3.893	13.0187	13.56	4.57	355.8	2.35	11.799	0.018	3.738	11.4993	6.09	4.4	385	2.26	15.586	0.035	4.123	13.5762	15.47	587	9.94915	14.3492	
366.6	2.23	18.939	0.038	4.253	13.5504	14.4	4.54	358.7	2.44	14.128	0.021	3.975	11.0868	9.82	4.32	397.7	2.24	21.186	0.044	4.423	14.8561	17.98	599.7	10.1644	14.4844	
427	2.33	18.117	0.008	3.752	12.2061	14.32	4.45	418.7	2.46	15.366	0.004	3.395	11.0106	11.83	4.27	433.6	2.3	18.884	0.019	3.834	12.8727	16.48	635.6	10.7729	15.0429	
456.8	2.32	19.316	0.01	4.227	13.5856	16.59	4.39	442.9	2.34	16.744	0.013	4.327	12.3317	13.56	4.21	457	2.31	20.667	0.024	4.538	14.3517	18.55	659	11.1695	15.3795	
451.5	2.23	21.317	0.029	4.401	12.7592	18.06	4.37	443.9	2.32	19.219	0.034	4.231	12.7158	15.67	4.27	450	2.22	22.682	0.035	4.211	14.4914	20.12	652	11.0508	15.3208	
459.6	2.24	21.983	0.02	3.834	14.7124	15.72	4.36	447.9	2.37	20.572	0.012	3.667	13.8918	14.58	4.26	454.3	2.23	22.698	0.034	4.208	15.7418	19.78	656.3	11.1237	15.3837	
462.8	2.23	19.35	0.016	3.668	13.8155	17.9	4.34	457.1	2.34	17.96	0.012	3.809	13.0229	16.9	4.24	438.2	2.24	20.289	0.02	3.841	14.3833	21.81	640.2	10.8508	15.0908	
460	2.24	19.014	0.044	4.272	13.6647	18.8	4.28	469.1	2.31	17.654	0.043	3.848	13.4534	17.93	4.2	477.2	1.893	20.693	0.05	4.078	14.4901	23.11	679.2	11.5119	15.7119	
465.9	2.14	18.758	-0.004	3.721	13.2391	17.08	4.36	467.4	2.19	19.194	0.001	3.668	12.8988	16.25	4.26	464.7	2.1	20.725	0.003	4.002	13.941	20.96	666.7	11.3	15.56	
485.5	2.3	22.008	0.036	4.694	14.9222	19.37	4.3	485.4	2.24	21.841	0.043	4.451	14.7265	19.71	4.21	486.5	2.2	22.836	0.037	4.394	15.974	23.78	688.5	11.6695	15.8795	
499.4	2.11	21.067	0.001	3.808	12.9615	18.52	4.32	483.8	2.14	20.381	0.006	3.474	12.6444	19.28	4.22	486.8	1.986	21.71	0.015	3.531	13.4854	23.24	688.8	11.6746	15.8946	
505.7	2.19	21.892	0.028	3.891	14.2093	17.92	4.25	495	2.31	22.509	0.037	3.889	13.8652	17.8	4.21	493.5	2.06	23.591	0.045	3.928	14.4697	21.38	695.5	11.7881	15.9981	
477.3	2.26	21.753	0.043	4.01	14.5907	16.89	4.26	478.4	2.27	21.11	0.047	3.762	14.7363	18.2	4.16	469.9	2.22	22.985	0.056	3.861	15.4431	21.7	671.9	11.3881	15.5481	
513.9	2.3	22.296	0.038	3.817	13.4439	17.53	4.25	503.2	2.34	22.074	0.053	3.503	12.935	16.5	4.17	501.5	2.26	23.655	0.054	3.59	14.1519	20.94	703.5	11.9237	16.0937	
506.9	2.26	26.11	0.046	4.249	15.0632	21.67	4.25	505.3	2.29	25.046	0.043	3.816	14.2465	22.36	4.17	505.8	2.24	27.117	0.051	3.842	15.4052	23.22	707.8	11.9966	16.1666	
529.2	2.28	27.14	0.078	4.424	15.2599	21.29	4.26	509.5	2.3	26.659	0.082	4.194	14.4569	20.45	4.16	509.3	2.23	29.266	0.087	4.164	15.4214	24.43	711.3	12.0559	16.2159	
463.9	2.22	25.504	0.067	4.13	14.2888	22.49	4.21	468.6	2.33	23.759	0.06	3.907	13.4332	21.15	4.16	444.7	2.24	26.884	0.07	4.003	14.2489	24.94	646.7	10.961	15.121	
502.9	2.28	22.071	0.058	3.8	14.9877	21.8	4.18	504.4	2.31	21.15	0.053	3.763	14.0383	20.9	4.13	504.7	2.19	23.988	0.062	3.623	14.9245	25.23	706.7	11.978	16.108	
475.5	2.23	21.895	0.055	4.128	13.3766	21.44	4.23	468.8	2.27	20.919	0.049	3.752	12.7577	20.04	4.18	475.1	2.18	22.593	0.052	3.847	13.1989	21.86	677.1	11.4763	15.6563	

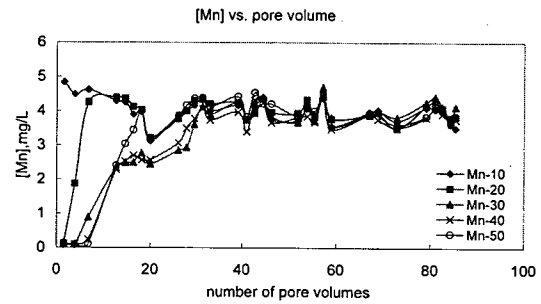

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

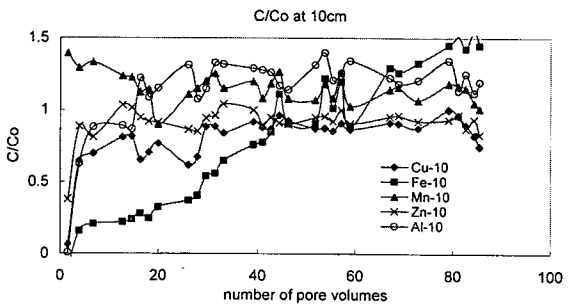

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

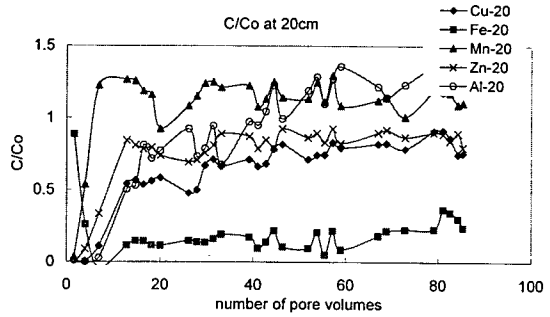

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

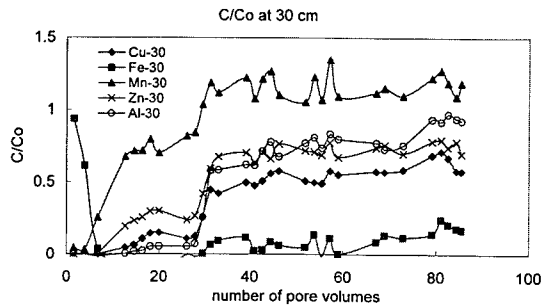

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

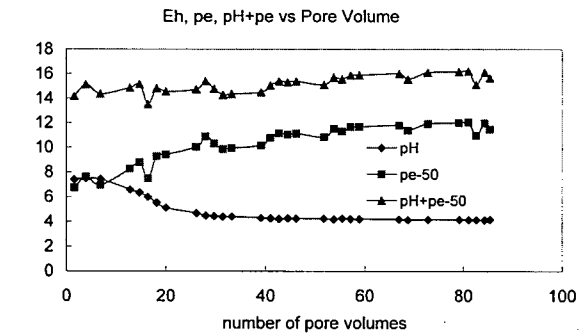

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

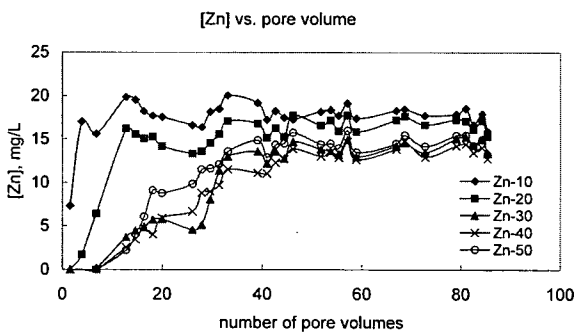

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

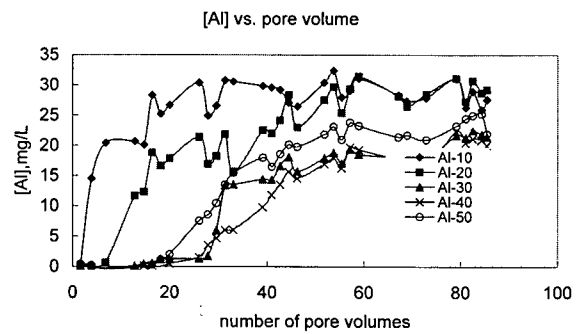

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

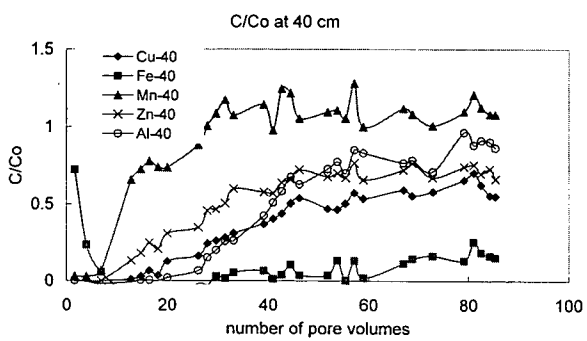

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

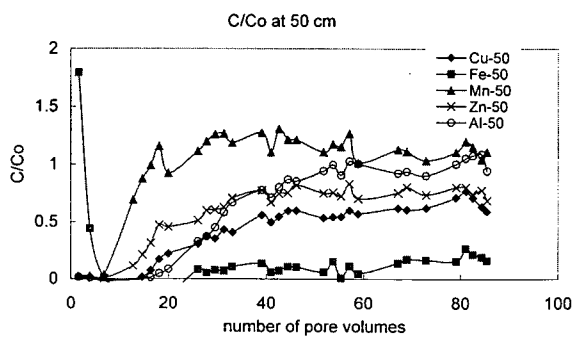

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
pH
pe-50
pH+pe-50
number of pore volumes


[Zn] vs. pore volume
[Zn], mg/L
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50
number of pore volumes


[Al] vs. pore volume
[Al],mg/L
Al-10
Al-20
Al-30
Al-40
Al-50
number of pore volumes


C/Co at 40 cm
C/Co
Cu-40
Fe-40
Mn-40
Zn-40
Al-40
number of pore volumes


C/Co at 50 cm
C/Co
Cu-50
Fe-50
Mn-50
Zn-50
Al-50
number of pore volumes

Cell ID CPA1

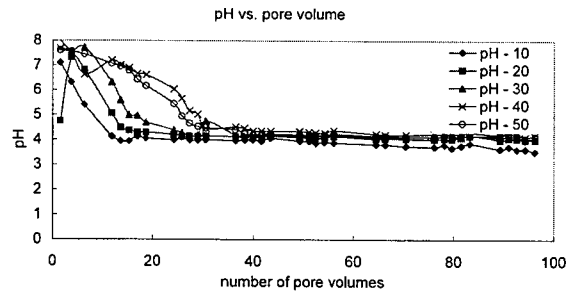
wt soil before filling column	2499.35 g
wt soil after filling column	1639.29 g
wt soil in column	850 g
Date start	Jan 19,2003 04:00
leachate	max conc -non-filtered (design flowrate 0.5m/day)
pore volume	323.773 ml
flowrate	0.50917 m/day

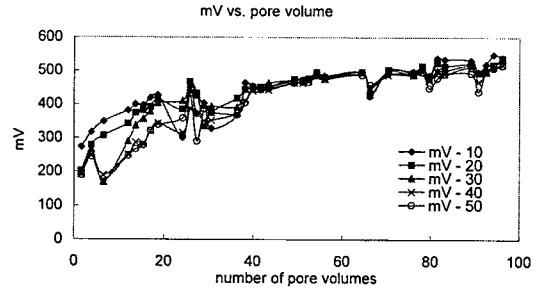
initial concentration of metals, Co		
[Cu]o	37.991	mg/L
[Fe]o	0.323	mg/L
[Mn]o	3.475	mg/L
[Zn]o	19.2104	mg/L
[Al]o	23.17	mg/L
pH	3.27	
redox pot	560.5	mV
EC	2.31	mS/cm

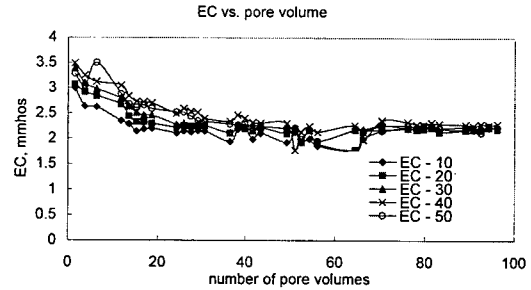
# of pore volumes passed through column:
96.18 pore volumes

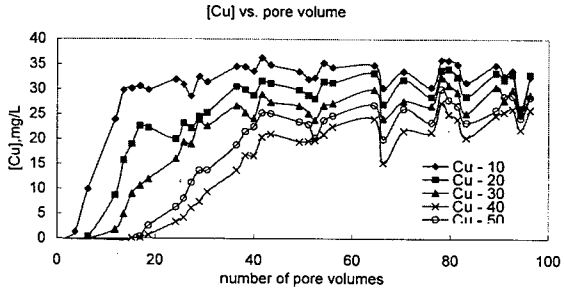
	Date	Time	vol effl (m	time used hh:mm:ss	(min)	Flowrate L/day	m/day	#pore vol	10cm pH	mV	EC	Cu	Fe	Mn	Zn	Al	20cm pH	mV	EC	Cu	Fe	Mn	Zn	Al	30cm pH
1	Apr 15, 2	9:00a	502.46	21:00:00	1260.00	0.57424	0.42865	1.55189	7.11	273.4	3	-0.082	0.229	0.443	0.037	0.13	4.75	202.8	3.07	-0.075	0.303	0.068	-0.0301	0.24	8.01
2	Apr 16,2(	9:00a	725.32	21:15:39	1275.65	0.81877	0.61118	3.7921	6.31	317.2	2.64	1.335	0.027	4.405	6.2051	-0.02	7.32	278.3	2.92	-0.084	0.205	0.718	0.0647	0.01	7.57
3	Apr 18,2(	3:40p	866.68	74:49:25	3218.83	0.77545	0.57885	6.46891	5.4	348.8	2.62	9.939	-0.018	5.495	13.7875	2.12	6.81	306.8	2.84	0.35	-0.015	3.516	3.1707	-0.23	7.73
4	Apr 21,2(	9:00a	1764.38	61:47:20	3707.33	0.68532	0.51157	11.9183	4.13	382.1	2.35	23.895	0.042	4.638	16.9307	15.04	5.06	343	2.67	8.658	-0.023	4.913	11.3888	1.9	6.31
5	Apr 22,2(	9:32a	559.67	20:35:08	1235.13	0.6525	0.48707	13.6469	3.95	400.6	2.29	29.799	0.064	4.443	20.9305	19.68	4.49	374.9	2.44	15.697	-0.005	4.886	15.2156	5.74	5.59
6	Apr 23,2(	9:05a	541.03	18:40:45	1120.75	0.69514	0.5189	15.3179	3.95	397.9	2.14	30.105	0.068	4.3	19.8254	27.28	4.37	382.4	2.33	18.934	0.015	4.927	15.7629	11.25	4.99
7	Apr 24,2(	8:50a	520.87	18:55:16	1135.27	0.66068	0.49318	16.9267	4.13	419.5	2.19	30.549	0.065	4.496	18.0247	27.23	4.29	392.2	2.33	22.606	0.007	4.775	15.0228	15.45	4.97
8	Apr 25,2(	9:00a	546.71	19:58:58	1198.97	0.65662	0.49014	18.6152	4.05	428.3	2.2	29.866	0.081	3.394	18.1697	24.95	4.28	415	2.3	22.24	0.049	3.472	14.5973	16.62	4.7
9	Apr 28,2(	9:35a	1808.18	68:39:13	4119.22	0.63211	0.47185	24.2	3.99	301.3	2.11	31.922	0.059	3.857	18.8302	28.97	4.2	385.9	2.22	19.982	0.041	4.066	14.8887	19.68	4.39
10	Apr 29,2(	9:30a	526.85	19:56:33	1196.55	0.63404	0.47329	25.8272	4.1	441.8	2.15	30.897	0.056	4.159	16.2733	28.16	4.12	467.6	2.26	23.181	0.024	4.296	14.0028	19.65	4.28
11	Apr 30,2(	8:45a	509.45	19:11:55	1151.92	0.63686	0.47539	27.4007	3.98	372.2	2.13	28.6	0.065	4.342	16.7511	26.04	4.14	433.4	2.24	22.157	0.048	4.475	16.1858	18.64	4.16
12	May 1,20	9:20a	527.3	20:13:02	1213.03	0.62596	0.46726	29.0293	3.97	404.3	2.15	32.494	0.069	4.381	18.7945	30.73	4.13	334.7	2.24	24.485	0.071	4.406	15.4008	21.89	4.17
13	May 2,20	9:15a	510.67	19:46:52	1186.8667	0.61959	0.4625	30.6065	4	328.2	2.15	31.431	0.082	4.081	18.8052	28.36	4.15	375.8	2.26	25.276	0.06	4.157	17.1068	23.85	4.75
14	May 5,20	9:50a	1888.01	67:08:46	4028.77	0.67483	0.50374	36.4378	3.96	367	1.943	34.529	0.071	4.341	19.1162	29.21	4.12	418.4	2.11	30.504	0.059	4.421	17.3703	22.76	4.18
15	May 6,20	10:00a	577.24	20:15:05	1215.0833	0.68409	0.51065	38.2206	3.99	463.9	2.19	34.424	0.078	4.151	18.8375	28.87	4.1	444.2	2.24	29.885	0.048	3.979	16.9449	24.51	4.16
16	May 7,20	9:10a	541.11	18:50:37	1130.6167	0.68918	0.51445	39.8919	3.99	447.9	2.2	33.55	0.065	4.009	18.0288	30.06	4.1	450.1	2.2	28.76	0.044	4.186	17.1564	24.41	4.14
17	May 8,20	8:50a	556.24	19:35:05	1175.0833	0.68164	0.50882	41.6099	3.94	443.2	1.988	36.234	0.094	4.354	17.2835	26.99	4.09	451.4	2.15	31.599	0.065	4.31	15.8222	21.95	4.14
18	May 9,20	9:00a	566.31	20:17:14	1217.2333	0.66995	0.5001	43.359	4.06	451.5	2.11	34.847	0.076	3.813	16.7058	27.53	4.14	453.4	2.22	31.145	0.038	3.731	16.3792	22.88	4.17
19	May 12,2	8:25a	1888.02	66:52:30	4012.50	0.67757	0.50578	49.1903	3.95	470.2	1.927	33.519	0.081	3.855	18.1554	30.03	4.09	474.9	2.1	29.815	0.057	3.961	17.3897	25.82	4.14
20	May 13,2	11:00a	591.57	22:19:47	1339.7833	0.63582	0.47462	51.0174	3.95	473.9	2.13	31.982	0.101	4.23	18.257	30.66	4.08	471.5	2.18	28.763	0.06	4.356	17.1531	26.66	4.14
21	May 14,2	9:05a	426.4	18:15:24	1095.4	0.56054	0.41842	52.3344	3.86	477.3	1.928	32.3	0.089	3.856	18.0998	30.2	4.07	477.5	1.95	28.093	0.047	3.843	16.7871	25.5	4.15
22	May 15,2	8:55a	587.38	19:25:12	1165.2	0.72591	0.54187	54.1485	3.91	494.7	1.998	35.266	0.103	4.278	18.6979	29.62	4.09	495.6	2.16	31.469	0.062	4.324	17.7014	27.21	4.14
23	May 16,2	9:15a	592.68	19:47:06	1187.1	0.71894	0.53667	55.9791	3.88	485.2	1.86	34.372	0.087	3.604	17.8468	29.77	4.14	480.9	1.904	31.268	0.047	4.065	16.6058	27.7	4.17
24	May 20,2	9:00a	2726.12	91:50:20	5510.33	0.71241	0.53179	64.3989	3.82	495.9	1.756	34.835	0.122	3.983	18.5293	30.05	4.04	496.7	1.781	33.212	0.057	4	17.3453	27.73	4.11
25	May 21,2	9:10a	589.75	19:41:13	1181.2167	0.71895	0.53667	66.2204	3.81	424	1.997	30.286	0.13	3.582	17.0406	28.8	4.06	427.1	2.13	27.03	0.052	3.541	16.081	27.06	4.09
26	May 23,2	9:45a	1346.27	44:00:32	2640.53	0.73418	0.54804	70.3785	3.75	501.5	2.15	33.564	0.141	3.622	17.9758	27.14	4.04	503.8	2.17	31.875	0.064	3.816	16.8004	26.53	4.11
27	May 26,2	9:05a	1848.24	66:11:46	3971.77	0.6701	0.5002	76.0869	3.72	498.7	2.2	30.403	0.168	3.552	16.5272	29.2	4.02	494.7	2.21	28.482	0.051	3.668	15.6039	26.83	4.1
28	May 27,2	11:05a	641.18	21:37:43	1297.72	0.71148	0.5311	78.0672	3.79	513.3	2.19	35.89	0.264	4.265	18.7797	30.23	4.05	514.2	2.18	33.776	0.107	4.235	17.9258	30.89	4.12
29	May 28,2	9:00a	498.48	17:25:00	1045.00	0.6869	0.51275	79.6068	3.67	485.9	2.2	35.816	0.217	4.242	17.6715	28.26	4.03	482.1	2.19	34.066	0.099	4.118	16.5254	28.78	4.1
30	May 29,2	9:30a	590.29	20:10:04	1210.07	0.70246	0.52436	81.43	3.76	538.3	2.22	35.042	0.212	4.234	18.6869	26.88	4.11	524.5	2.22	32.462	0.074	3.895	18.0305	26.33	4.11
31	May 30,2	9:00a	551.41	19:26:09	1166.15	0.6809	0.50827	83.1331	3.85	535.2	2.14	31.396	0.206	3.751	17.0408	31.31	4.18	514.5	2.13	28.548	0.069	3.84	16.0962	32.08	4.17
32	June 02,:	9:05a	1935.08	68:08:16	4088.27	0.68159	0.50878	89.1097	3.63	531.5	2.18	34.827	0.249	3.823	19.0916	26.54	4	520.9	2.17	33.28	0.069	3.85	19.2217	24.53	4.09
33	June 03,:	9:20a	556.84	19:34:46	1174.77	0.68256	0.50951	90.8296	3.72	494.9	2.18	32.626	0.244	3.782	16.1724	23.57	4.05	494.5	2.18	31.873	0.045	3.6	14.8375	22.24	4.14
34	June 04,:	9:25a	535.42	19:16:57	1156.95	0.66641	0.49745	92.4833	3.61	519.4	2.19	33.679	0.209	3.706	15.8317	22.13	4.04	496.4	2.17	32.943	0.054	3.984	14.8673	21.52	4.11
35	June 05,:	8:55a	548.33	19:28:24	1168.4	0.67579	0.50446	94.1768	3.62	549.2	2.22	26.19	0.264	3.185	16.3493	28.42	4.01	518.3	2.25	24.938	0.067	3.108	15.9164	28.1	4.05
36	June 06,:	9:30a	647.28	18:21:14	1101.2333	0.8464	0.63181	**96.176**	3.52	540.5	2.22	32.484	0.29	3.518	18.3776	28.86	3.98	537.3	2.19	32.923	0.078	3.713	18.3519	29.19	4.05

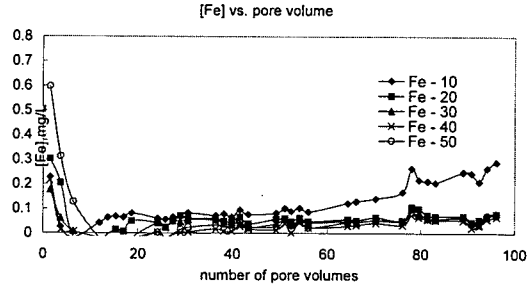
							40cm										50cm											
mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	pH	mV	EC	Cu	Fe	Mn	Zn	Al	Eh-50	pe-50	pH+pe-5	DO
196.7	3.39	-0.076	0.177	0.098	-0.0223	0.19	7.68	191.3	3.49	-0.077	0.215	0.067	-0.0304	0.09	7.61	188.9	3.28	-0.085	0.598	0.082	0.0266	0.42	390.9	6.62542	14.2354	
267.3	3.09	-0.092	0.062	0.106	-0.0502	-0.03	7.52	250.8	3.25	-0.087	0.013	0.018	-0.0285	-0.03	7.56	244.3	3.05	-0.092	0.313	0.068	0.0036	0.09	446.3	7.56441	15.1244	
169.8	2.98	-0.047	0.008	0.833	0.0156	-0.31	6.63	189.7	3.12	-0.093	0.006	0.114	-0.0128	-0.45	7.45	176.3	3.5	-0.096	0.127	0.128	0.0457	-0.26	378.3	6.41186	13.8619	
290.7	2.79	1.759	-0.02	4.007	6.0841	0	7.2	250.8	3.05	-0.258	-0.02	0.892	0.1199	-0.13	7.07	247.4	2.88	-0.327	-0.022	1.652	0.3199	-0.18	449.4	7.61695	14.6869	
337.4	2.64	4.896	-0.042	4.471	9.4679	0.61	7.01	286.8	2.84	-0.272	-0.016	1.455	0.7709	-0.16	6.96	266.4	2.68	-0.396	-0.022	2.214	1.1831	-0.12	468.4	7.93898	14.899	
357.1	2.51	8.992	-0.025	4.374	10.8146	2.44	6.89	283.3	2.73	0.074	-0.023	1.834	1.6555	-0.16	6.79	278.1	2.61	-0.09	-0.024	2.811	2.9845	-0.04	480.1	8.13729	14.9273	
378.8	2.46	10.595	-0.044	4.562	10.3863	3.61	6.66	320.5	2.72	0.199	-0.051	2.351	2.8108	0	6.42	321.1	2.66	0.365	-0.05	3.107	4.2732	-0.03	523.1	8.8661	15.2861	
403.9	2.46	11.971	-0.019	3.432	10.5568	4.4	6.61	343.5	2.7	0.713	-0.027	2.097	3.3016	-0.14	6.16	339.1	2.59	2.571	-0.037	3.209	7.3023	-0.12	541.1	9.17119	15.3312	
410.8	2.28	16.053	0.042	3.983	12.4981	13.35	6.03	315.2	2.5	3.282	0.004	3.282	5.731	0.2	5.44	359	2.52	6.299	0.003	3.655	7.5089	1.38	561	9.50847	14.9485	
459.2	2.3	19.352	0.023	4.207	12.1102	15.95	5.66	387.8	2.59	4.203	-0.02	3.786	6.3099	0.36	4.94	431.5	2.52	8.026	-0.02	4.239	7.9357	2.44	633.5	10.7373	15.6773	
427.7	2.25	18.975	0.052	4.468	13.8977	17.43	5.16	372.2	2.54	6.098	-0.007	4.214	8.2398	1.44	4.66	290.3	2.44	11.222	-0.003	4.542	10.4196	4.8	492.3	8.34407	13.0041	
396.8	2.29	23.988	0.047	4.382	15.5603	22.32	5.02	351.4	2.52	7.379	0.002	4.424	9.8525	2.21	4.53	387.3	2.35	13.637	0.015	4.618	12.2554	8.36	589.3	9.98814	14.5181	
394.2	2.26	22.633	0.054	4.153	15.9996	21.97	4.45	352.5	2.4	9.355	0.005	4.384	11.6909	4.45	4.47	375.4	2.34	13.704	0.024	4.284	12.9591	8.7	577.4	9.78644	14.2564	
392.6	2.12	26.684	0.053	4.423	16.3386	21.37	4.51	372.1	2.34	13.691	0.017	4.327	11.8703	7.55	4.4	371.7	2.29	18.781	0.033	4.758	14.6102	12.94	573.7	9.72373	14.1237	
445.3	2.26	25.252	0.039	3.947	15.551	21.63	4.45	411.6	2.47	16.687	0.008	3.74	12.1158	10.99	4.24	404.9	2.27	21.457	0.025	3.815	14.3981	19.82	606.9	10.2864	14.5264	
445.6	2.26	24.12	0.037	4.098	15.3757	21.81	4.35	440.3	2.4	16.654	0.008	4.214	12.773	12.74	4.2	453.6	2.28	22.447	0.033	4.23	14.9391	19.97	655.6	11.1119	15.3119	
448.6	2.26	28.956	0.039	4.446	14.775	18.8	4.35	445.6	2.32	20.387	0.027	4.3	12.3118	12.17	4.23	448.5	2.19	25.255	0.05	4.514	14.1576	19.73	650.5	11.0254	15.2554	
463.7	2.25	27.398	0.022	3.835	13.443	19.49	4.34	443.1	2.31	20.998	0.016	3.711	12.1906	13.57	4.23	447.3	2.24	25.078	0.025	3.83	13.5642	21.31	649.3	11.0051	15.2351	
472.6	2.2	26.643	0.038	4.043	15.8495	23.75	4.33	464.9	2.3	19.467	0.014	3.739	13.3877	16.6	4.2	464.9	2.2	23.424	0.026	3.767	14.904	22.74	666.9	11.3034	15.5034	
471.7	2.19	25.115	0.058	4.307	15.7616	25.48	4.31	464.5	1.774	19.537	0.039	4.011	13.4803	17.3	4.18	467.6	2.21	22.891	0.055	4.06	14.7022	22.19	669.6	11.3492	15.5292	
475.8	1.94	23.86	0.037	3.778	15.3867	22.12	4.29	469.2	2.13	19.717	0.003	3.657	13.1594	16.25	4.19	466.5	1.987	20.154	0.019	3.918	14.4743	20.55	668.5	11.3305	15.5205	
491.6	2.17	26.719	0.052	4.32	16.3146	24.08	4.27	485.8	2.24	20.872	0.043	4.021	14.4468	18.42	4.18	487.1	2.17	23.746	0.054	4.256	15.7522	22.16	689.1	11.6797	15.8597	
477.3	1.945	27.162	0.041	3.741	15.6034	25.58	4.37	475	2.13	22.486	0.022	3.59	13.2146	19.46	4.23	479	1.949	24.665	0.022	3.813	14.0997	22.82	681	11.5424	15.7724	
496.1	2.18	29.906	0.049	3.984	16.5921	25.29	4.23	491.2	2.26	24.013	0.029	3.948	14.4145	18.38	4.15	488	2.17	26.813	0.045	4.025	15.4108	21.78	690	11.6949	15.8449	
447.7	2.18	24.115	0.043	3.375	15.4568	24.61	4.21	449.1	1.975	15.23	0.033	2.786	13.5723	18.29	4.15	457.9	2.15	19.953	0.046	3.166	14.472	22.75	659.9	11.1847	15.3347	
500.2	2.26	27.643	0.054	3.558	15.4932	24.69	4.21	488	2.36	21.616	0.042	3.541	14.0115	18.39	4.13	491.5	2.25	26.067	0.052	3.729	14.8797	24.19	693.5	11.7542	15.8842	
489.1	2.21	26.711	0.049	3.773	15.0787	26.45	4.22	487.6	2.33	21.354	0.034	3.666	13.1349	19.82	4.12	492	2.26	23.349	0.048	3.69	14.3016	23.88	694	11.7627	15.8827	
509.4	2.19	32.355	0.101	4.34	16.5082	28.53	4.24	497.5	2.28	27.321	0.073	4.328	15.2852	19.29	4.15	497.1	2.21	30.036	0.087	4.283	15.7314	27.99	699.1	11.8492	15.9992	
477.8	2.22	30.808	0.081	3.962	15.634	24.49	4.23	470.5	2.27	25.018	0.064	4.132	13.9783	19.04	4.14	448.5	2.25	27.873	0.072	4.107	14.4957	25.25	650.5	11.0254	15.1654	
501.6	2.24	29.393	0.06	3.949	16.3296	24.8	4.24	500.2	2.32	24.053	0.057	4.004	14.9999	19.07	4.15	477.7	2.24	26.682	0.065	3.952	15.5056	23.32	679.7	11.5203	15.6703	
501.8	2.19	25.186	0.057	3.721	15.2994	28.76	4.29	491.1	2.29	20.29	0.053	3.485	13.7347	23.12	4.15	490.9	2.21	23.279	0.058	3.669	13.8908	25.71	692.9	11.7441	15.8941	
517	2.19	30.508	0.068	3.73	17.4423	22.21	4.2	510.7	2.28	24.742	0.052	3.758	14.7052	18.09	4.17	492.3	2.23	25.859	0.062	3.708	15.3188	19.81	694.3	11.7678	15.9378	
495.8	2.22	27.816	0.043	3.685	13.9153	20.69	4.35	466.6	2.25	25.398	0.022	3.595	12.186	17.31	4.24	437.3	2.19	28.537	0.042	3.615	13.2697	19.84	639.3	10.8356	15.0756	
502.7	2.18	29.875	0.036	3.714	13.7875	19.53	4.24	498.5	2.29	26.074	0.031	4.019	12.6791	16.89	4.18	501.1	2.12	28.667	0.044	4.294	13.6109	20.01	703.1	11.9169	16.0969	
512.4	2.23	25.36	0.073	3.402	15.6057	26.75	4.11	512.7	2.27	21.962	0.056	3.347	14.3963	21.48	3.98	508.6	2.22	24.217	0.072	3.432	15.5026	25.29	710.6	12.0441	16.0241	
534.2	2.22	28.904	0.08	3.675	16.7087	25.88	4.15	518.2	2.29	25.888	0.067	3.718	15.4127	21.82	4.11	516.3	2.22	28.399	0.073	3.915	16.8939	25.91	718.3	12.1746	16.2846	

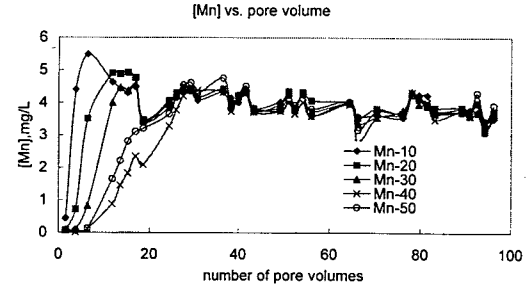

pH vs. pore volume
pH
number of pore volumes
pH - 10
pH - 20
pH - 30
pH - 40
pH - 50

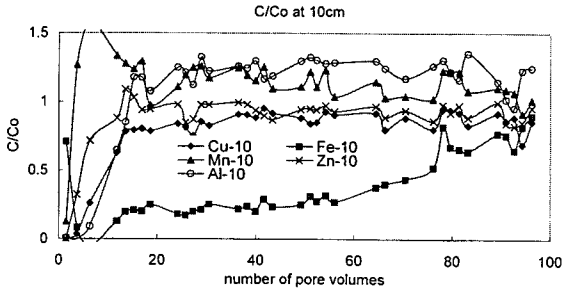

mV vs. pore volume
mV
number of pore volumes
mV - 10
mV - 20
mV - 30
mV - 40
mV - 50

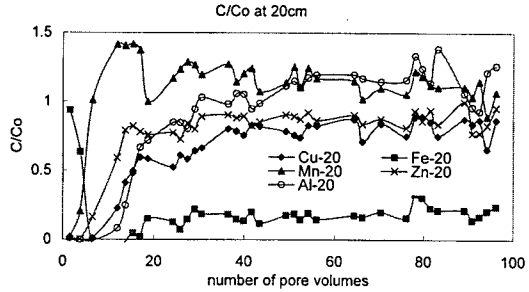

EC vs. pore volume
EC, mmhos
number of pore volumes
EC - 10
EC - 20
EC - 30
EC - 40
EC - 50

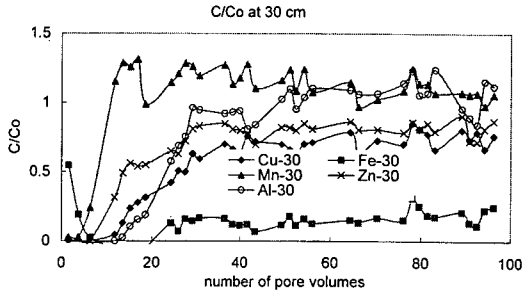

[Cu] vs. pore volume
[Cu],mg/L
number of pore volumes
Cu - 10
Cu - 20
Cu - 30
Cu - 40
Cu - 50

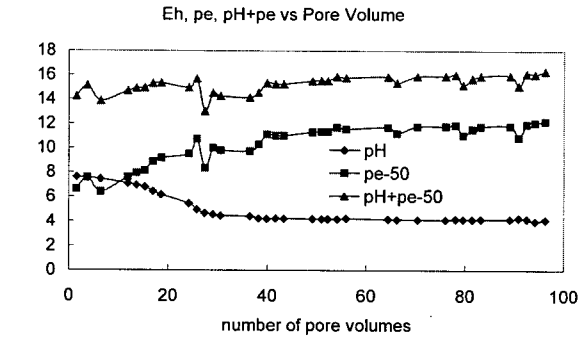

[Fe] vs. pore volume
[Fe],mg/L
number of pore volumes
Fe - 10
Fe - 20
Fe - 30
Fe - 40
Fe - 50

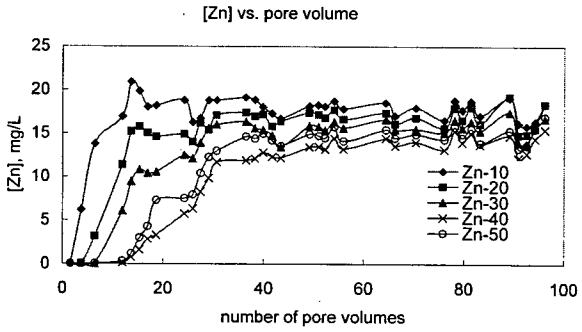

[Mn] vs. pore volume
[Mn],mg/L
number of pore volumes
Mn-10
Mn-20
Mn-30
Mn-40
Mn-50

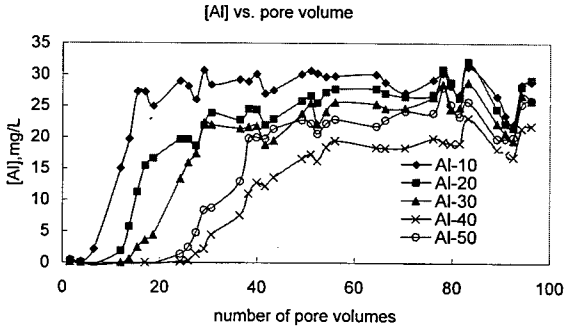

C/Co at 10cm
C/Co
number of pore volumes
Cu-10
Fe-10
Mn-10
Zn-10
Al-10

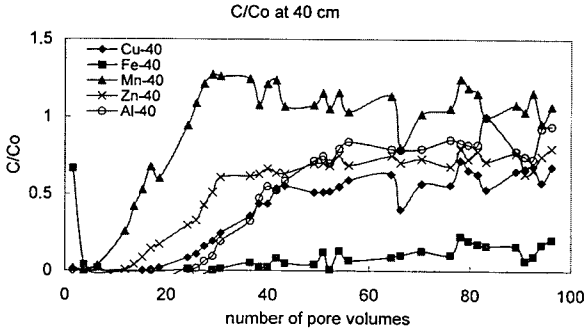

C/Co at 20cm
C/Co
number of pore volumes
Cu-20
Fe-20
Mn-20
Zn-20
Al-20

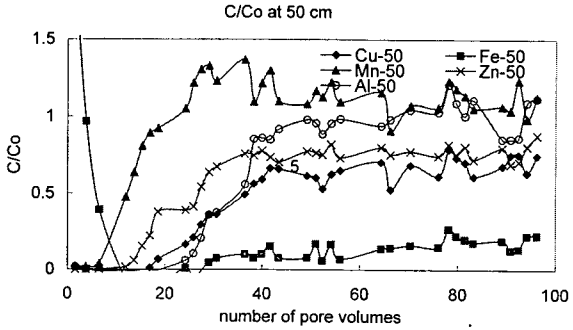

C/Co at 30 cm
C/Co
number of pore volumes
Cu-30
Fe-30
Mn-30
Zn-30
Al-30


Eh, pe, pH+pe vs Pore Volume
pH
pe-50
pH+pe-50
number of pore volumes


[Zn] vs. pore volume
[Zn], mg/L
Zn-10
Zn-20
Zn-30
Zn-40
Zn-50
number of pore volumes


[Al] vs. pore volume
[Al],mg/L
Al-10
Al-20
Al-30
Al-40
Al-50
number of pore volumes


C/Co at 40 cm
C/Co
Cu-40
Fe-40
Mn-40
Zn-40
Al-40
number of pore volumes


C/Co at 50 cm
C/Co
Cu-50
Fe-50
Mn-50
Zn-50
Al-50
number of pore volumes

Appendix J. Results of soil analyses on tested clinoptilolite from Critical Path Analysis leaching column cells

J-1. Results of metal partitioning on clinoptilolite extracted from leaching cell after 15, 26, 38, 45, 57, 73, 85, and 96 pore volumes

Soil analysis

CELL ID: **CPA8**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	12.97	13.25	14.33	11.85	11.57
wt. dry soil + container	12.63	12.92	13.95	11.5	11.26
water content, w%	0.02929	0.02773	0.02939	0.0334	0.03027
soil pH	4.3	5.18	5.29	6.24	6.57

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0009	1.9925	1.9957	2.0051	1.9971
equiv. dry soil wt (g)			1.94397	1.93874	1.93872	1.9403	1.93842
SSE-0	Initial rins	Cu	0.073	0.149	0.176	0.15	0.084
		Fe	1.267	17.007	17.682	23.146	24.521
		Mn	0.051	0.091	0.111	0.151	0.173
		Zn	0.1224	0.2412	0.2932	0.4447	0.4533
		Al	7.16	13.23	13.42	18.31	19.42
SSE-1	Exchang	Cu	10.776	3.38	3.235	0.683	0.345
		Fe	0.712	0.428	0.584	0.407	0.339
		Mn	2.138	2.113	2.313	1.932	1.255
		Zn	5.0782	3.9738	4.7799	2.8918	1.68
		Al	12.29	9.42	10.24	1.62	5.73
SSE-2	Carbonat	Cu	11.123	5.663	5.524	3.737	2.503
		Fe	5.147	3.938	3.621	3.2	2.685
		Mn	2.198	2.074	2.628	2.41	2.51
		Zn	3.8273	2.3065	2.6286	2.7864	2.7252
		Al	6.83	6.12	6.2	3.54	2.52
SSE-3	Fe-, Mn-	Cu	10.163	4.411	4.067	2.092	1.229
		Fe	46.585	47.494	47.124	46.496	44.469
		Mn	3.621	4.119	4.85	5.073	5.597
		Zn	4.1056	2.7813	2.9666	2.6042	2.3485
		Al	22.55	21.87	22.52	18.6	17.82
SSE-4	Organics	Cu	2.36	1.484	1.488	1.063	0.828
		Fe	20.544	19.484	19.681	21.427	19.807
		Mn	2.44	2.56	3.398	2.808	3.233
		Zn	3.2923	2.1873	2.3619	1.9144	1.6512
		Al	51.8	51.38	51.6	57.84	56.28
SSE-5	Residual	Cu	1.303	0.905	0.894	0.67	0.535
		Fe	459.64	472.88	488.76	470.16	496.41
		Mn	2.841	2.604	2.974	2.805	2.763
		Zn	3.1615	2.6066	2.7885	2.5296	2.3007
		Al	1106.4	1079.2	1209.5	1128.1	1132.9
wt. wet soil T.D. (g)			2.0027	2.0032	2.0052	2.0052	1.9913
amount of dry soil (g)			1.94572	1.94915	1.94795	1.9404	1.93279
Total digestion initial rinse		Cu	0.152	0.449	0.35	0.307	0.324
		Fe	8.668	33.569	24.825	33.374	47.052
		Mn	0.053	0.23	0.194	0.266	0.384
		Zn	0.1144	0.4945	0.4273	0.6287	0.8855
		Al	7.36	33.73	25.42	35.92	52.22
Total digestion		Cu	52.538	32.471	29.144	23.563	20.756
		Fe	435.36	450.14	425.93	419.16	432.73
		Mn	8.761	9.054	8.622	8.038	9.034
		Zn	15.596	10.882	11.622	9.268	8.202
		Al	1138.7	1333.9	1252.4	1138.3	1126.9

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0009	1.9925	1.9957	2.0051	1.9971
equiv. dry soil wt (g)			1.94397	1.93874	1.93872	1.9403	1.93842
SSE-0	Initial rins	Cu-0	0.0006	0.00123	0.00145	0.00124	0.00069
		Fe-0	0.01043	0.14036	0.14593	0.19087	0.2024
		Mn-0	0.00042	0.00075	0.00092	0.00125	0.00143
		Zn	0.00101	0.00199	0.00242	0.00367	0.00374
		Al	0.05893	0.10918	0.11075	0.15099	0.1603
SSE-1	Exchang	Cu	0.08869	0.02789	0.0267	0.00563	0.00285
		Fe	0.00586	0.00353	0.00482	0.00336	0.0028
		Mn	0.0176	0.01744	0.01909	0.01593	0.01036
		Zn	0.0418	0.03279	0.03945	0.02385	0.01387
		Al	0.10115	0.07774	0.08451	0.01336	0.0473
SSE-2	Carbonat	Cu	0.09155	0.04674	0.04559	0.03082	0.02066
		Fe	0.04236	0.0325	0.02988	0.02639	0.02216
		Mn	0.01809	0.01712	0.02169	0.01987	0.02072
		Zn	0.0315	0.01904	0.02169	0.02298	0.02249
		Al	0.05621	0.05051	0.05117	0.02919	0.0208
SSE-3	Fe-, Mn-	Cu	0.20912	0.09101	0.08391	0.04313	0.02536
		Fe	0.95855	0.9799	0.97227	0.95853	0.91764
		Mn	0.07451	0.08498	0.10007	0.10458	0.1155
		Zn	0.08448	0.05738	0.06121	0.05369	0.04846
		Al	0.464	0.45122	0.46464	0.38345	0.36772
SSE-4	Organics	Cu	0.04856	0.03062	0.0307	0.02191	0.01709
		Fe	0.42272	0.40199	0.40606	0.44173	0.40873
		Mn	0.05021	0.05282	0.07011	0.05789	0.06671
		Zn	0.06774	0.04513	0.04873	0.03947	0.03407
		Al	1.06586	1.06007	1.06462	1.19239	1.16136
SSE-5	Residual	Cu	0.02681	0.01867	0.01845	0.01381	0.01104
		Fe	9.45776	9.75646	10.0842	9.69252	10.2436
		Mn	0.05846	0.05373	0.06136	0.05783	0.05702
		Zn	0.06505	0.05378	0.05753	0.05215	0.04748
		Al	22.7658	22.266	24.9546	23.2562	23.3778
SSE total	SSE1+2+	Cu	0.46473	0.21493	0.20534	0.1153	0.07699
		Fe	10.8873	11.1744	11.4972	11.1225	11.5949
		Mn	0.21886	0.22608	0.27231	0.2561	0.2703
		Zn	0.29057	0.20812	0.22861	0.19212	0.16637
		Al	24.453	23.9056	26.6195	24.8746	24.975
wt. wet soil T.D. (g)			2.0027	2.0032	2.0052	2.0052	1.9913
amount of dry soil (g)			1.94572	1.94915	1.94795	1.9404	1.93279
Total digestion initial rinse		Cu	0.00312	0.00921	0.00719	0.00633	0.00671
		Fe	0.1782	0.6889	0.50977	0.68798	0.97376
		Mn	0.00109	0.00472	0.00398	0.00548	0.00795
		Zn	0.00235	0.01015	0.00877	0.01296	0.01833
		Al	0.15131	0.6922	0.52198	0.74047	1.08072
Total digestion		Cu	1.08007	0.66636	0.59845	0.48574	0.42956
		Fe	8.95011	9.23768	8.74621	8.64071	8.95556
		Mn	0.18011	0.1858	0.17705	0.1657	0.18696
		Zn	0.32062	0.22332	0.23865	0.19105	0.16974
		Al	23.4093	27.374	25.7173	23.4653	23.3218
Recovery	SSE/tota	Cu	43.0%	32.3%	34.3%	23.7%	17.9%
		Fe	121.6%	121.0%	131.5%	128.7%	129.5%
		Mn	121.5%	121.7%	153.8%	154.6%	144.6%
		Zn	90.6%	93.2%	95.8%	100.6%	98.0%
		Al	104.5%	87.3%	103.5%	106.0%	107.1%

Soil analysis

CELL ID: **CPA7**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	12.19	14.11	11.62	12.52	11.83
wt. dry soil + container (g)	11.93	13.81	11.36	12.23	11.6
water content, w%	0.02383	0.02346	0.02515	0.02587	0.02174
soil pH	4.28	4.94	4.48	4.85	5.54

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9951	2.0068	2.0029	2.0011	1.9919
equiv. dry soil wt (g)			1.94866	1.96081	1.95377	1.95064	1.94952
SSE-0	Initial rins	Cu	0.078	0.194	0.088	0.196	0.222
		Fe	8.296	15.555	7.7	13.137	18.771
		Mn	0.05	0.101	0.055	0.094	0.144
		Zn	0.1223	0.1761	0.0964	0.2243	0.327
		Al	7.87	12.76	7.81	12.87	16.74
SSE-1	Exchang	Cu	8.401	3.68	5.667	7.308	2.126
		Fe	0.418	0.306	0.221	0.510	0.384
		Mn	1.66	1.491	1.294	2.614	2.079
		Zn	4.988	3.9134	5.457	5.2829	3.6039
		Al	17.76	10.52	18.11	8.1	7.82
SSE-2	Carbonat	Cu	11.1	7.311	11.304	7.768	5.515
		Fe	5.102	4.021	4.951	4.113	3.351
		Mn	2.091	1.813	2.375	2.33	2.386
		Zn	4.0224	2.5924	4.7278	3.6272	2.4693
		Al	5.28	6.72	9.78	14.48	4.46
SSE-3	Fe-, Mn-	Cu	10.654	6.121	10.08	6.858	3.262
		Fe	51.338	46.788	45.896	46.626	47.091
		Mn	4.089	3.99	3.805	4.766	4.722
		Zn	4.4516	3.3316	4.7674	4.0862	2.9653
		Al	20.94	23.9	25.79	22.4	16.89
SSE-4	Organics	Cu	2.29	1.616	2.412	1.987	1.486
		Fe	20.316	17.266	19.936	20.163	29.42
		Mn	2.509	2.191	2.534	2.958	3.045
		Zn	3.4036	2.2669	3.8411	3.0321	2.1807
		Al	54.82	46.76	52.43	52.66	51.97
SSE-5	Residual	Cu	1.219	0.98	1.349	1.213	0.871
		Fe	462.73	474.27	491.35	460.88	452.55
		Mn	2.575	2.398	2.835	2.881	2.638
		Zn	2.9436	2.6616	3.4073	3.0578	2.521
		Al	1119.7	1073.1	1125.9	1199.1	938.8
wt. wet soil T.D. (g)			1.9966	2.0081	2.0026	2.0049	2.0027
amount of dry soil (g)			1.95013	1.96208	1.95348	1.95434	1.96009
Total digestion initial rinse		Cu	0.114	0.369	0.043	0.425	0.286
		Fe	9.744	24.193	7.402	22.423	24.6
		Mn	0.071	0.151	0.044	0.152	0.194
		Zn	0.1676	0.3907	0.1465	0.4306	0.4832
		Al	8.95	22.13	6.27	21.09	25.5
Total digestion		Cu	51.925	23.891	47.382	36.132	27.869
		Fe	469.76	259.99	402.49	448.84	410.8
		Mn	9.331	4.388	8.709	8.426	9.194
		Zn	15.005	7.315	16.069	13.892	9.809
		Al	1153.2	702.1	1174.8	1200.8	1004

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9951	2.0068	2.0029	2.0011	1.9919
equiv. dry soil wt (g)			1.94866	1.96081	1.95377	1.95064	1.94952
SSE-0	Initial rins	Cu	0.00064	0.00158	0.00072	0.00161	0.00182
		Fe	0.06812	0.12693	0.06306	0.10776	0.15406
		Mn	0.00041	0.00082	0.00045	0.00077	0.00118
		Zn	0.001	0.00144	0.00079	0.00184	0.00268
		Al	0.06462	0.10412	0.06396	0.10557	0.13739
SSE-1	Exchang	Cu	0.06898	0.03003	0.04641	0.05994	0.01745
		Fe	0.00343	0.0025	0.00181	0.00418	0.00315
		Mn	0.01363	0.01217	0.0106	0.02144	0.01706
		Zn	0.04096	0.03193	0.04469	0.04333	0.02958
		Al	0.14582	0.08584	0.14831	0.06644	0.06418
SSE-2	Carbonat	Cu	0.09114	0.05966	0.09257	0.06372	0.04526
		Fe	0.04189	0.03281	0.04055	0.03374	0.0275
		Mn	0.01717	0.01479	0.01945	0.01911	0.01958
		Zn	0.03303	0.02115	0.03872	0.02975	0.02027
		Al	0.04335	0.05483	0.08009	0.11877	0.0366
SSE-3	Fe-, Mn-	Cu	0.21869	0.12487	0.20637	0.14063	0.06693
		Fe	1.05381	0.95446	0.93964	0.95612	0.96621
		Mn	0.08393	0.0814	0.0779	0.09773	0.09689
		Zn	0.09138	0.06796	0.0976	0.08379	0.06084
		Al	0.42983	0.48755	0.528	0.45934	0.34655
SSE-4	Organics	Cu	0.04701	0.03297	0.04938	0.04075	0.03049
		Fe	0.41702	0.35222	0.40815	0.41346	0.60364
		Mn	0.0515	0.0447	0.05188	0.06066	0.06248
		Zn	0.06987	0.04624	0.07864	0.06218	0.04474
		Al	1.12529	0.95389	1.07341	1.07985	1.06631
SSE-5	Residual	Cu	0.02502	0.01999	0.02762	0.02487	0.01787
		Fe	9.49842	9.67499	10.0595	9.45086	9.28537
		Mn	0.05286	0.04892	0.05804	0.05908	0.05413
		Zn	0.06042	0.0543	0.06976	0.0627	0.05173
		Al	22.984	21.891	23.0508	24.5889	19.2622
SSE tota	SSE1+2+	Cu	0.45084	0.26751	0.42235	0.32991	0.178
		Fe	11.0146	11.017	11.4497	10.8584	10.8859
		Mn	0.21909	0.20197	0.21787	0.25802	0.25013
		Zn	0.29565	0.22159	0.32941	0.28176	0.20715
		Al	24.7283	23.4731	24.8806	26.3133	20.7758
wt. wet soil T.D. (g)			1.9966	2.0081	2.0026	2.0049	2.0027
amount of dry soil (g)			1.95013	1.96208	1.95348	1.95434	1.96009
Total digestion initial rinse		Cu	0.00234	0.00752	0.00088	0.0087	0.00584
		Fe	0.19986	0.49321	0.15157	0.45894	0.50202
		Mn	0.00146	0.00308	0.0009	0.00311	0.00396
		Zn	0.00344	0.00797	0.003	0.00881	0.00986
		Al	0.18358	0.45115	0.12839	0.43165	0.52038
Total digestion		Cu	1.06506	0.48706	0.97021	0.73952	0.56873
		Fe	9.63548	5.3003	8.2415	9.18652	8.38329
		Mn	0.19139	0.08946	0.17833	0.17246	0.18762
		Zn	0.30778	0.14913	0.32903	0.28433	0.20017
		Al	23.6539	14.3134	24.0555	24.5771	20.4889
Recovery	SSE/tota	Cu	42.3%	54.9%	43.5%	44.6%	31.3%
		Fe	114.3%	207.9%	138.9%	118.2%	129.9%
		Mn	114.5%	225.8%	122.2%	149.6%	133.3%
		Zn	96.1%	148.6%	100.1%	99.1%	103.5%
		Al	104.5%	164.0%	103.4%	107.1%	101.4%

Soil analysis

CELL ID: CPA6

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container	11.63	14.66	14	14.14	11.71
wt. dry soil + container (g)	11.37	14.35	13.71	13.88	11.5
water content, w%	0.02512	0.02326	0.02285	0.02022	0.02004
soil pH	4.03	4.85	4.39	4.62	4.97

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9901	2.0083	1.9918	1.9997	2.0065
equiv. dry soil wt (g)			1.94133	1.96266	1.9473	1.96007	1.96708
SSE-0	Initial rins	Cu	0.081	0.187	0.065	0.14	0.194
		Fe	2.927	14.82	5.959	9.858	13.12
		Mn	0.045	0.095	0.044	0.062	0.097
		Zn	0.0709	0.1849	0.0863	0.0922	0.193
		Al	6.18	14.47	7.79	10.69	13.38
SSE-1	Exchang	Cu	11.311	5.139	6.884	8.978	4.608
		Fe	0.518	0.375	0.305	0.512	0.436
		Mn	1.434	1.78	1.411	2.193	2.427
		Zn	4.3933	3.7244	4.3076	4.5162	5.6665
		Al	25.61	11.08	19.36	12.17	10.85
SSE-2	Carbonat	Cu	18.431	9.682	12.73	11.33	7.543
		Fe	5.514	3.673	5.319	4.436	3.896
		Mn	2.452	2.405	2.646	2.776	2.531
		Zn	5.8322	3.215	4.6775	4.3892	3.0743
		Al	3.77	9.77	10.05	15.14	6.18
SSE-3	Fe-, Mn-	Cu	14.376	6.765	10.194	9.031	5.634
		Fe	48.705	47.627	45.617	50.923	50.444
		Mn	3.281	4.761	5.104	4.121	4.332
		Zn	4.8608	3.5989	4.7744	4.6806	3.7167
		Al	19.97	20.55	23.89	26.91	22.96
SSE-4	Organics	Cu	2.844	2.045	2.415	2.033	1.745
		Fe	20.712	20.263	22.166	24.313	21.534
		Mn	2.201	3.52	4.508	2.595	2.619
		Zn	4.1035	2.8095	3.7779	3.4197	2.847
		Al	51.99	58.21	53.79	58.04	59.68
SSE-5	Residual	Cu	1.691	1.248	1.454	1.203	1.074
		Fe	479.82	514.96	526.7	476.04	462.52
		Mn	2.623	3.042	3.493	2.754	2.993
		Zn	3.473	2.7724	3.2164	3.0834	2.9202
		Al	1103	1199.9	1203.5	1115.3	1049.8
wt. wet soil T.D. (g)			1.9935	1.9933	1.993	2.0025	2.0071
amount of dry soil (g)			1.94465	1.948	1.94847	1.96282	1.96767
Total digestion initial rinse		Cu	0.144	0.544	0.132	0.255	0.309
		Fe	4.644	23.865	4.91	10.762	15.507
		Mn	0.057	0.234	0.054	0.099	0.141
		Zn	0.0749	0.1056	0.0258	0.1319	0.0905
		Al	-0.68	-0.68	-0.66	-0.67	-0.66
Total digestion		Cu	59.033	34.121	47.343	40.738	34.785
		Fe	415.68	382.59	413.24	387.22	374.56
		Mn	7.432	8.514	8.043	7.858	9.162
		Zn	16.096	11.066	15.197	14.129	13.443
		Al	964.5	852.2	875.9	880.6	977

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9901	2.0083	1.9918	1.9997	2.0065
equiv. dry soil wt (g)			1.94133	1.96266	1.9473	1.96007	1.96708
SSE-0	Initial rins	Cu	0.00067	0.00152	0.00053	0.00114	0.00158
		Fe	0.02412	0.12082	0.04896	0.08047	0.10672
		Mn	0.00037	0.00077	0.00036	0.00051	0.00079
		Zn	0.00058	0.00151	0.00071	0.00075	0.00157
		Al	0.05093	0.11796	0.06401	0.08726	0.10883
SSE-1	Exchang	Cu	0.09322	0.04189	0.05656	0.07329	0.03748
		Fe	0.00427	0.00306	0.00251	0.00418	0.00355
		Mn	0.01182	0.01451	0.01159	0.0179	0.01974
		Zn	0.03621	0.03036	0.03539	0.03687	0.04609
		Al	0.21107	0.09033	0.15907	0.09934	0.08825
SSE-2	Carbonat	Cu	0.1519	0.07893	0.1046	0.09249	0.06135
		Fe	0.04545	0.02994	0.0437	0.03621	0.03169
		Mn	0.02021	0.01961	0.02174	0.02266	0.02059
		Zn	0.04807	0.02621	0.03843	0.03583	0.02501
		Al	0.03107	0.07965	0.08258	0.12359	0.05027
SSE-3	Fe-, Mn-	Cu	0.29621	0.13787	0.2094	0.1843	0.11457
		Fe	1.00354	0.97066	0.93703	1.03921	1.02576
		Mn	0.0676	0.09703	0.10484	0.0841	0.08809
		Zn	0.10015	0.07335	0.09807	0.09552	0.07558
		Al	0.41147	0.41882	0.49073	0.54916	0.46688
SSE-4	Organics	Cu	0.0586	0.04168	0.04961	0.04149	0.03548
		Fe	0.42676	0.41297	0.45532	0.49617	0.43789
		Mn	0.04535	0.07174	0.0926	0.05296	0.05326
		Zn	0.08455	0.05726	0.0776	0.06979	0.05789
		Al	1.07122	1.18635	1.10492	1.18445	1.21357
SSE-5	Residual	Cu	0.03484	0.02543	0.02987	0.02455	0.02184
		Fe	9.88641	10.4952	10.8191	9.71475	9.40519
		Mn	0.05405	0.062	0.07175	0.0562	0.06086
		Zn	0.07156	0.0565	0.06607	0.06292	0.05938
		Al	22.7267	24.4546	24.7214	22.7604	21.3473
SSE tota	SSE1+2+	Cu	0.63478	0.32581	0.45003	0.41611	0.27072
		Fe	11.3664	11.9118	12.2576	11.2905	10.9041
		Mn	0.19903	0.26489	0.30253	0.23382	0.24254
		Zn	0.34054	0.24368	0.31557	0.30092	0.26395
		Al	24.4515	26.2298	26.5587	24.7169	23.1663
wt. wet soil T.D. (g)			1.9935	1.9933	1.993	2.0025	2.0071
amount of dry soil (g)			1.94465	1.948	1.94847	1.96282	1.96767
Total digestion initial rinse		Cu	0.00296	0.01117	0.00271	0.0052	0.00628
		Fe	0.09552	0.49004	0.1008	0.21932	0.31524
		Mn	0.00117	0.0048	0.00111	0.00202	0.00287
		Zn	0.00154	0.00217	0.00053	0.00269	0.00184
		Al	-0.014	-0.014	-0.0135	-0.0137	-0.0134
Total digestion		Cu	1.21427	0.70064	0.9719	0.83019	0.70713
		Fe	8.55023	7.85607	8.48336	7.89111	7.61428
		Mn	0.15287	0.17483	0.16511	0.16014	0.18625
		Zn	0.33108	0.22723	0.31198	0.28793	0.27328
		Al	19.8391	17.499	17.9813	17.9456	19.861
Recoven	SSE/tota	Cu	52.3%	46.5%	46.3%	50.1%	38.3%
		Fe	132.9%	151.6%	144.5%	143.1%	143.2%
		Mn	130.2%	151.5%	183.2%	146.0%	130.2%
		Zn	102.9%	107.2%	101.2%	104.5%	96.6%
		Al	123.2%	149.9%	147.7%	137.7%	116.6%

Soil analysis

CELL ID: **CPA5**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	11.91	15.08	17.25	15.47	13.26
wt. dry soil + container	11.67	14.8	16.93	15.18	13.02
water content, w%	0.02254	0.02032	0.02011	0.02048	0.02
soil pH	4.06	4.42	4.48	4.34	4.79

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9955	1.9963	2.0099	2.0006	1.9921
equiv. dry soil wt (g)			1.95152	1.95654	1.97027	1.96045	1.95304
SSE-0	Initial rins	Cu	0.12	0.112	0.183	0.071	0.188
		Fe	6.956	6.622	11.97	5.448	12.472
		Mn	0.048	0.048	0.088	0.037	0.088
		Zn	0.0534	0.0714	0.1702	0.0401	0.1604
		Al	8.96	8.36	12.62	8.57	13.15
SSE-1	Exchang	Cu	9.908	12.937	4.749	10.054	5.755
		Fe	0.472	0.541	0.355	0.480	0.387
		Mn	1.437	2.019	1.655	1.824	2.188
		Zn	5.1656	5.5404	5.3368	5.4566	4.7162
		Al	21.29	20.13	15.92	22.25	13.24
SSE-2	Carbonat	Cu	15.134	13.254	9.599	13.826	9.373
		Fe	4.562	4.062	2.937	3.557	3.296
		Mn	1.995	2.138	2.59	2.605	2.317
		Zn	4.8506	4.6752	3.5795	4.9081	3.4925
		Al	3.46	10.28	8.11	10.51	11.71
SSE-3	Fe-, Mn-	Cu	12.318	11.572	6.946	10.761	6.43
		Fe	55.627	47.799	44.319	44.748	48.249
		Mn	4.093	3.432	3.909	5.27	4.13
		Zn	4.6706	4.8239	4.0835	5.3401	4.0873
		Al	21.95	23.33	23.07	28.09	21.43
SSE-4	Organics	Cu	2.482	2.611	1.914	2.518	2.137
		Fe	19.309	19.016	18.236	18.74	20.151
		Mn	2.8	2.785	2.52	4.309	2.954
		Zn	3.737	4.1078	3.2856	4.2279	3.3026
		Al	51.89	56.24	61.64	58.15	52.25
SSE-5	Residual	Cu	1.341	1.508	1.14	1.365	1.174
		Fe	479.3	463.24	453.64	443.31	452.79
		Mn	2.83	2.985	2.813	3.701	3.08
		Zn	3.1248	3.5917	3.0346	3.5133	2.9905
		Al	1088.9	1068.6	1051.1	1185.2	1090.2
wt. wet soil T.D. (g)			2.006	1.9949	1.9997	1.9938	1.993
amount of dry soil (g)			2.05225	2.03628	2.04075	2.03549	2.03367
Total digestion initial rinse		Cu	0.144	0.156	0.144	0.178	0.041
		Fe	1.259	7.955	7.952	8.11	2.39
		Mn	0.058	0.094	0.086	0.103	0.054
		Zn	0.0541	0.1125	0.142	0.1249	0.1005
		Al	0.71	7.12	7.2	6.93	1.69
Total digestion		Cu	68.282	62.073	55.163	56.863	53.911
		Fe	517.65	530.11	480.86	493.14	469.34
		Mn	9.03	9.791	10.273	10.23	10.291
		Zn	19.047	19.2	18.253	18.898	19.285
		Al	1083.4	1211.4	1127.7	1139.3	1047

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9955	1.9963	2.0099	2.0006	1.9921
equiv. dry soil wt (g)			1.9515	1.95654	1.97027	1.96045	1.95304
SSE-0	Initial rins	Cu	0.001	0.00092	0.00149	0.00058	0.00154
		Fe	0.057	0.05415	0.0972	0.04446	0.10218
		Mn	0.0004	0.00039	0.00071	0.0003	0.00072
		Zn	0.0004	0.00058	0.00138	0.00033	0.00131
		Al	0.0735	0.06837	0.10248	0.06994	0.10773
SSE-1	Exchang	Cu	0.0812	0.10579	0.03857	0.08205	0.04715
		Fe	0.0039	0.00442	0.00288	0.00392	0.00317
		Mn	0.0118	0.01651	0.01344	0.01489	0.01792
		Zn	0.0424	0.04531	0.04334	0.04453	0.03864
		Al	0.1746	0.16462	0.12928	0.18159	0.10847
SSE-2	Carbonat	Cu	0.1241	0.10839	0.07795	0.11284	0.07679
		Fe	0.0374	0.03322	0.02385	0.02903	0.027
		Mn	0.0164	0.01748	0.02103	0.02126	0.01898
		Zn	0.0398	0.03823	0.02907	0.04006	0.02861
		Al	0.0284	0.08407	0.06586	0.08578	0.09593
SSE-3	Fe-, Mn-	Cu	0.2525	0.23658	0.14102	0.21956	0.13169
		Fe	1.1402	0.97721	0.89975	0.91302	0.98818
		Mn	0.0839	0.07016	0.07936	0.10753	0.08459
		Zn	0.0957	0.09862	0.0829	0.10896	0.08371
		Al	0.4499	0.47696	0.46836	0.57313	0.43891
SSE-4	Organics	Cu	0.0509	0.05338	0.03886	0.05138	0.04377
		Fe	0.3958	0.38877	0.37022	0.38236	0.41271
		Mn	0.0574	0.05694	0.05116	0.08792	0.0605
		Zn	0.0766	0.08398	0.0667	0.08626	0.06764
		Al	1.0636	1.14978	1.2514	1.18646	1.07013
SSE-5	Residual	Cu	0.0275	0.03083	0.02314	0.02785	0.02404
		Fe	9.8241	9.47057	9.20969	9.04507	9.27355
		Mn	0.058	0.06103	0.05711	0.07551	0.06308
		Zn	0.064	0.07343	0.06161	0.07168	0.06125
		Al	22.319	21.8467	21.3392	24.1822	22.3283
SSE tota	SSE1+2+	Cu	0.5362	0.53497	0.31953	0.49368	0.32344
		Fe	11.401	10.8742	10.5064	10.3734	10.7046
		Mn	0.2274	0.22212	0.2221	0.30711	0.24507
		Zn	0.3185	0.33957	0.28362	0.35149	0.27985
		Al	24.035	23.7221	23.2541	26.2092	24.0417
wt. wet soil T.D. (g)			2.006	1.9949	1.9997	1.9938	1.993
amount of dry soil (g)			2.0522	2.03628	2.04075	2.03549	2.03367
Total digestion initial rinse		Cu	0.0028	0.00306	0.00282	0.0035	0.00081
		Fe	0.0245	0.15627	0.15586	0.15937	0.04701
		Mn	0.0011	0.00185	0.00169	0.00202	0.00106
		Zn	0.0011	0.00221	0.00278	0.00245	0.00198
		Al	0.0138	0.13986	0.14112	0.13618	0.03324
Total digestion		Cu	1.3309	1.21934	1.08123	1.11743	1.06037
		Fe	10.089	10.4133	9.42518	9.69085	9.23137
		Mn	0.176	0.19233	0.20136	0.20103	0.20241
		Zn	0.3712	0.37716	0.35777	0.37137	0.37931
		Al	21.116	23.7964	22.1037	22.3887	20.5933
Recovery	SSE/tota	Cu	40.3%	43.9%	29.6%	44.2%	30.5%
		Fe	113.0%	104.4%	111.5%	107.0%	116.0%
		Mn	129.2%	115.5%	110.3%	152.8%	121.1%
		Zn	85.8%	90.0%	79.3%	94.6%	73.8%
		Al	113.8%	99.7%	105.2%	117.1%	116.7%

Soil analysis

CELL ID: **CPA4**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container	13.31	15.85	15.78	13.55	13.86
wt. dry soil + container (g)	13.05	15.55	15.51	13.32	13.62
water content, w%	0.02161	0.02065	0.01863	0.0187	0.01905
soil pH	3.74	4.43	4.51	4.38	4.54

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9954	1.997	2.0035	2.0054	1.9917
equiv. dry soil wt (g)			1.95319	1.9566	1.96685	1.96859	1.95447
SSE-0	Initial rins	Cu	0.659	0.147	0.17	-0.007	0.17
		Fe	0.021	8.745	8.654	2.978	7.569
		Mn	0.107	0.061	0.062	0.018	0.053
		Zn	0.1082	0.0846	0.0712	-0.0102	0.0725
		Al	0.32	7.49	7.6	2.56	6.55
SSE-1	Exchang	Cu	14.076	8.636	7.525	9.13	6.064
		Fe	0.689	0.432	0.400	0.405	0.284
		Mn	1.236	1.748	1.532	1.261	1.325
		Zn	5.1878	4.6656	4.7313	5.8075	5.2301
		Al	34.05	21.15	15.52	23.86	9.41
SSE-2	Carbonat	Cu	25.239	12.936	11.894	15.161	10.172
		Fe	5.255	5.329	5.435	5.869	4.37
		Mn	2.531	2.18	2.285	2.31	2.212
		Zn	7.3387	4.0307	4.1311	5.1783	3.6705
		Al	2.84	7.02	13.08	17.73	8.26
SSE-3	Fe-, Mn-	Cu	16.543	10.217	8.973	11.996	9.045
		Fe	50.04	50.257	44.504	46.929	50.638
		Mn	3.648	4.37	4.244	4.423	4.789
		Zn	5.4354	4.7555	4.429	5.7539	5.0159
		Al	18.59	22.71	22.96	26.5	24.63
SSE-4	Organics	Cu	3.71	2.594	2.372	3.204	2.371
		Fe	21.785	21.114	20.404	33.366	16.411
		Mn	3.372	3.202	3.163	3.566	3.225
		Zn	4.5771	3.6965	3.6358	4.4201	3.4569
		Al	44.69	51.7	50.54	59.34	43.5
SSE-5	Residual	Cu	1.925	1.405	1.286	1.706	1.298
		Fe	466.93	507.27	454.57	486.18	467.35
		Mn	3.232	3.628	3.36	3.695	3.354
		Zn	3.8886	3.3455	3.2258	3.8541	3.2004
		Al	1183.3	1184.4	1135.6	1180.4	1123.7
wt. wet soil T.D. (g)			2.0065	2.0019	1.9943	1.9985	2.0098
amount of dry soil (g)			1.96405	1.9614	1.95782	1.96182	1.97223
Total digestion initial rinse		Cu	0.773	0.197	0.282	0.049	0.216
		Fe	0.24	9.448	11.148	1.756	8.923
		Mn	0.128	0.104	0.105	0.043	0.097
		Zn	0.1483	0.1239	0.1728	0.0529	0.1478
		Al	-0.26	8.69	10.8	1.13	8.21
Total digestion		Cu	94.329	57.108	47.245	66.142	50.706
		Fe	530.35	549.42	529.24	539.57	540.7
		Mn	8.726	8.982	10.197	10.762	10.872
		Zn	22.957	17.978	17.057	20.165	18.382
		Al	1206.3	1111.2	1184.1	1166.9	1222.7

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9954	1.997	2.0035	2.0054	1.9917
equiv. dry soil wt (g)			1.95319	1.9566	1.96685	1.96859	1.95447
SSE-0	Initial rins	Cu	0.0054	0.0012	0.00138	-6E-05	0.00139
		Fe	0.00017	0.0715	0.0704	0.0242	0.06196
		Mn	0.00088	0.0005	0.0005	0.00015	0.00043
		Zn	0.00089	0.0007	0.00058	-8E-05	0.00059
		Al	0.00262	0.0612	0.06182	0.02081	0.05362
SSE-1	Exchang	Cu	0.11531	0.0706	0.06121	0.07421	0.04964
		Fe	0.00564	0.0035	0.00325	0.00329	0.00232
		Mn	0.01012	0.0143	0.01246	0.01025	0.01085
		Zn	0.0425	0.0382	0.03849	0.0472	0.04282
		Al	0.27893	0.173	0.12625	0.19393	0.07703
SSE-2	Carbonat	Cu	0.20675	0.1058	0.09676	0.12322	0.08327
		Fe	0.04305	0.0436	0.04421	0.0477	0.03577
		Mn	0.02073	0.0178	0.01859	0.01877	0.01811
		Zn	0.06012	0.033	0.03361	0.04209	0.03005
		Al	0.02326	0.0574	0.1064	0.1441	0.06762
SSE-3	Fe-, Mn-	Cu	0.33879	0.2089	0.18248	0.24375	0.18511
		Fe	1.02479	1.0274	0.90508	0.95356	1.03635
		Mn	0.07471	0.0893	0.08631	0.08987	0.09801
		Zn	0.11131	0.0972	0.09007	0.11691	0.10265
		Al	0.38071	0.4643	0.46694	0.53846	0.50407
SSE-4	Organics	Cu	0.07598	0.053	0.04824	0.0651	0.04852
		Fe	0.44614	0.4316	0.41496	0.67797	0.33587
		Mn	0.06906	0.0655	0.06433	0.07246	0.066
		Zn	0.09374	0.0756	0.07394	0.08981	0.07075
		Al	0.91522	1.0569	1.02784	1.20574	0.89027
SSE-5	Residual	Cu	0.03942	0.0287	0.02615	0.03466	0.02656
		Fe	9.56243	10.37	9.24463	9.87875	9.56473
		Mn	0.06619	0.0742	0.06833	0.07508	0.06864
		Zn	0.07964	0.0684	0.0656	0.07831	0.0655
		Al	24.2332	24.213	23.0948	23.9847	22.9975
SSE tota	SSE1+2+	Cu	0.77625	0.467	0.41485	0.54094	0.39312
		Fe	11.082	11.877	10.6121	11.5613	10.975
		Mn	0.24081	0.2611	0.25002	0.26643	0.26161
		Zn	0.3873	0.3123	0.30171	0.37433	0.31177
		Al	25.8313	25.965	24.8222	26.0669	24.5365
wt. wet soil T.D. (g)			2.0065	2.0019	1.9943	1.9985	2.0098
amount of dry soil (g)			1.96405	1.9614	1.95782	1.96182	1.97223
Total digestion initial rinse		Cu	0.01574	0.004	0.00576	0.001	0.00438
		Fe	0.00489	0.1927	0.22776	0.0358	0.18097
		Mn	0.00261	0.0021	0.00215	0.00088	0.00197
		Zn	0.00302	0.0025	0.00353	0.00108	0.003
		Al	-0.0053	0.1772	0.22065	0.02304	0.16651
Total digestion		Cu	1.92111	1.1646	0.96526	1.34859	1.0284
		Fe	10.8011	11.205	10.8128	11.0014	10.9662
		Mn	0.17771	0.1832	0.20833	0.21943	0.2205
		Zn	0.46754	0.3666	0.34849	0.41115	0.37282
		Al	24.5676	22.661	24.1922	23.7922	24.7983
Recovery	SSE/tota	Cu	40.4%	40.1%	43.0%	40.1%	38.2%
		Fe	102.6%	106.0%	98.1%	105.1%	100.1%
		Mn	135.5%	142.5%	120.0%	121.4%	118.6%
		Zn	82.8%	85.2%	86.6%	91.0%	83.6%
		Al	105.1%	114.6%	102.6%	109.6%	98.9%

Soil analysis

CELL ID: **CPA3**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	16.44	17.13	15.34	16.57	15.44
wt. dry soil + container (g)	15.93	16.65	14.99	16.13	15.08
water content, w%	0.03421	0.03071	0.02505	0.02912	0.0256
soil pH	3.43	4.27	4.31	4.34	4.3

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9925	2.0004	1.9924	2.0085	1.9958
equiv. dry soil wt (g)			1.9266	1.9408	1.9437	1.95167	1.94597
SSE-0	Initial rins	Cu	2.212	0.097	0.061	0.098	0.065
		Fe	-0.031	5.191	1.542	3.083	0.662
		Mn	0.212	0.041	0.021	0.029	0.028
		Zn	0.2881	0.0383	0.0168	0.0281	0.0246
		Al	0.96	5.22	1.91	3.59	1.59
SSE-1	Exchang	Cu	28.329	14.195	15.431	13.995	12.698
		Fe	1.883	0.600	0.588	0.505	0.484
		Mn	2.066	1.886	1.872	2.079	1.713
		Zn	7.0463	4.0036	4.3986	4.214	4.2456
		Al	30.91	15.12	17.44	19.08	18.37
SSE-2	Carbonat	Cu	32.839	16.043	16.584	14.052	15.37
		Fe	6.634	5.019	2.147	1.065	8.474
		Mn	2.882	2.521	2.609	2.433	2.611
		Zn	13.8898	6.6207	6.5918	6.2798	6.5793
		Al	2.11	10.84	13.28	12.75	13.49
SSE-3	Fe-, Mn-	Cu	18.64	11.503	12.373	11.508	12.835
		Fe	56.26	54.638	53.498	54.307	52.597
		Mn	3.255	4.332	4.956	4.428	5.184
		Zn	5.7228	5.3188	6.2159	5.8771	6.6313
		Al	14.68	30.78	28.3	28.97	31.33
SSE-4	Organics	Cu	3.785	2.245	2.932	2.642	2.954
		Fe	20.997	16.535	18.28	21.112	18.939
		Mn	2.644	2.478	3.309	3.148	3.449
		Zn	4.2495	3.5071	4.209	4.2912	4.6048
		Al	44.51	46.74	53.7	54.17	53.19
SSE-5	Residual	Cu	2.007	1.491	1.196	1.475	1.474
		Fe	467.47	471.23	462.44	503.77	503.17
		Mn	2.87	3.08	3.087	3.337	3.272
		Zn	3.5612	3.5753	3.3285	3.6275	3.6715
		Al	1187.7	1143.8	1130	1283.6	1257.8
wt. wet soil T.D. (g)			2.0014	2.0016	2.0089	1.9997	2.0028
amount of dry soil (g)			1.93521	1.94196	1.9598	1.94312	1.9528
Total digestion initial rinse		Cu	2.225	0.073	0.077	0.115	0.134
		Fe	0.145	2.923	2.008	2.011	0.818
		Mn	0.259	0.067	0.057	0.05	0.046
		Zn	0.3895	0.0588	0.0871	0.066	0.1016
		Al	-0.1	1.91	1.3	1.1	0.16
Total digestion		Cu	128.38	57.822	58.969	59.655	58.425
		Fe	522.87	540.75	509.67	546.87	522.23
		Mn	9.43	10.066	11.076	9.624	10.404
		Zn	25.534	18.825	20.025	20.766	21.774
		Al	1240.4	1243.5	1245.4	1363.5	1207.6

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.9925	2.0004	1.9924	2.0085	1.9958
equiv. dry soil wt (g)			1.9266	1.9408	1.9437	1.95167	1.94597
SSE-0	Initial rins	Cu	0.01837	0.0008	0.0005	0.0008	0.00053
		Fe	-0.0003	0.0428	0.01269	0.02527	0.00544
		Mn	0.00176	0.0003	0.00017	0.00024	0.00023
		Zn	0.00239	0.0003	0.00014	0.00023	0.0002
		Al	0.00797	0.043	0.01572	0.02943	0.01307
SSE-1	Exchang	Cu	0.23527	0.117	0.12702	0.11473	0.1044
		Fe	0.01564	0.0049	0.00484	0.00414	0.00398
		Mn	0.01716	0.0155	0.01541	0.01704	0.01408
		Zn	0.05852	0.033	0.03621	0.03455	0.03491
		Al	0.2567	0.1246	0.14356	0.15642	0.15104
SSE-2	Carbonat	Cu	0.27272	0.1323	0.13651	0.1152	0.12637
		Fe	0.05509	0.0414	0.01767	0.00873	0.06967
		Mn	0.02393	0.0208	0.02148	0.01995	0.02147
		Zn	0.11535	0.0546	0.05426	0.05148	0.0541
		Al	0.01752	0.0894	0.10932	0.10453	0.11092
SSE-3	Fe-, Mn-	Cu	0.387	0.2371	0.25463	0.23586	0.26383
		Fe	1.16807	1.1261	1.10095	1.11304	1.08114
		Mn	0.06758	0.0893	0.10199	0.09075	0.10656
		Zn	0.11882	0.1096	0.12792	0.12045	0.13631
		Al	0.30479	0.6344	0.58239	0.59375	0.644
SSE-4	Organics	Cu	0.07858	0.0463	0.06034	0.05415	0.06072
		Fe	0.43594	0.3408	0.37619	0.4327	0.3893
		Mn	0.05489	0.0511	0.0681	0.06452	0.0709
		Zn	0.08823	0.0723	0.08662	0.08795	0.09465
		Al	0.92411	0.9633	1.10511	1.11023	1.09333
SSE-5	Residual	Cu	0.04167	0.0307	0.02461	0.03023	0.0303
		Fe	9.70559	9.7121	9.51668	10.3249	10.3428
		Mn	0.05959	0.0635	0.06353	0.06839	0.06726
		Zn	0.07394	0.0737	0.0685	0.07435	0.07547
		Al	24.659	23.574	23.2546	26.3078	25.8544
SSE total	SSE1+2+	Cu	1.01524	0.5634	0.60312	0.55017	0.58562
		Fe	11.3803	11.225	11.0163	11.8835	11.8869
		Mn	0.22315	0.2402	0.2705	0.26066	0.28026
		Zn	0.45485	0.3432	0.3735	0.36878	0.39543
		Al	26.1621	25.386	25.195	28.2727	27.8537
wt. wet soil T.D. (g)			2.0014	2.0016	2.0089	1.9997	2.0028
amount of dry soil (g)			1.93521	1.942	1.9598	1.94312	1.9528
Total digestion initial rinse		Cu	0.04599	0.0015	0.00157	0.00237	0.00274
		Fe	0.003	0.0602	0.04098	0.0414	0.01676
		Mn	0.00535	0.0014	0.00116	0.00103	0.00094
		Zn	0.00805	0.0012	0.00178	0.00136	0.00208
		Al	-0.0021	0.0393	0.02653	0.02264	0.00328
Total digestion		Cu	2.65357	1.191	1.20357	1.22803	1.19674
		Fe	10.8075	11.138	10.4025	11.2576	10.6971
		Mn	0.19491	0.2073	0.22606	0.19811	0.21311
		Zn	0.52778	0.3878	0.40872	0.42748	0.44601
		Al	25.6386	25.613	25.4189	28.0683	24.7358
Recovery	SSE/total	Cu	38.3%	47.3%	50.1%	44.8%	48.9%
		Fe	105.3%	100.8%	105.9%	105.6%	111.1%
		Mn	114.5%	115.8%	119.7%	131.6%	131.5%
		Zn	86.2%	88.5%	91.4%	86.3%	88.7%
		Al	102.0%	99.1%	99.1%	100.7%	112.6%

Soil analysis

CELL ID: **CPA2**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container	19.06	16.11	17.01	17.26	16.41
wt. dry soil + container (g)	18.67	15.79	16.68	16.93	16.1
water content, w%	0.0221	0.02167	0.02107	0.02074	0.02056
soil pH	3.48	4.14	4.41	4.55	4.32

metals in soil, ppm (from AAS)

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.999	2.0003	2.0005	1.9999	2.0041
equiv. dry soil wt (g)			1.95578	1.95788	1.95921	1.95926	1.96373
SSE-0	Initial rins	Cu	2.292	0.685	0.245	0.275	0.41
		Fe	0.118	0.102	0.213	1.863	3.098
		Mn	0.272	0.106	0.056	0.103	0.133
		Zn	0.4157	0.1495	0.0819	0.118	0.1013
		Al	0.5	0.3	0.24	0.77	2.56
SSE-1	Exchang	Cu	23.143	20.938	15.085	11.317	7.993
		Fe	1.428	0.725	0.558	0.481	0.361
		Mn	1.796	1.951	1.987	2.171	2.557
		Zn	6.7292	6.5877	6.2434	6.3766	6.928
		Al	32.03	29.33	24.38	15.75	11.16
SSE-2	Carbonat	Cu	7.534	6.775	6.392	7.332	7.475
		Fe	3.492	3.54	3.086	3.179	3.46
		Mn	0.871	0.847	0.958	1.194	1.506
		Zn	5.1462	3.9442	3.9338	3.3055	2.8318
		Al	2.06	8.63	10.78	8.62	7.43
SSE-3	Fe-, Mn-	Cu	20.58	17.474	15.071	11.285	7.853
		Fe	63.964	47.395	47.16	52.72	54.073
		Mn	3.162	3.598	3.267	3.844	3.718
		Zn	5.4802	5.7526	5.7775	5.4783	4.8638
		Al	14.95	21.75	24.86	28.42	22.56
SSE-4	Organics	Cu	3.347	3.237	3.084	2.356	1.952
		Fe	12.174	11.327	12.35	10.357	13.203
		Mn	2.437	2.523	2.101	2.403	2.02
		Zn	4.8017	4.914	4.4925	3.9536	3.5253
		Al	24.88	28.7	30.23	31.17	32.4
SSE-5	Residual	Cu	4.5095	4.94625	3.96375	3.337	3.36425
		Fe	455.93	472.96	487.41	436.33	437.4
		Mn	3.878	4.367	3.251	3.804	3.796
		Zn	6.0669	6.1994	6.2523	5.0746	4.6865
		Al	1146.4	1112.4	1156	1131.8	1076.5
wt. wet soil T.D. (g)			2.0085	2.0027	1.992	2.0017	2.0073
amount of dry soil (g)			1.96508	1.96023	1.95089	1.96103	1.96687
Total digestion initial rinse		Cu	2.003	0.71	0.238	0.229	0.4
		Fe	0.537	0.629	0.266	1.378	2.197
		Mn	0.235	0.125	0.046	0.082	0.153
		Zn	0.4089	0.1846	0.1104	0.1302	0.1411
		Al	0.48	0.51	0.17	0.51	2.2
Total digestion		Cu	41.994	37.3985	29.0129	23.78	17.959
		Fe	496.17	534.89	493.88	468.28	513.23
		Mn	8.286	9.839	8.902	10.65	11.67
		Zn	16.9618	17.1136	16.8109	14.4205	13.3217
		Al	1020.4	1067.7	1089	1053.7	1108

Amount of metals in soil, mg metal/kg soil

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			1.999	2.0003	2.0005	1.9999	2.0041
equiv. dry soil wt (g)			1.95578	1.95788	1.95921	1.95926	1.96373
SSE-0	Initial rins	Cu	0.01875	0.0056	0.002	0.00225	0.00334
		Fe	0.00097	0.00083	0.00174	0.01521	0.02524
		Mn	0.00223	0.00087	0.00046	0.00084	0.00108
		Zn	0.0034	0.00122	0.00067	0.00096	0.00083
		Al	0.00409	0.00245	0.00196	0.00629	0.02086
SSE-1	Exchang	Cu	0.18933	0.17111	0.12319	0.09242	0.06512
		Fe	0.01168	0.00592	0.00456	0.00393	0.00294
		Mn	0.01469	0.01594	0.01623	0.01773	0.02083
		Zn	0.05505	0.05384	0.05099	0.05207	0.05645
		Al	0.26203	0.23969	0.1991	0.12862	0.09093
SSE-2	Carbonat	Cu	0.06163	0.05537	0.0522	0.05988	0.0609
		Fe	0.02857	0.02893	0.0252	0.02596	0.02819
		Mn	0.00713	0.00692	0.00782	0.00975	0.01227
		Zn	0.0421	0.03223	0.03213	0.02699	0.02307
		Al	0.01685	0.07053	0.08804	0.07039	0.06054
SSE-3	Fe-, Mn-	Cu	0.42091	0.357	0.30769	0.23039	0.15996
		Fe	1.3082	0.96829	0.96284	1.07632	1.10143
		Mn	0.06467	0.07351	0.0667	0.07848	0.07573
		Zn	0.11208	0.11753	0.11796	0.11184	0.09907
		Al	0.30576	0.44436	0.50755	0.58022	0.45953
SSE-4	Organics	Cu	0.06845	0.06613	0.06296	0.0481	0.03976
		Fe	0.24898	0.23141	0.25214	0.21145	0.26894
		Mn	0.04984	0.05155	0.04289	0.04906	0.04115
		Zn	0.09821	0.10039	0.09172	0.08072	0.07181
		Al	0.50885	0.58635	0.61719	0.63636	0.65997
SSE-5	Residual	Cu	0.09223	0.10105	0.08093	0.06813	0.06853
		Fe	9.32475	9.66269	9.95113	8.90805	8.90957
		Mn	0.07931	0.08922	0.06637	0.07766	0.07732
		Zn	0.12408	0.12666	0.12765	0.1036	0.09546
		Al	23.4463	22.7266	23.6013	23.1067	21.9276
SSE tota	SSE1+2+	Cu	0.83255	0.75066	0.62698	0.49891	0.39428
		Fe	10.9222	10.8972	11.1959	10.2257	10.3111
		Mn	0.21564	0.23714	0.20002	0.23268	0.22731
		Zn	0.43152	0.43064	0.42044	0.37523	0.34586
		Al	24.5398	24.0675	25.0132	24.5223	23.1986
wt. wet soil T.D. (g)			2.0085	2.0027	1.992	2.0017	2.0073
amount of dry soil (g)			1.96508	1.96023	1.95089	1.96103	1.96687
Total digestion initial rinse		Cu	0.04077	0.01449	0.00488	0.00467	0.00813
		Fe	0.01093	0.01284	0.00545	0.02811	0.04468
		Mn	0.00478	0.00255	0.00094	0.00167	0.00311
		Zn	0.00832	0.00377	0.00226	0.00266	0.00287
		Al	0.00977	0.01041	0.00349	0.0104	0.04474
Total digestion		Cu	0.85481	0.76314	0.59486	0.48505	0.36523
		Fe	10.0997	10.9148	10.1263	9.55174	10.4375
		Mn	0.16866	0.20077	0.18252	0.21723	0.23733
		Zn	0.34526	0.34922	0.34468	0.29414	0.27092
		Al	20.7707	21.7872	22.3283	21.4928	22.5333
Recovery	SSE/tota	Cu	97.4%	98.4%	105.4%	102.9%	108.0%
		Fe	108.1%	99.8%	110.6%	107.1%	98.8%
		Mn	127.9%	118.1%	109.6%	107.1%	95.8%
		Zn	125.0%	123.3%	122.0%	127.6%	127.7%
		Al	118.1%	110.5%	112.0%	114.1%	103.0%

Soil analysis

CELL ID: **CPA1**

sample ID	0-10	10-20	20-30	30-40	40-50
distance up column (cm)	10	20	30	40	50
wt. container(g)	1.02	1.02	1.02	1.02	1.02
wt. wet soil+container (g)	16.86	19.14	18.91	22.21	19.13
wt. dry soil + container	16.46	18.63	18.29	21.43	18.59
water content, w%	0.02591	0.02896	0.0359	0.03822	0.03073
soil pH	3.85	4.12	4.22	4.37	4.41

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0078	2.0059	2.0061	1.9944	2.0097
equiv. dry soil wt (g)			1.9571	1.94944	1.93658	1.92099	1.94978
SSE-0	Initial rins	Cu	2.47	0.968	0.364	0.272	0.284
		Fe	0.159	0.131	0.174	0.285	2.582
		Mn	0.233	0.127	0.062	0.059	0.104
		Zn	0.456	0.1938	0.1357	0.1054	0.1118
		Al	0.35	0.17	0.23	0.22	4.69
SSE-1	Exchang	Cu	17.837	12.99	10.949	9.848	7.815
		Fe	2.095	0.583	0.399	0.379	0.343
		Mn	1.627	1.615	1.467	1.677	1.645
		Zn	8.5977	6.5177	6.1306	5.7504	4.7234
		Al	42.24	34.7	26.11	16.68	10.21
SSE-2	Carbonat	Cu	20.588	16.012	12.091	12.162	9.125
		Fe	5.72931	5.2019	4.28591	3.804	3.629
		Mn	1.772	1.809	1.441	1.587	1.499
		Zn	8.0489	6.0563	4.1393	4.0493	3.3021
		Al	1.42	6.78	12.92	11.84	9.36
SSE-3	Fe-, Mn-	Cu	19.337	18.63	14.756	13.336	9.714
		Fe	62.186	52.162	54.455	49.586	49.252
		Mn	2.766	3.483	3.8	3.66	3.775
		Zn	5.7008	5.9774	6.1552	6.2165	5.0116
		Al	13.8	18.34	23.18	22.63	21.04
SSE-4	Organics	Cu	3.589	3.253	2.962	2.563	1.98
		Fe	14.976	10.505	11.407	9.867	10.326
		Mn	2.036	2.761	2.741	2.223	2.322
		Zn	4.7483	4.9078	4.4659	4.0881	3.7748
		Al	28.09	33.58	33.5	40.34	32.88
SSE-5	Residual	Cu	3.97425	4.05075	3.86975	3.72825	3.39075
		Fe	449.06	469.99	513.71	434.06	442.07
		Mn	3.189	4.241	4.736	3.837	3.47
		Zn	5.44	5.8975	5.532	5.3144	4.704
		Al	1006.6	1096.1	1062	1026.3	925.3
wt. wet soil T.D. (g)			2.0088	2.0082	2.0013	1.9929	2.0093
amount of dry soil (g)			1.95807	1.95168	1.93194	1.91954	1.94939
Total digestion initial rinse		Cu	2.553	1.079	0.289	0.204	0.157
		Fe	0.371	0.111	0.119	0.395	1.361
		Mn	0.267	0.135	0.045	0.054	0.089
		Zn	0.5099	0.2654	0.1105	0.0498	0.0494
		Al	0.25	-0.03	-0.08	0.3	0.79
Total digestion		Cu	40.9513	37.1408	26.678	26.957	20.156
		Fe	488.56	520.68	509.36	495.19	493.28
		Mn	8.4	9.287	8.721	11.435	10.297
		Zn	16.6829	15.1091	11.6581	11.9988	13.6123
		Al	1079.1	1070.2	1069.4	1131	1052.7

sample ID			0-10	10-20	20-30	30-40	40-50
wt. wet soil (g)			2.0078	2.0059	2.0061	1.9944	2.0097
equiv. dry soil wt (g)			1.9571	1.94944	1.93658	1.92099	1.94978
SSE-0	Initial rins	Cu	0.02019	0.00794	0.00301	0.00227	0.00233
		Fe	0.0013	0.00108	0.00144	0.00237	0.02119
		Mn	0.0019	0.00104	0.00051	0.00049	0.00085
		Zn	0.00373	0.00159	0.00112	0.00088	0.00092
		Al	0.00286	0.0014	0.0019	0.00183	0.03849
SSE-1	Exchang	Cu	0.14582	0.10662	0.09046	0.08202	0.06413
		Fe	0.01713	0.00478	0.0033	0.00316	0.00281
		Mn	0.0133	0.01326	0.01212	0.01397	0.0135
		Zn	0.07029	0.05349	0.05065	0.0479	0.03876
		Al	0.34533	0.2848	0.21572	0.13893	0.08378
SSE-2	Carbonat	Cu	0.16831	0.13142	0.0999	0.1013	0.07488
		Fe	0.04684	0.04269	0.03541	0.03168	0.02978
		Mn	0.01449	0.01485	0.01191	0.01322	0.0123
		Zn	0.0658	0.04971	0.0342	0.03373	0.0271
		Al	0.01161	0.05565	0.10675	0.09862	0.07681
SSE-3	Fe-, Mn-	Cu	0.39522	0.38226	0.30479	0.27769	0.19928
		Fe	1.27098	1.0703	1.12477	1.03251	1.01041
		Mn	0.05653	0.07147	0.07849	0.07621	0.07744
		Zn	0.11652	0.12265	0.12714	0.12944	0.10281
		Al	0.28205	0.37631	0.47878	0.47122	0.43164
SSE-4	Organics	Cu	0.07335	0.06675	0.06118	0.05337	0.04062
		Fe	0.30609	0.21555	0.23561	0.20546	0.21184
		Mn	0.04161	0.05665	0.05662	0.04629	0.04764
		Zn	0.09705	0.1007	0.09224	0.08513	0.07744
		Al	0.57412	0.68902	0.69194	0.83999	0.67454
SSE-5	Residual	Cu	0.08123	0.08312	0.07993	0.07763	0.06956
		Fe	9.17808	9.64358	10.6107	9.03827	9.06915
		Mn	0.06518	0.08702	0.09782	0.0799	0.07119
		Zn	0.11119	0.12101	0.11426	0.11066	0.0965
		Al	20.5733	22.4905	21.9356	21.3703	18.9827
SSE total	SSE1+2+	Cu	0.86394	0.77016	0.63625	0.59201	0.44848
		Fe	10.8191	10.9769	12.0098	10.3111	10.324
		Mn	0.19111	0.24324	0.25695	0.22958	0.22207
		Zn	0.46084	0.44756	0.41849	0.40685	0.34262
		Al	21.7864	23.8963	23.4288	22.919	20.2495
wt. wet soil T.D. (g)			2.0088	2.0082	2.0013	1.9929	2.0093
amount of dry soil (g)			1.95807	1.95168	1.93194	1.91954	1.94939
Total digestion initial rinse		Cu	0.05215	0.02211	0.00598	0.00425	0.00322
		Fe	0.00758	0.00227	0.00246	0.00823	0.02793
		Mn	0.00545	0.00277	0.00093	0.00113	0.00183
		Zn	0.01042	0.00544	0.00229	0.00104	0.00101
		Al	0.00511	-0.0006	-0.0017	0.00625	0.01621
Total digestion		Cu	0.83656	0.76121	0.55236	0.56174	0.41359
		Fe	9.98043	10.6714	10.5461	10.3189	10.1217
		Mn	0.1716	0.19034	0.18056	0.23829	0.21129
		Zn	0.3408	0.30966	0.24138	0.25003	0.27931
		Al	22.0441	21.9339	22.1414	23.5681	21.6006
Recovery	SSE/total	Cu	103.3%	101.2%	115.2%	105.4%	108.4%
		Fe	108.4%	102.9%	113.9%	99.9%	102.0%
		Mn	111.4%	127.8%	142.3%	96.3%	105.1%
		Zn	135.2%	144.5%	173.4%	162.7%	122.7%
		Al	98.8%	108.9%	105.8%	97.2%	93.7%

Appendix J. Results of soil analyses on tested clinoptilolite from Critical Path Analysis leaching column cells

J-2. Numerical and graphical presentation of metal partitioning on clinoptilolite after subtracting background concentration from 1M treated clinoptilolite

CPA8 14.6911 pore volumes

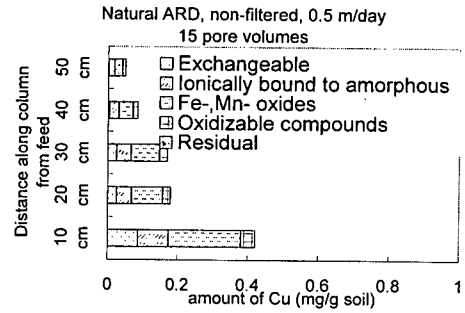
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.00013	0.00076	0.00098	0.00076	0.000221
Exchangeabl	0.08648	0.02568	0.02449	0.00342	0.000635
Ionically bour	0.08809	0.04328	0.04213	0.02736	0.017204
Fe-,Mn- oxide	0.20661	0.0885	0.0814	0.04062	0.022854
Oxidizable co	0.04112	0.02318	0.02326	0.01448	0.009648
Residual	0	0	0	0	0
SSE-sum	0.42244	0.1814	0.17227	0.08664	0.050562
Total digestio	0.00352	0.00961	0.00758	0.00672	0.007096
Total digestio	1.01593	0.60222	0.53431	0.42159	0.365409

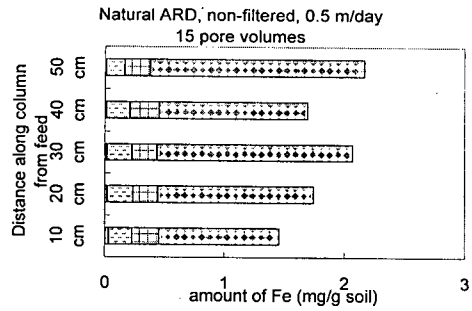
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0263	0.10364	0.10921	0.15415	0.16568
Exchangeabl	0.00413	0.0018	0.00309	0.00162	0.001066
Ionically bour	0.02821	0.01834	0.01573	0.01223	0.008008
Fe-,Mn- oxide	0.19655	0.2179	0.21027	0.19653	0.155636
Oxidizable co	0.22619	0.20546	0.20953	0.24519	0.212191
Residual	1.00551	1.30421	1.63192	1.24027	1.791366
SSE-sum	1.46059	1.74771	2.07053	1.69586	2.168267
Total digestio	0.1142	0.6249	0.44577	0.62399	0.909772
Total digestio	-1.0843	-0.7968	-1.2882	-1.3937	-1.07889

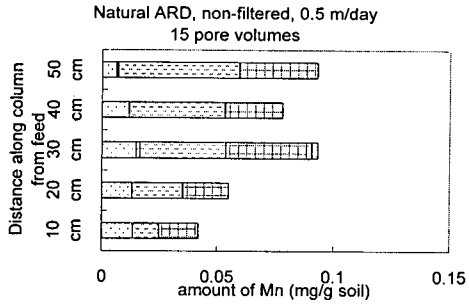
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0011	-0.0008	-0.0006	-0.0003	-0.00011
Exchangeabl	0.01345	0.01329	0.01494	0.01178	0.006207
Ionically bour	-0.0019	-0.0029	0.00169	-0.0001	0.000721
Fe-,Mn- oxide	0.01152	0.022	0.03708	0.0416	0.052513
Oxidizable co	0.01718	0.01979	0.03708	0.02486	0.033689
Residual	-0.0002	-0.0049	0.00269	-0.0008	-0.00166
SSE-sum	0.04003	0.04725	0.09348	0.07727	0.091471
Total digestio	-0.0029	0.00071	-3E-05	0.00147	0.003936
Total digestio	-0.0151	-0.0094	-0.0181	-0.0295	-0.00822

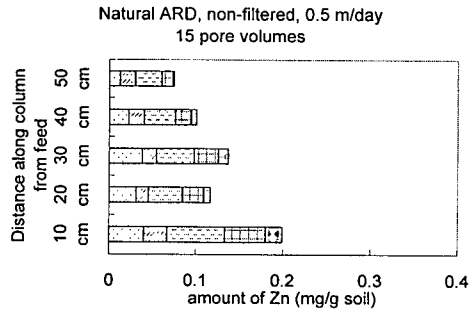
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.00026	0.00124	0.00167	0.00292	0.002994
Exchangeabl	0.04029	0.03129	0.03794	0.02234	0.012359
Ionically bour	0.0268	0.01433	0.01699	0.01828	0.017794
Fe-,Mn- oxide	0.06657	0.03947	0.0433	0.03578	0.030553
Oxidizable co	0.04664	0.02403	0.02763	0.01837	0.012974
Residual	0.01928	0.008	0.01176	0.00637	0.001699
SSE-sum	0.19958	0.11713	0.13762	0.10113	0.075378
Total digestio	0.0018	0.00959	0.00822	0.01241	0.017773
Total digestio	0.23615	0.13885	0.15418	0.10658	0.085273

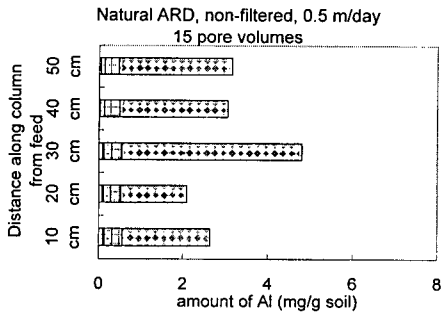
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.01128	0.06153	0.0631	0.10333	0.112644
Exchangeabl	0.09469	0.07128	0.07805	0.00689	0.040832
Ionically bour	0.04113	0.03542	0.03608	0.01411	0.005718
Fe-,Mn- oxide	0.18969	0.17691	0.19033	0.10914	0.093412
Oxidizable co	0.24065	0.23486	0.23941	0.36718	0.336149
Residual	2.0806	1.58087	4.2694	2.57102	2.692657
SSE-sum	2.64676	2.09934	4.81326	3.06834	3.168768
Total digestio	-0.0799	0.461	0.29078	0.50927	0.849517
Total digestio	0.41462	4.3793	2.72256	0.47059	0.327038











CPA8

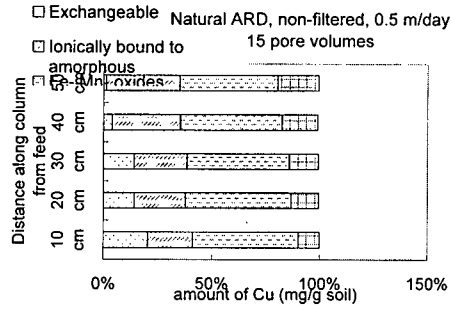
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	20.47%	14.16%	14.21%	3.95%	1.26%
Ionically bour	20.85%	23.86%	24.46%	31.58%	34.03%
Fe-,Mn- oxide	48.91%	48.79%	47.26%	46.88%	45.20%
Oxidizable co	9.73%	12.78%	13.50%	16.71%	19.08%
Residual	0.00%	0.00%	0.00%	0.00%	0.00%
SSE-sum	100%	100%	99%	99%	100%
Total digestio	0.0159809	0.0023644	0.0013299	0.0022209	0.00154
Total digestio	0.4550629	0.3274629	0.2235737	0.3185298	0.27638

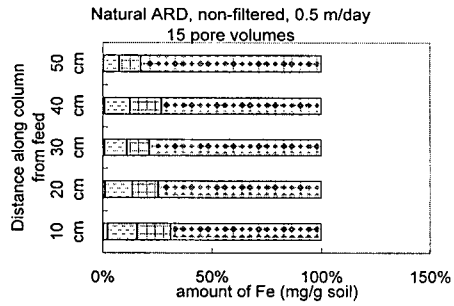
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	0.28%	0.10%	0.15%	0.10%	0.05%
Ionically bour	1.93%	1.05%	0.76%	0.72%	0.37%
Fe-,Mn- oxide	13.46%	12.47%	10.16%	11.59%	7.18%
Oxidizable co	15.49%	11.76%	10.12%	14.46%	9.79%
Residual	68.84%	74.62%	78.82%	73.14%	82.62%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.0603088	-0.0517382	-0.0537327	-0.0588651	-0.0574
Total digestio	0.8364882	0.3226452	-0.1032376	-0.1851873	0.35734

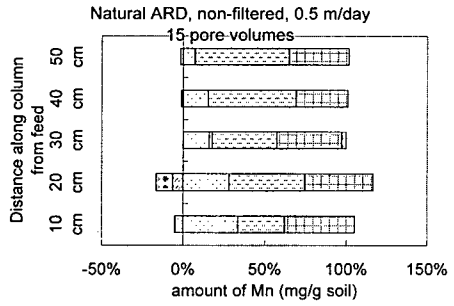
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	33.59%	28.12%	15.98%	15.25%	6.79%
Ionically bour	-4.76%	-6.10%	1.81%	-0.16%	0.79%
Fe-,Mn- oxide	28.79%	46.56%	39.67%	53.84%	57.41%
Oxidizable co	42.92%	41.89%	39.67%	32.18%	36.83%
Residual	-0.54%	-10.47%	2.87%	-1.10%	-1.81%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.0028874	-0.0033943	-0.0034833	-0.0034922	-0.0036
Total digestio	-0.0363956	-0.0430407	-0.0584578	-0.0548307	-0.0629

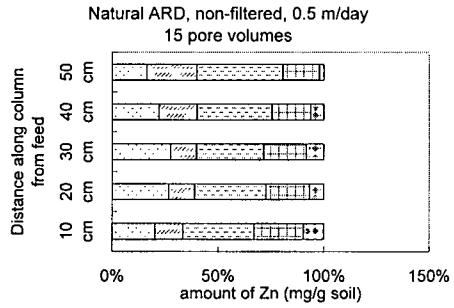
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	20.19%	26.71%	27.57%	22.09%	16.40%
Ionically bour	13.43%	12.24%	12.35%	18.07%	23.61%
Fe-,Mn- oxide	33.36%	33.70%	31.46%	35.38%	40.53%
Oxidizable co	23.37%	20.52%	20.08%	18.16%	17.21%
Residual	9.66%	6.83%	8.54%	6.30%	2.25%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	0.0009636	0.0001252	0.0002594	1.955E-05	-0.0006
Total digestio	0.2587575	0.2433951	0.2263064	0.2681074	0.25867

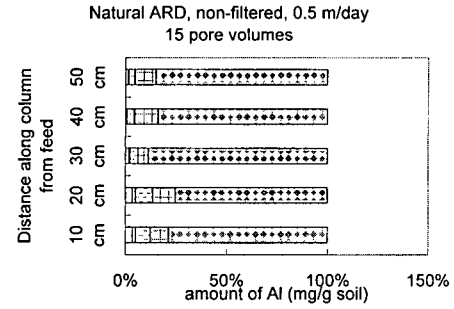
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	3.58%	3.40%	1.62%	0.22%	1.29%
Ionically bour	1.55%	1.69%	0.75%	0.46%	0.18%
Fe-,Mn- oxide	7.17%	8.43%	3.95%	3.56%	2.95%
Oxidizable co	9.09%	11.19%	4.97%	11.97%	10.61%
Residual	78.61%	75.30%	88.70%	83.79%	84.97%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.2293291	-0.2248283	-0.2286687	-0.2295414	-0.226
Total digestio	1.1326381	2.1707136	-1.2011856	1.0638715	1.21577











CPA7 26.1675 pore volumes

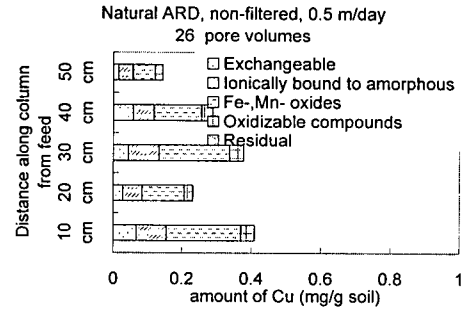
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.00017	0.00111	0.00025	0.00114	0.00135
Exchange	0.06677	0.02782	0.0442	0.05773	0.01524
Ionically b	0.08768	0.0562	0.08912	0.06026	0.04181
Fe-,Mn- o	0.21619	0.12236	0.20386	0.13812	0.06442
Oxidizable	0.03957	0.02553	0.04194	0.03331	0.02305
Residual	0	0	0	0	0
SSE-sum	0.41037	0.23302	0.37937	0.29056	0.14587
Total dige	0.00273	0.00791	0.00127	0.00909	0.00623
Total dige	1.00091	0.42291	0.90606	0.67538	0.50458

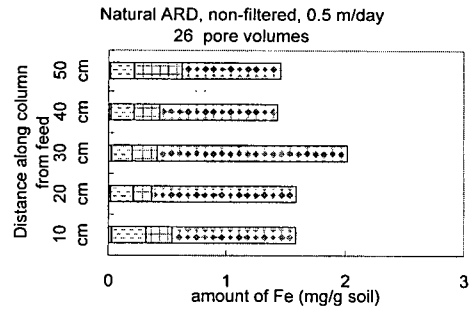
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.0314	0.09021	0.02634	0.07104	0.11734
Exchange	0.0017	0.00076	7.8E-05	0.00245	0.00142
Ionically b	0.02774	0.01866	0.02639	0.01958	0.01335
Fe-,Mn- o	0.29181	0.19246	0.17764	0.19412	0.20421
Oxidizable	0.22049	0.15569	0.21162	0.21693	0.4071
Residual	1.04617	1.22274	1.60727	0.99861	0.83312
SSE-sum	1.58791	1.59032	2.02299	1.43169	1.4592
Total dige	0.13587	0.42922	0.08757	0.39495	0.43803
Total dige	-0.39897	-4.7342	-1.793	-0.8479	-1.6512

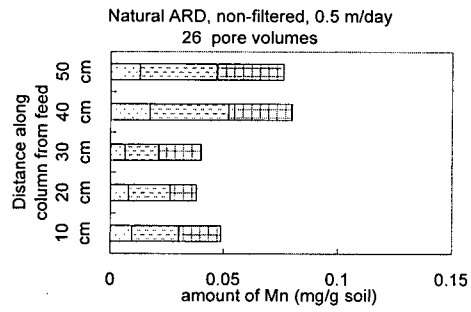
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	-0.00113	-0.0007	-0.0011	-0.0008	-0.0004
Exchange	0.00948	0.00801	0.00644	0.01729	0.01291
Ionically b	-0.00283	-0.0052	-0.0005	-0.0009	-0.0004
Fe-,Mn- o	0.02095	0.01841	0.01492	0.03475	0.0339
Oxidizable	0.01848	0.01167	0.01885	0.02763	0.02945
Residual	-0.00582	-0.0098	-0.0006	0.0004	-0.0045
SSE-sum	0.04026	0.02314	0.03904	0.07919	0.0713
Total dige	-0.00255	-0.0009	-0.0031	-0.0009	-5E-05
Total dige	-0.00379	-0.1057	-0.0169	-0.0227	-0.0076

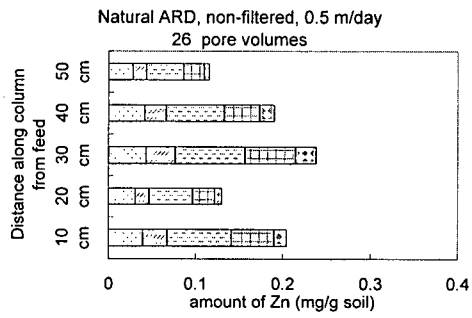
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.00026	0.00069	4.2E-05	0.00109	0.00194
Exchange	0.03945	0.03042	0.04318	0.04182	0.02807
Ionically b	0.02833	0.01645	0.03402	0.02505	0.01557
Fe-,Mn- o	0.07347	0.05005	0.0797	0.06588	0.04293
Oxidizable	0.04877	0.02514	0.05754	0.04108	0.02364
Residual	0.01465	0.00852	0.02398	0.01693	0.00595
SSE-sum	0.20465	0.1306	0.23841	0.19076	0.11616
Total dige	0.00288	0.00741	0.00245	0.00826	0.00931
Total dige	0.2233	0.06466	0.24456	0.19986	0.1157

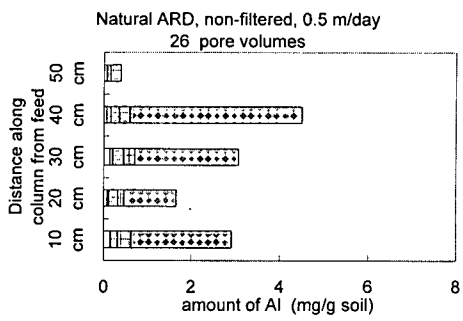
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.01697	0.05647	0.01631	0.05791	0.08974
Exchange	0.13936	0.07938	0.14184	0.05998	0.05772
Ionically b	0.02827	0.03975	0.06501	0.10369	0.02152
Fe-,Mn- o	0.15552	0.21324	0.25369	0.18503	0.07224
Oxidizable	0.30007	0.12868	0.2482	0.25464	0.2411
Residual	2.29881	1.2058	2.36562	3.90371	-1.423
SSE-sum	2.92204	1.66686	3.07436	4.50704	-1.0304
Total dige	-0.04762	0.21995	-0.1028	0.20045	0.28918
Total dige	0.65914	-8.6813	1.06082	1.58236	-2.5059











CPA7 minus conc leached by bulk clinoı (%)

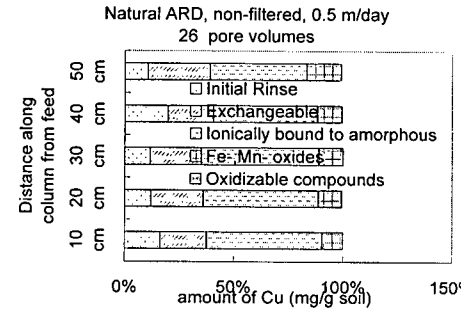
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	16.27%	11.94%	11.65%	19.87%	10.44%
Ionically b	21.37%	24.12%	23.49%	20.74%	28.66%
Fe-,Mn- o	52.68%	52.51%	53.74%	47.54%	44.17%
Oxidizable	9.64%	10.96%	11.06%	11.46%	15.80%
Residual	0.00%	0.00%	0.00%	0.00%	0.00%
SSE-sum	100%	100%	100%	100%	99%
Total dige	0.0272	0.010064	0.006336	0.005103	0.003023
Total dige	0.5014	0.511395	0.396896	0.352674	0.29728

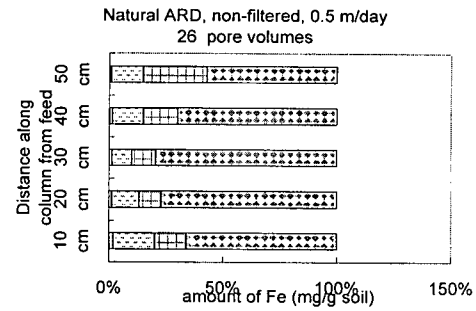
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	0.11%	0.05%	0.00%	0.17%	0.10%
Ionically b	1.75%	1.17%	1.30%	1.37%	0.91%
Fe-,Mn- o	18.38%	12.10%	8.78%	13.56%	13.99%
Oxidizable	13.89%	9.79%	10.46%	15.15%	27.90%
Residual	65.88%	76.89%	79.45%	69.75%	57.09%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.03728	-0.037911	-0.03801	-0.03571	-0.03408
Total dige	-1.4017	-0.661033	-0.39904	-0.21189	-1.8256

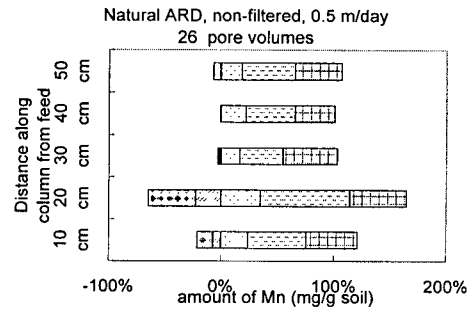
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	23.54%	34.64%	16.51%	21.83%	18.11%
Ionically b	-7.03%	-22.49%	-1.40%	-1.12%	-0.58%
Fe-,Mn- o	52.04%	79.57%	38.21%	43.88%	47.55%
Oxidizable	45.89%	50.44%	48.30%	34.89%	41.31%
Residual	-14.45%	-42.16%	-1.62%	0.51%	-6.38%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.00146	-0.002248	-0.00261	-0.00261	-0.00306
Total dige	-0.10556	-0.082915	-0.07687	-0.0557	-0.05724

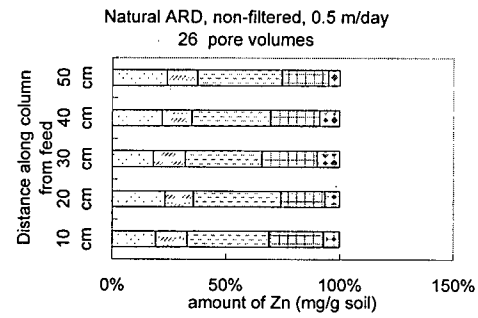
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	19.27%	23.30%	18.11%	21.92%	24.16%
Ionically b	13.84%	12.60%	14.27%	13.13%	13.40%
Fe-,Mn- o	35.90%	38.33%	33.43%	34.54%	36.96%
Oxidizable	23.83%	19.25%	24.13%	21.53%	20.35%
Residual	7.16%	6.52%	10.06%	8.87%	5.12%
SSE-sum	100%	100%	100%	100%	100%
Total dige	0.00392	0.001842	0.0013	0.001023	0.000404
Total dige	0.16353	0.186653	0.178546	0.172424	0.186624

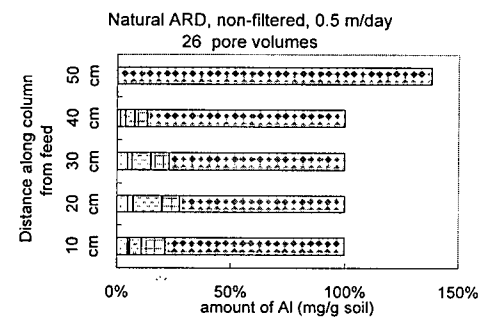
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	4.77%	4.76%	4.61%	1.33%	-5.60%
Ionically b	0.97%	2.38%	2.11%	2.30%	-2.09%
Fe-,Mn- o	5.32%	12.79%	8.25%	4.11%	-7.01%
Oxidizable	10.27%	7.72%	8.07%	5.65%	-23.40%
Residual	78.67%	72.34%	76.95%	86.61%	138.10%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.01468	-0.016125	-0.01694	-0.01406	-0.01345
Total dige	0.05791	0.583077	-0.40038	2.606505	1.053072











CPA6 38.2096 pore volumes

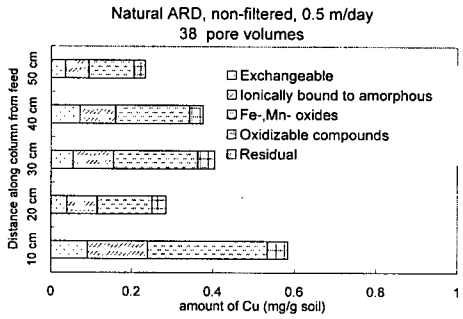
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.0002	0.00105	6.17E-05	0.00067	0.001106
Exchangeabl	0.09101	0.03968	0.0543497	0.071074	0.035268
Ionically bour	0.14845	0.07547	0.1011403	0.089031	0.057898
Fe-,Mn- oxide	0.2937	0.13537	0.2068908	0.181792	0.112059
Oxidizable co	0.05116	0.03424	0.0421693	0.03405	0.028046
Residual	0	0	0	0	0
SSE-sum	0.58452	0.28582	0.4046119	0.376618	0.234376
Total digestio	0.00335	0.01156	0.0031006	0.005587	0.006672
Total digestio	1.15012	0.63649	0.9077537	0.766049	0.642984

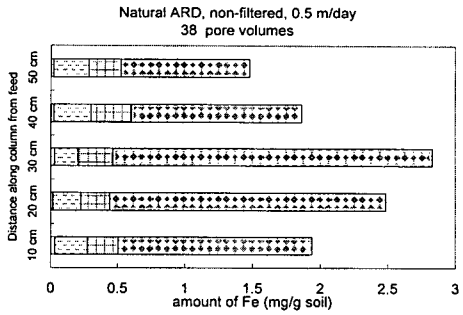
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0126	0.0841	0.0122419	0.04375	0.069996
Exchangeabl	0.00254	0.00133	0.000774	0.002447	0.001814
Ionically bour	0.03129	0.01579	0.0295489	0.022056	0.017535
Fe-,Mn- oxide	0.24154	0.20866	0.1750319	0.277208	0.263763
Oxidizable co	0.23022	0.21644	0.2587838	0.299631	0.241353
Residual	1.43416	2.04291	2.3668399	1.262498	0.952946
SSE-sum	1.93975	2.48513	2.8309785	1.863841	1.477411
Total digestio	0.03153	0.42605	0.036805	0.155326	0.251244
Total digestio	-1.4842	-2.1784	-1.551085	-2.143339	-2.42017

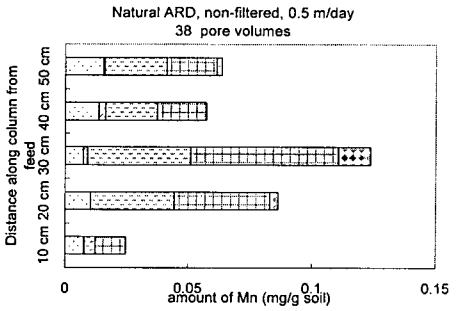
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0012	-0.0008	-0.00118	-0.001035	-0.00075
Exchangeabl	0.00767	0.01036	0.0074415	0.013749	0.015589
Ionically bour	0.00021	-0.0004	0.0017436	0.002663	0.000589
Fe-,Mn- oxide	0.00462	0.03405	0.0418589	0.021115	0.025106
Oxidizable co	0.01233	0.03871	0.059575	0.019932	0.020232
Residual	-0.0046	0.00332	0.0130764	-0.002472	0.002187
SSE-sum	0.02019	0.08605	0.1236954	0.054988	0.063703
Total digestio	-0.0028	0.00079	-0.002903	-0.001994	-0.00114
Total digestio	-0.0423	-0.0204	-0.030071	-0.035047	-0.00893

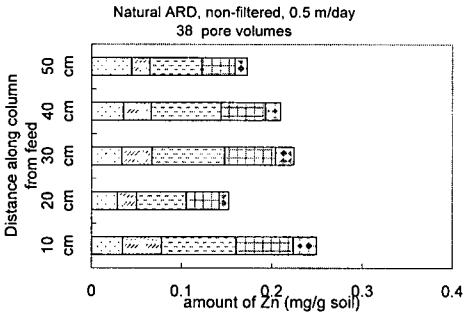
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0002	0.00076	-3.84E-05	5.11E-06	0.000822
Exchangeabl	0.0347	0.02885	0.0338851	0.035357	0.044582
Ionically bour	0.04337	0.02151	0.0337321	0.031128	0.020305
Fe-,Mn- oxide	0.08224	0.05544	0.0801633	0.07761	0.057669
Oxidizable co	0.06345	0.03616	0.0565033	0.048688	0.036793
Residual	0.02578	0.01073	0.0202918	0.017147	0.013604
SSE-sum	0.24954	0.15269	0.2245758	0.20993	0.172954
Total digestio	0.00099	0.00162	-2.37E-05	0.002135	0.001286
Total digestio	0.24661	0.14276	0.2275068	0.203462	0.188806

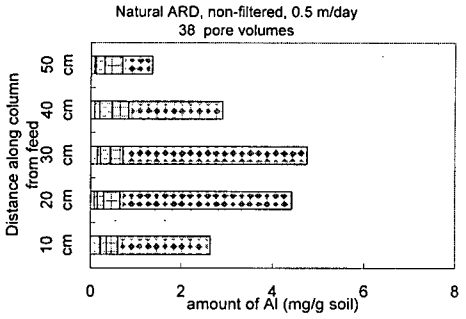
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.00328	0.07031	0.0163545	0.03961	0.061179
Exchangeabl	0.20461	0.08386	0.1526075	0.092879	0.081788
Ionically bour	0.01599	0.06456	0.067493	0.108504	0.035184
Fe-,Mn- oxide	0.13716	0.14451	0.2164204	0.274853	0.192574
Oxidizable co	0.24601	0.36114	0.2797041	0.359236	0.388363
Residual	2.04149	3.76943	4.0362448	2.075215	0.662166
SSE-sum	2.64525	4.42351	4.7524697	2.910687	1.360075
Total digestio	-0.2452	-0.2452	-0.244751	-0.244856	-0.24462
Total digestio	-3.1557	-5.4957	-5.013447	-5.049071	-3.13367











CPA6

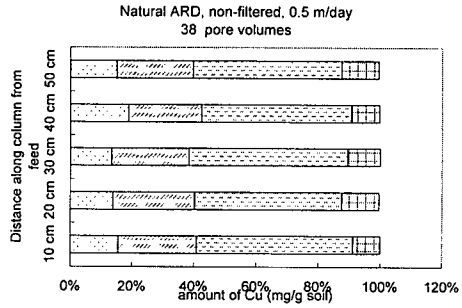
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	15.57%	13.88%	13.43%	18.87%	15.05%
Ionically bour	25.40%	26.41%	25.00%	23.64%	24.70%
Fe-,Mn- oxide	50.25%	47.36%	51.13%	48.27%	47.81%
Oxidizable co	8.75%	11.98%	10.42%	9.04%	11.97%
Residual	0.00%	0.00%	0.00%	0.00%	0.00%
SSE-sum	100%	100%	100%	100%	100%
Total digestio	0.01598	0.00236	0.00133	0.002221	0.00154
Total digestio	0.45506	0.32746	0.22357	0.31853	0.27638

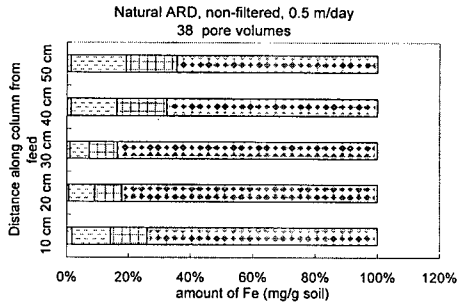
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	0.13%	0.05%	0.03%	0.13%	0.12%
Ionically bour	1.61%	0.64%	1.04%	1.18%	1.19%
Fe-,Mn- oxide	12.45%	8.40%	6.18%	14.87%	17.85%
Oxidizable co	11.87%	8.71%	9.14%	16.08%	16.34%
Residual	73.94%	82.21%	83.61%	67.74%	64.50%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.06031	-0.0517	-0.05373	-0.058865	-0.0574
Total digestio	0.83649	0.32265	-0.10324	-0.185187	0.35734

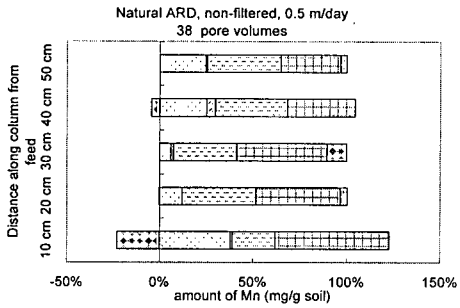
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	37.97%	12.04%	6.02%	25.00%	24.47%
Ionically bour	1.05%	-0.45%	1.41%	4.84%	0.93%
Fe-,Mn- oxide	22.87%	39.57%	33.84%	38.40%	39.41%
Oxidizable co	61.03%	44.99%	48.16%	36.25%	31.76%
Residual	-22.92%	3.86%	10.57%	-4.50%	3.43%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.00289	-0.0034	-0.00348	-0.003492	-0.0036
Total digestio	-0.0364	-0.043	-0.05846	-0.054831	-0.0629

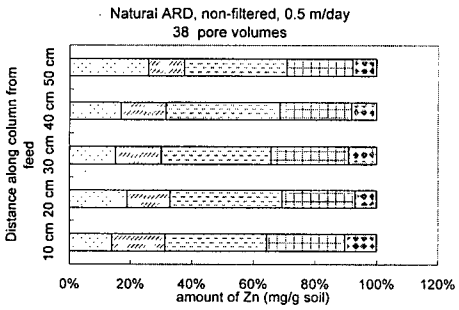
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	13.91%	18.90%	15.09%	16.84%	25.78%
Ionically bour	17.38%	14.09%	15.02%	14.83%	11.74%
Fe-,Mn- oxide	32.96%	36.31%	35.70%	36.97%	33.34%
Oxidizable co	25.43%	23.68%	25.16%	23.19%	21.27%
Residual	10.33%	7.02%	9.04%	8.17%	7.87%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	0.00096	0.00013	0:00026	1.96E-05	-0.0006
Total digestio	0.25876	0.2434	0.22631	0.268107	0.25867

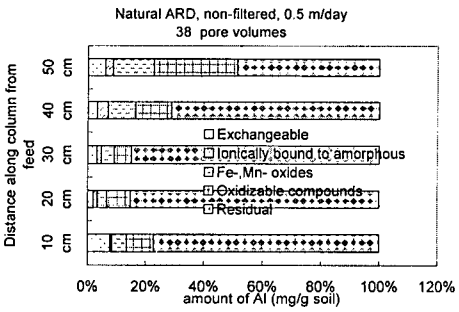
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	7.73%	1.90%	3.21%	3.19%	6.01%
Ionically bour	0.60%	1.46%	1.42%	3.73%	2.59%
Fe-,Mn- oxide	5.19%	3.27%	4.55%	9.44%	14.16%
Oxidizable co	9.30%	8.16%	5.89%	12.34%	28.55%
Residual	77.18%	85.21%	84.93%	71.30%	48.69%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.22933	-0.2248	-0.22867	-0.229541	-0.226
Total digestio	1.13264	2.17071	-1.20119	1.063872	1.21577











CPA5 44.9171 pore volumes

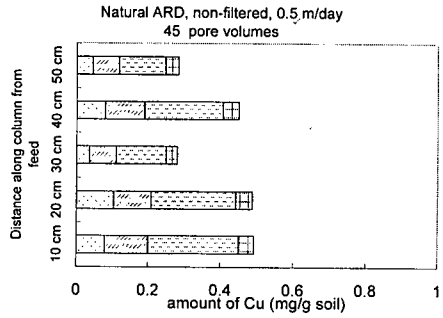
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.000511	0.00044	0.00101	0.00011	0.00107
Exchange	0.07902	0.10358	0.03635	0.07984	0.04493
Ionically b	0.120624	0.10493	0.07449	0.10938	0.07333
Fe-,Mn- o	0.249973	0.23407	0.13851	0.21705	0.12919
Oxidizable	0.043435	0.04594	0.03142	0.04394	0.03633
Residual	0	0	0	0	0
SSE-sum	0.493564	0.48897	0.28179	0.45033	0.28485
Total dige	0.003198	0.00346	0.00321	0.00389	0.0012
Total dige	1.266726	1.1552	1.01709	1.05329	0.99622

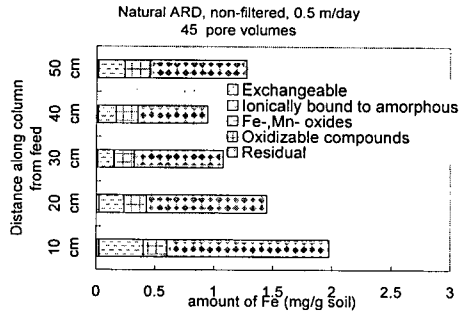
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.02031	0.01743	0.06048	0.00774	0.06545
Exchange	0.002138	0.00269	0.00115	0.00219	0.00144
Ionically b	0.023248	0.01906	0.0097	0.01488	0.01285
Fe-,Mn- o	0.378177	0.21521	0.13775	0.15102	0.22618
Oxidizable	0.199239	0.19223	0.17369	0.18583	0.21618
Residual	1.371879	1.01833	0.75745	0.59282	0.8213
SSE-sum	1.974681	1.44753	1.07974	0.94672	1.27794
Total dige	-0.03945	0.09227	0.09187	0.09538	-0.017
Total dige	0.054975	0.37887	-0.6093	-0.3436	-0.8031

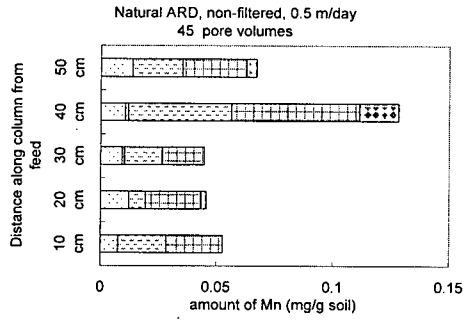
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	-0.00115	-0.0011	-0.0008	-0.0012	-0.0008
Exchange	0.00763	0.01236	0.00929	0.01073	0.01377
Ionically b	-0.00364	-0.0025	0.00104	0.00126	-0.001
Fe-,Mn- o	0.02091	0.00718	0.01638	0.04454	0.0216
Oxidizable	0.024366	0.02391	0.01814	0.05489	0.02748
Residual	-0.00067	0.00235	-0.0016	0.01684	0.00441
SSE-sum	0.048596	0.04329	0.04327	0.12827	0.06624
Total dige	-0.00288	-0.0022	-0.0023	-0.002	-0.0029
Total dige	-0.01918	-0.0029	0.00617	0.00585	0.00723

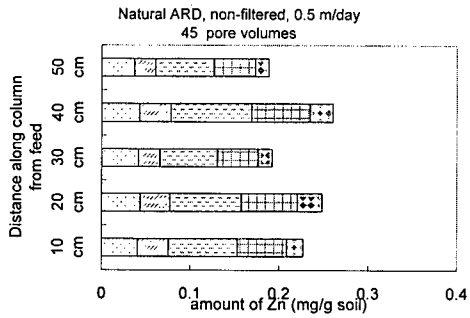
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	-0.00031	-0.0002	0.00063	-0.0004	0.00057
Exchange	0.040843	0.0438	0.04183	0.04303	0.03713
Ionically b	0.035068	0.03353	0.02437	0.03536	0.02391
Fe-,Mn- o	0.077824	0.08071	0.06499	0.09105	0.0658
Oxidizable	0.055497	0.06288	0.0456	0.06516	0.04654
Residual	0.018271	0.02765	0.01583	0.02591	0.01547
SSE-sum	0.227503	0.24858	0.19263	0.2605	0.18885
Total dige	0.000501	0.00166	0.00223	0.0019	0.00142
Total dige	0.286771	0.29269	0.2733	0.2869	0.29484

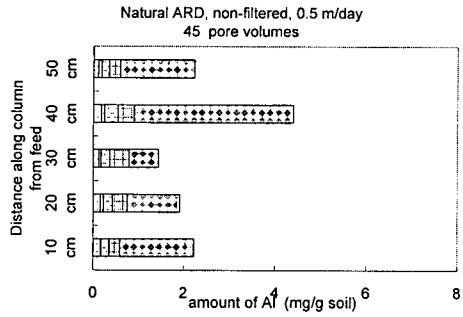
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.025808	0.02071	0.05483	0.02229	0.06008
Exchange	0.168087	0.15815	0.12282	0.17513	0.102
Ionically b	0.013285	0.06898	0.05078	0.07069	0.08085
Fe-,Mn- o	0.175595	0.20265	0.19405	0.29882	0.1646
Oxidizable	0.238369	0.32457	0.42619	0.36125	0.24492
Residual	1.633813	1.1615	0.65401	3.49703	1.6431
SSE-sum	2.229149	1.91586	1.44785	4.40293	2.23546
Total dige	-0.21736	-0.0913	-0.0901	-0.095	-0.198
Total dige	-1.87836	0.80167	-0.891	-0.606	-2.4014











CPA5 minus conc leached by bulk clinop (%)

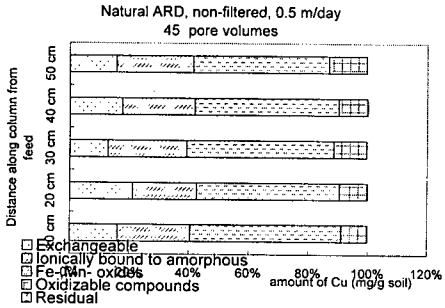
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	16.01%	21.18%	12.90%	17.73%	15.77%
Ionically b	24.44%	21.46%	26.44%	24.29%	25.74%
Fe-,Mn- o	50.65%	47.87%	49.15%	48.20%	45.35%
Oxidizable	8.80%	9.40%	11.15%	9.76%	12.75%
Residual	0.00%	0.00%	0.00%	0.00%	0.00%
SSE-sum	100%	100%	100%	100%	100%
Total dige	0.0272	0.0100645	0.006336	0.005103	0.003023
Total dige	0.501398	0.5113945	0.396896	0.352674	0.29728

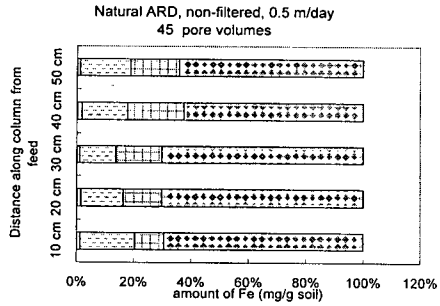
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	0.11%	0.19%	0.11%	0.23%	0.11%
Ionically b	1.18%	1.32%	0.90%	1.57%	1.01%
Fe-,Mn- o	19.15%	14.87%	12.76%	15.95%	17.70%
Oxidizable	10.09%	13.28%	16.09%	19.63%	16.92%
Residual	69.47%	70.35%	70.15%	62.62%	64.27%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.03728	-0.037911	-0.038008	-0.035715	-0.034083
Total dige	-1.4017	-0.661033	-0.399035	-0.211892	-1.825599

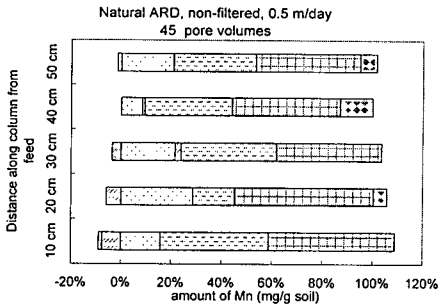
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	15.70%	28.55%	21.47%	8.37%	20.79%
Ionically b	-7.49%	-5.81%	2.39%	0.98%	-1.53%
Fe-,Mn- o	43.03%	16.59%	37.85%	34.72%	32.61%
Oxidizable	50.14%	55.24%	41.91%	42.79%	41.48%
Residual	-1.38%	5.43%	-3.62%	13.13%	6.65%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.00146	-0.002248	-0.002613	-0.002608	-0.003062
Total dige	-0.10556	-0.082915	-0.076871	-0.055702	-0.05724

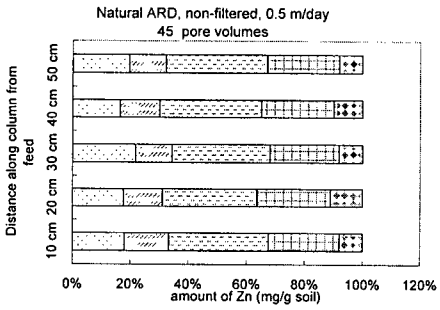
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	17.95%	17.62%	21.72%	16.52%	19.66%
Ionically b	15.41%	13.49%	12.65%	13.57%	12.66%
Fe-,Mn- o	34.21%	32.47%	33.74%	34.95%	34.84%
Oxidizable	24.39%	25.30%	23.67%	25.02%	24.64%
Residual	8.03%	11.12%	8.22%	9.94%	8.19%
SSE-sum	100%	100%	100%	100%	100%
Total dige	0.003918	0.0018417	0.0013	0.001023	0.000404
Total dige	0.163527	0.1866525	0.178546	0.172424	0.186624

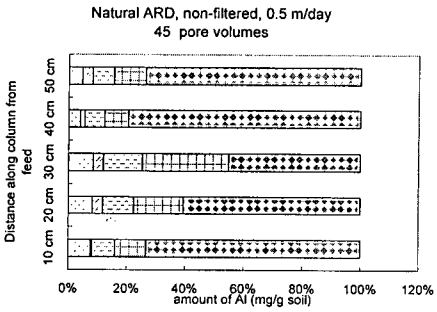
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	7.54%	8.25%	8.48%	3.98%	4.56%
Ionically b	0.60%	3.60%	3.51%	1.61%	3.62%
Fe-,Mn- o	7.88%	10.58%	13.40%	6.79%	7.36%
Oxidizable	10.69%	16.94%	29.44%	8.20%	10.96%
Residual	73.29%	60.63%	45.17%	79.43%	73.50%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.01468	-0.016125	-0.016941	-0.014062	-0.013452
Total dige	0.057913	0.5830768	-0.40038	2.606505	1.053072











CPA4 56.8406 pore volumes

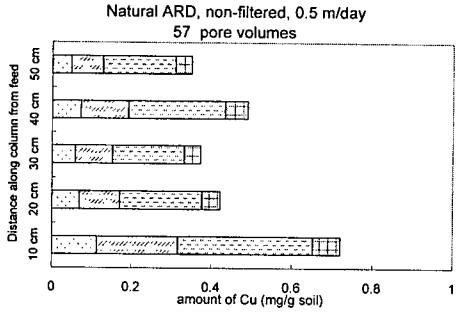
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.00493	0.00073	0.00091	-0.0005	0.000919
Exchangeabl	0.11309	0.06841	0.059	0.07199	0.047429
Ionically bour	0.2033	0.10233	0.0933	0.11977	0.079816
Fe-,Mn- oxide	0.33628	0.20637	0.17998	0.24124	0.182607
Oxidizable co	0.06854	0.04559	0.0408	0.05766	0.041087
Residual	0	0	0	0	0
SSE-sum	0.72614	0.42342	0.37399	0.49014	0.351858
Total digestio	0.01613	0.00441	0.00615	0.00139	0.004772
Total digestio	1.85696	1.10049	0.90111	1.28444	0.964251

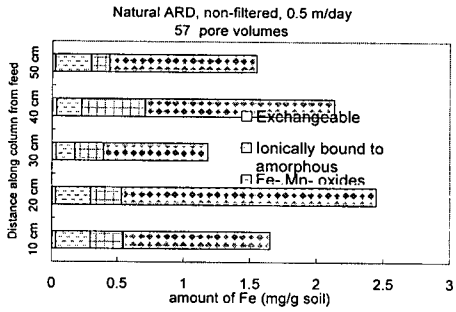
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0365	0.03479	0.03368	-0.0125	0.025242
Exchangeabl	0.00391	0.0018	0.00152	0.00156	0.000593
Ionically bour	0.02889	0.02942	0.03006	0.03355	0.02162
Fe-,Mn- oxide	0.26279	0.26543	0.14308	0.19156	0.274352
Oxidizable co	0.24961	0.23511	0.21842	0.48143	0.139332
Residual	1.11018	1.91818	0.79238	1.4265	1.112484
SSE-sum	1.65538	2.44995	1.18546	2.1346	1.54838
Total digestio	-0.0591	0.12869	0.16377	-0.0282	0.116981
Total digestio	0.76669	1.17018	0.7784	0.96699	0.931797

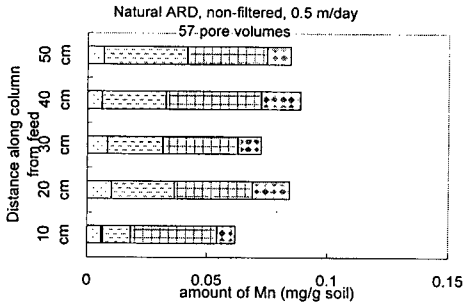
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0007	-0.001	-0.001	-0.0014	-0.00111
Exchangeabl	0.00597	0.01014	0.00831	0.0061	0.006695
Ionically bour	0.00074	-0.0022	-0.0014	-0.0012	-0.00189
Fe-,Mn- oxide	0.01172	0.02635	0.02333	0.02689	0.035027
Oxidizable co	0.03603	0.03244	0.0313	0.03943	0.032977
Residual	0.00751	0.0155	0.00966	0.0164	0.009968
SSE-sum	0.06198	0.08226	0.07119	0.0876	0.082779
Total digestio	-0.0014	-0.0019	-0.0019	-0.0031	-0.00204
Total digestio	-0.0175	-0.012	0.01315	0.02424	0.025317

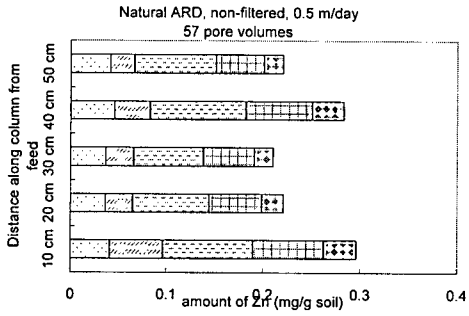
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.00014	-6E-05	-0.0002	-0.0008	-0.00015
Exchangeabl	0.04099	0.03664	0.03698	0.04569	0.041307
Ionically bour	0.05542	0.02826	0.02891	0.03739	0.025347
Fe-,Mn- oxide	0.0934	0.07931	0.07216	0.09901	0.084746
Oxidizable co	0.07264	0.05447	0.05284	0.06871	0.049649
Residual	0.03386	0.02262	0.01983	0.03253	0.019722
SSE-sum	0.2963	0.2213	0.21072	0.28333	0.220771
Total digestio	0.00247	0.00197	0.00298	0.00053	0.002444
Total digestio	0.38307	0.28216	0.26402	0.32668	0.288345

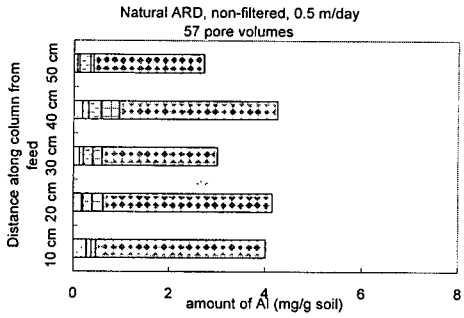
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.045	0.0136	0.01417	-0.0268	0.005968
Exchangeabl	0.27246	0.16649	0.11979	0.18746	0.070569
Ionically bour	0.00818	0.04232	0.09132	0.12902	0.052536
Fe-,Mn- oxide	0.1064	0.18996	0.19263	0.26415	0.229764
Oxidizable co	0.09001	0.23172	0.20263	0.38053	0.065055
Residual	3.54804	3.52823	2.40961	3.29952	2.31234
SSE-sum	4.0251	4.15873	3.01598	4.26067	2.730265
Total digestio	-0.2365	-0.054	-0.0105	-0.2082	-0.06469
Total digestio	1.57287	-0.3334	1.19751	0.79753	1.803565











CPA4

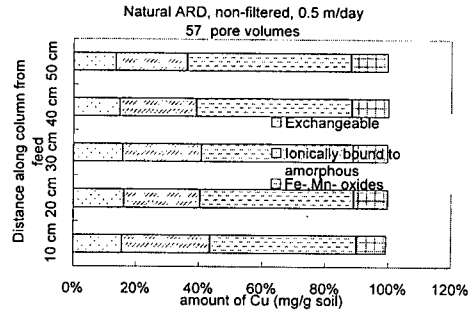
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	15.57%	16.16%	15.78%	14.69%	13.48%
Ionically bour	28.00%	24.17%	24.95%	24.44%	22.68%
Fe-,Mn- oxide	46.31%	48.74%	48.12%	49.22%	51.90%
Oxidizable co	9.44%	10.77%	10.91%	11.76%	11.68%
Residual	0.00%	0.00%	0.00%	0.00%	0.00%
SSE-sum	99%	100%	100%	100%	100%
Total digestio	0.01598	0.00236	0.00133	0.00222	0.00154
Total digestio	0.45506	0.32746	0.22357	0.31853	0.27638

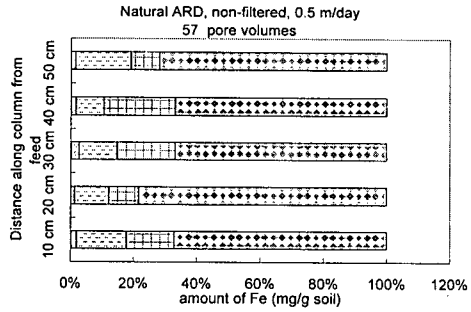
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	0.24%	0.07%	0.13%	0.07%	0.04%
Ionically bour	1.75%	1.20%	2.54%	1.57%	1.40%
Fe-,Mn- oxide	15.87%	10.83%	12.07%	8.97%	17.72%
Oxidizable co	15.08%	9.60%	18.43%	22.55%	9.00%
Residual	67.06%	78.29%	66.84%	66.83%	71.85%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.06031	-0.05174	-0.05373	-0.05887	-0.0574
Total digestio	0.83649	0.32265	-0.10324	-0.18519	0.35734

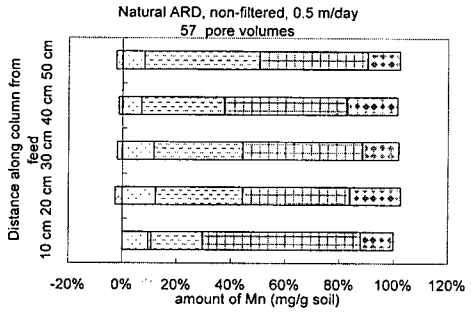
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	9.64%	12.33%	11.67%	6.96%	8.09%
Ionically bour	1.19%	-2.64%	-1.98%	-1.40%	-2.28%
Fe-,Mn- oxide	18.92%	32.04%	32.77%	30.69%	42.31%
Oxidizable co	58.13%	39.43%	43.97%	45.01%	39.84%
Residual	12.12%	18.84%	13.57%	18.73%	12.04%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.00289	-0.00339	-0.00348	-0.00349	-0.0036
Total digestio	-0.0364	-0.04304	-0.05846	-0.05483	-0.0629

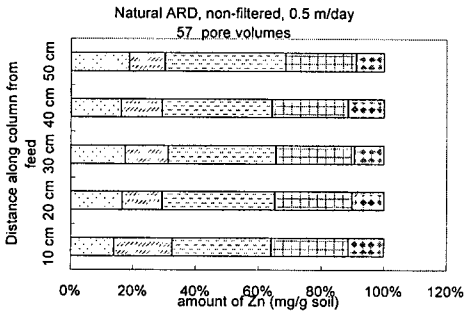
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	13.83%	16.56%	17.55%	16.13%	18.71%
Ionically bour	18.70%	12.77%	13.72%	13.20%	11.48%
Fe-,Mn- oxide	31.52%	35.84%	34.25%	34.94%	38.39%
Oxidizable co	24.51%	24.61%	25.08%	24.25%	22.49%
Residual	11.43%	10.22%	9.41%	11.48%	8.93%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	0.00096	0.00013	0.00026	2E-05	-0.0006
Total digestio	0.25876	0.2434	0.22631	0.26811	0.25867

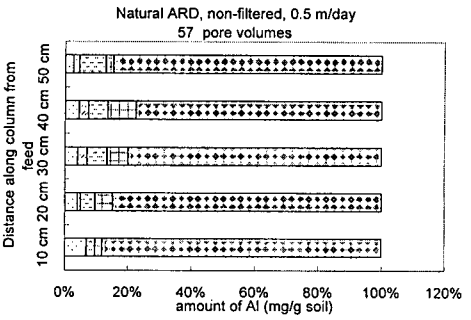
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchangeabl	6.77%	4.00%	3.97%	4.40%	2.58%
Ionically bour	0.20%	1.02%	3.03%	3.03%	1.92%
Fe-,Mn- oxide	2.64%	4.57%	6.39%	6.20%	8.42%
Oxidizable co	2.24%	5.57%	6.72%	8.93%	2.38%
Residual	88.15%	84.84%	79.89%	77.44%	84.69%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.22933	-0.22483	-0.22867	-0.22954	-0.226
Total digestio	1.13264	2.17071	-1.20119	1.06387	1.21577











CPA3 73.2728 pore volumes

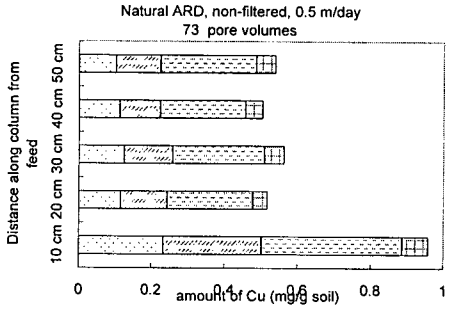
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.0179	0.00033	3E-05	0.00033	6.2E-05
Exchange	0.23305	0.11481	0.12481	0.11252	0.10219
Ionically b	0.26927	0.1288	0.13306	0.11174	0.12292
Fe-,Mn- o	0.3845	0.23457	0.25212	0.23335	0.26132
Oxidizable	0.07115	0.03883	0.0529	0.04671	0.05328
Residual	0	0	0	0	0
SSE-sum	0.97586	0.51734	0.56292	0.50466	0.53977
Total dige	0.04638	0.00189	0.00196	0.00276	0.00314
Total dige	2.58942	1.12686	1.13943	1.16388	1.1326

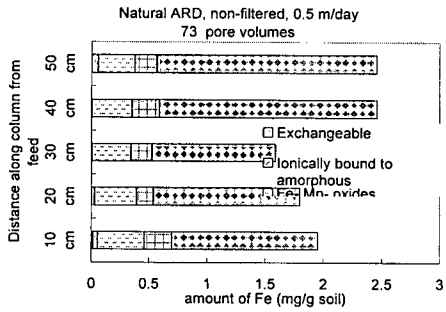
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	-0.03698	0.00607	-0.024	-0.0114	-0.0313
Exchange	0.01391	0.00321	0.00311	0.00241	0.00225
Ionically b	0.04094	0.02722	0.00352	-0.0054	0.05552
Fe-,Mn- o	0.40607	0.36409	0.33895	0.35104	0.31915
Oxidizable	0.2394	0.14425	0.17966	0.23616	0.19276
Residual	1.25335	1.25984	1.06443	1.87266	1.89054
SSE-sum	1.95366	1.79863	1.58966	2.45685	2.46022
Total dige	-0.06099	-0.0038	-0.023	-0.0226	-0.0472
Total dige	0.77308	1.10377	0.36804	1.22313	0.6626

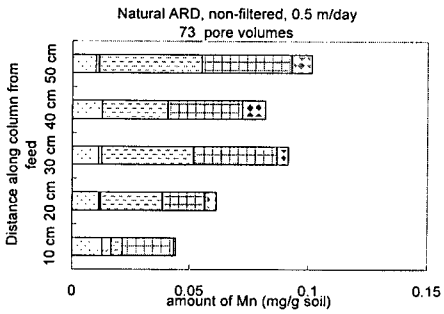
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.00022	-0.0012	-0.0014	-0.0013	-0.0013
Exchange	0.01301	0.0114	0.01126	0.01289	0.00993
Ionically b	0.00394	0.00079	0.00148	-5E-05	0.00147
Fe-,Mn- o	0.0046	0.0263	0.03901	0.02777	0.04357
Oxidizable	0.02187	0.01805	0.03507	0.03149	0.03787
Residual	0.00091	0.0048	0.00485	0.00972	0.00858
SSE-sum	0.04432	0.06133	0.09167	0.08182	0.10143
Total dige	0.00134	-0.0026	-0.0028	-0.003	-0.0031
Total dige	-0.00027	0.01215	0.03088	0.00293	0.01792

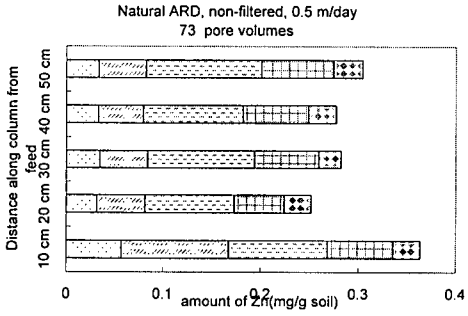
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.00165	-0.0004	-0.0006	-0.0005	-0.0005
Exchange	0.05701	0.0315	0.0347	0.03304	0.0334
Ionically b	0.11065	0.04988	0.04956	0.04678	0.0494
Fe-,Mn- o	0.10091	0.09171	0.11001	0.10254	0.1184
Oxidizable	0.06713	0.05118	0.06552	0.06685	0.07355
Residual	0.02816	0.02791	0.02272	0.02857	0.02969
SSE-sum	0.36386	0.25218	0.28251	0.27778	0.30444
Total dige	0.0075	0.00066	0.00122	0.00081	0.00153
Total dige	0.44331	0.30328	0.32424	0.34301	0.36153

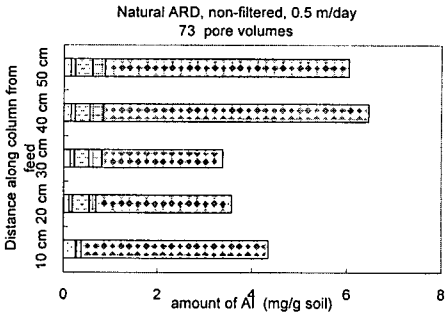
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	-0.03968	-0.0046	-0.0319	-0.0182	-0.0346
Exchange	0.25024	0.11819	0.1371	0.14996	0.14458
Ionically b	0.00244	0.07428	0.09423	0.08944	0.09583
Fe-,Mn- o	0.03047	0.36007	0.30808	0.31944	0.36969
Oxidizable	0.0989	0.1381	0.2799	0.28502	0.26812
Residual	3.97381	2.88864	2.5694	5.62258	5.16923
SSE-sum	4.35586	3.57928	3.38871	6.46644	6.04744
Total dige	-0.23327	-0.1919	-0.2047	-0.2086	-0.2279
Total dige	2.6439	2.61856	2.42421	5.07359	1.74106











CPA3 minus conc leached by bulk clinop (%)

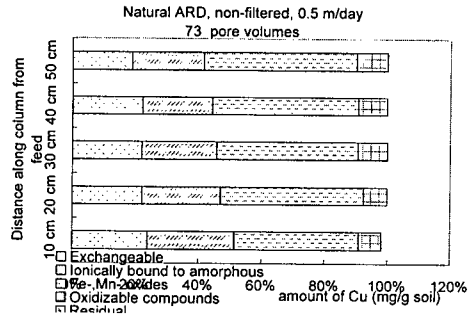
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	23.88%	22.19%	22.17%	22.30%	18.93%
Ionically b	27.59%	24.90%	23.64%	22.14%	22.77%
Fe-,Mn- o	39.40%	45.34%	44.79%	46.24%	48.41%
Oxidizable	7.29%	7.51%	9.40%	9.26%	9.87%
Residual	0.00%	0.00%	0.00%	0.00%	0.00%
SSE-sum	98%	100%	100%	100%	100%
Total dige	0.0272	0.0100645	0.006336	0.005103	0.003023
Total dige	0.5014	0.5113945	0.396896	0.352674	0.29728

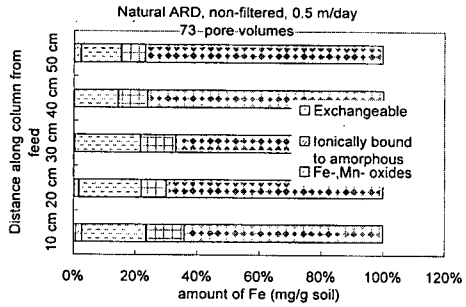
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	0.71%	0.18%	0.20%	0.10%	0.09%
Ionically b	2.10%	1.51%	0.22%	-0.22%	2.26%
Fe-,Mn- o	20.78%	20.24%	21.32%	14.29%	12.97%
Oxidizable	12.25%	8.02%	11.30%	9.61%	7.84%
Residual	64.15%	70.04%	66.96%	76.22%	76.84%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.03728	-0.037911	-0.038008	-0.035715	-0.034083
Total dige	-1.4017	-0.661033	-0.399035	-0.211892	-1.825599

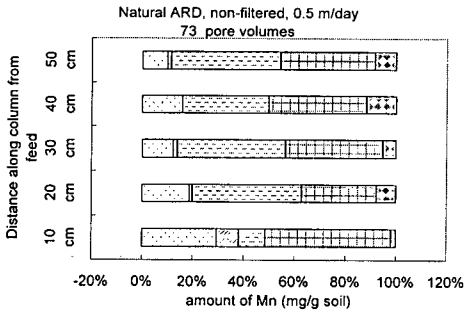
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	29.34%	18.58%	12.28%	15.76%	9.79%
Ionically b	8.88%	1.28%	1.61%	-0.06%	1.45%
Fe-,Mn- o	10.37%	42.88%	42.55%	33.94%	42.96%
Oxidizable	49.34%	29.42%	38.26%	38.49%	37.34%
Residual	2.06%	7.83%	5.30%	11.88%	8.46%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.00146	-0.002248	-0.002613	-0.002608	-0.003062
Total dige	-0.10556	-0.082915	-0.076871	-0.055702	-0.05724

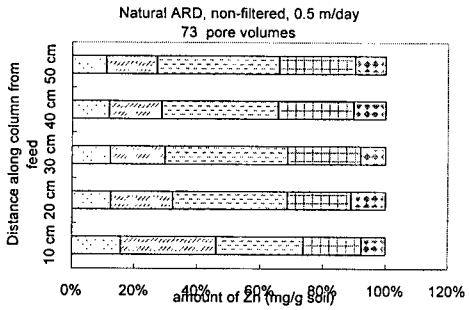
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	15.67%	12.49%	12.28%	11.89%	10.97%
Ionically b	30.41%	19.78%	17.54%	16.84%	16.22%
Fe-,Mn- o	27.73%	36.37%	38.94%	36.92%	38.89%
Oxidizable	18.45%	20.30%	23.19%	24.07%	24.16%
Residual	7.74%	11.07%	8.04%	10.28%	9.75%
SSE-sum	100%	100%	100%	100%	100%
Total dige	0.00392	0.0018417	0.0013	0.001023	0.000404
Total dige	0.16353	0.1866525	0.178546	0.172424	0.186624

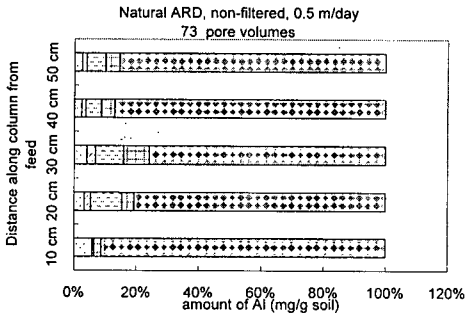
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse					
Exchange	5.74%	3.30%	4.05%	2.32%	2.39%
Ionically b	0.06%	2.08%	2.78%	1.38%	1.58%
Fe-,Mn- o	0.70%	10.06%	9.09%	4.94%	6.11%
Oxidizable	2.27%	3.86%	8.26%	4.41%	4.43%
Residual	91.23%	80.70%	75.82%	86.95%	85.48%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.01468	-0.016125	-0.016941	-0.014062	-0.013452
Total dige	0.05791	0.5830768	-0.40038	2.606505	1.053072











CPA2 85.3992 pore volumes

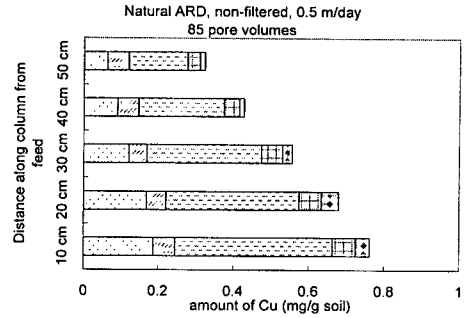
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.01828	0.00513	0.00153	0.00177	0.002868
Exchangeabl	0.18712	0.16889	0.12098	0.09021	0.062912
Ionically bour	0.05818	0.05191	0.04874	0.05642	0.057449
Fe-,Mn- oxide	0.4184	0.35449	0.30519	0.22789	0.157454
Oxidizable co	0.06102	0.05869	0.05553	0.04066	0.032323
Residual	0.03737	0.04619	0.02606	0.01327	0.013666
SSE-sum	0.76208	0.68018	0.5565	0.42844	0.323803
Total digestio	0.04116	0.01488	0.00527	0.00506	0.008526
Total digestio	0.79066	0.699	0.53072	0.42091	0.301084

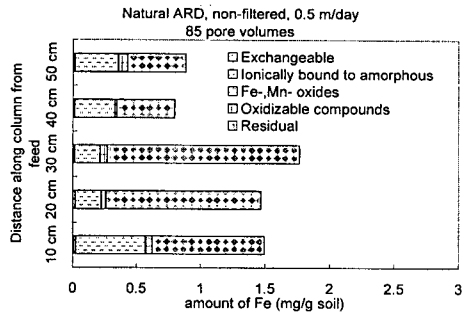
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0358	-0.0359	-0.035	-0.0215	-0.01148
Exchangeabl	0.00995	0.00419	0.00282	0.0022	0.001209
Ionically bour	0.01441	0.01477	0.01105	0.01181	0.014036
Fe-,Mn- oxide	0.5462	0.20629	0.20084	0.31432	0.339434
Oxidizable co	0.05245	0.03488	0.05561	0.01491	0.072403
Residual	0.8725	1.21044	1.49889	0.4558	0.45732
SSE-sum	1.49552	1.47058	1.7692	0.79904	0.884403
Total digestio	-0.0531	-0.0512	-0.0585	-0.0359	-0.01931
Total digestio	0.0653	0.88039	0.0918	-0.4827	0.403063

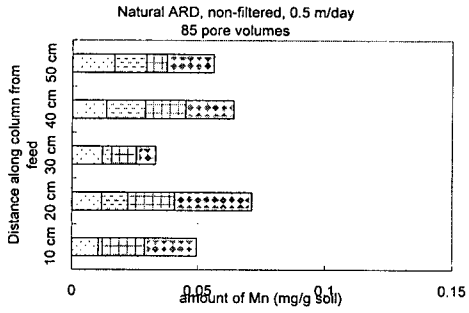
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.00068	-0.0007	-0.0011	-0.0007	-0.00046
Exchangeabl	0.01054	0.01179	0.01207	0.01358	0.016682
Ionically bour	-0.0129	-0.0131	-0.0122	-0.0102	-0.00773
Fe-,Mn- oxide	0.00169	0.01052	0.00372	0.01549	0.01275
Oxidizable co	0.01682	0.01852	0.00987	0.01603	0.008121
Residual	0.02064	0.03054	0.0077	0.01899	0.018648
SSE-sum	0.03681	0.05831	0.02119	0.05385	0.048474
Total digestio	0.00077	-0.0015	-0.0031	-0.0023	-0.0009
Total digestio	-0.0265	0.00559	-0.0127	0.02205	0.042147

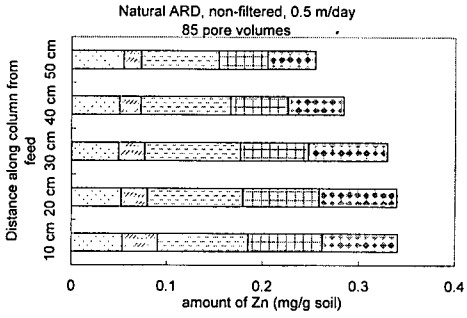
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	0.00265	0.00047	-8E-05	0.00022	7.79E-05
Exchangeabl	0.05354	0.05233	0.04948	0.05057	0.054939
Ionically bour	0.0374	0.02753	0.02742	0.02229	0.018372
Fe-,Mn- oxide	0.09417	0.09962	0.10005	0.09394	0.081164
Oxidizable co	0.07711	0.07929	0.07062	0.05962	0.050709
Residual	0.0783	0.08088	0.08187	0.05783	0.049684
SSE-sum	0.34052	0.33965	0.32944	0.28424	0.254868
Total digestio	0.00777	0.00321	0.00171	0.0021	0.002316
Total digestio	0.26079	0.26475	0.26021	0.20967	0.186451

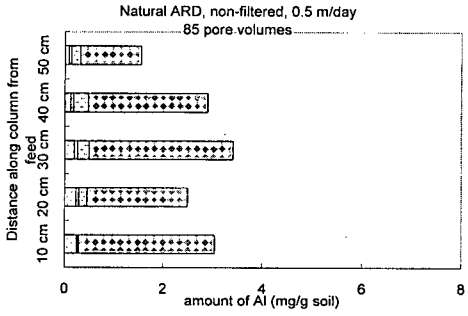
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rinse	-0.0436	-0.0452	-0.0457	-0.0414	-0.02679
Exchangeabl	0.25557	0.23322	0.19264	0.12216	0.084465
Ionically bour	0.00177	0.05544	0.07295	0.05531	0.045455
Fe-,Mn- oxide	0.03145	0.17005	0.23324	0.30591	0.185223
Oxidizable co	-0.3164	-0.2389	-0.208	-0.1888	-0.16524
Residual	2.76117	2.04143	2.91613	2.42149	1.242465
SSE-sum	2.7336	2.26128	3.20693	2.71601	1.392365
Total digestio	-0.2214	-0.2208	-0.2277	-0.2208	-0.18646
Total digestio	-2.224	-1.2075	-0.6664	-1.5019	-0.46142











CPA2

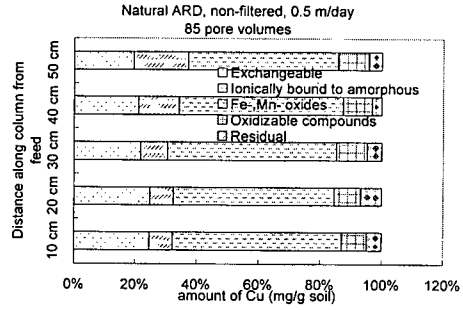
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	24.55%	24.83%	21.74%	21.05%	19.43%
Ionically bour	7.63%	7.63%	8.76%	13.17%	17.74%
Fe-,Mn- oxide	54.90%	52.12%	54.84%	53.19%	48.63%
Oxidizable co	8.01%	8.63%	9.98%	9.49%	9.98%
Residual	4.90%	6.79%	4.68%	3.10%	4.22%
SSE-sum	100%	100%	100%	100%	100%
Total digestio	0.015981	0.002364	0.00133	0.002221	0.00154
Total digestio	0.455063	0.327463	0.223574	0.31853	0.27638

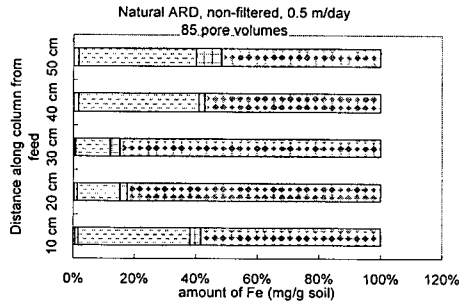
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	0.67%	0.29%	0.16%	0.27%	0.14%
Ionically bour	0.96%	1.00%	0.62%	1.48%	1.59%
Fe-,Mn- oxide	36.52%	14.03%	11.35%	39.34%	38.38%
Oxidizable co	3.51%	2.37%	3.14%	1.87%	8.19%
Residual	58.34%	82.31%	84.72%	57.04%	51.71%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.06031	-0.05174	-0.05373	-0.05887	-0.0574
Total digestio	0.836488	0.322645	-0.10324	-0.18519	0.35734

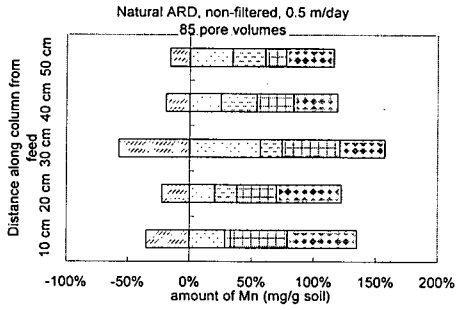
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	28.64%	20.22%	56.99%	25.21%	34.41%
Ionically bour	-34.97%	-22.43%	-57.46%	-19.03%	-15.94%
Fe-,Mn- oxide	4.58%	18.05%	17.54%	28.78%	26.30%
Oxidizable co	45.68%	31.76%	46.58%	29.78%	16.75%
Residual	56.07%	52.39%	36.34%	35.26%	38.47%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.00289	-0.00339	-0.00348	-0.00349	-0.0036
Total digestio	-0.0364	-0.04304	-0.05846	-0.05483	-0.0629

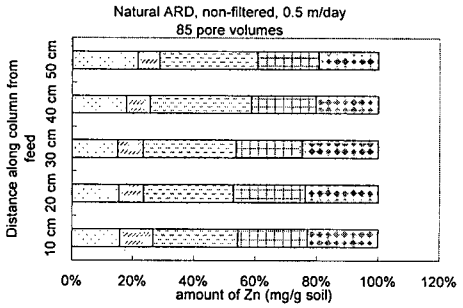
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	15.72%	15.41%	15.02%	17.79%	21.56%
Ionically bour	10.98%	8.11%	8.32%	7.84%	7.21%
Fe-,Mn- oxide	27.66%	29.33%	30.37%	33.05%	31.85%
Oxidizable co	22.64%	23.35%	21.44%	20.97%	19.90%
Residual	23.00%	23.81%	24.85%	20.34%	19.49%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	0.000964	0.000125	0.000259	1.96E-05	-0.0006
Total digestio	0.258758	0.243395	0.226306	0.268107	0.25867

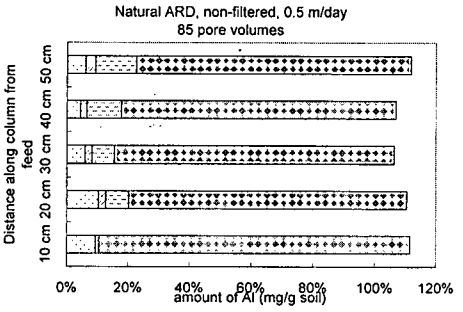
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Exchangeabl	9.35%	10.31%	6.01%	4.50%	6.07%
Ionically bour	0.06%	2.45%	2.27%	2.04%	3.26%
Fe-,Mn- oxide	1.15%	7.52%	7.27%	11.26%	13.30%
Oxidizable co	-11.57%	-10.56%	-6.49%	-6.95%	-11.87%
Residual	101.01%	90.28%	90.93%	89.16%	89.23%
SSE-sum	100.00%	100.00%	100.00%	100.00%	100.00%
Total digestio	-0.22933	-0.22483	-0.22867	-0.22954	-0.226
Total digestio	1.132638	2.170714	-1.20119	1.063872	1.21577











CPA1 96.176 pore volumes

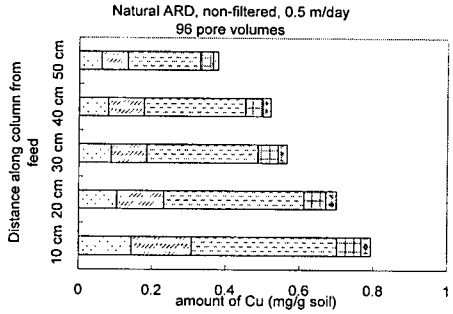
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.019721	0.00747	0.00253	0.00179	0.00186
Exchange	0.143611	0.1044	0.08825	0.07981	0.06192
Ionically b	0.164859	0.12796	0.09644	0.09784	0.07142
Fe-,Mn- o	0.392711	0.37976	0.30228	0.27518	0.19678
Oxidizable	0.065916	0.05931	0.05374	0.04593	0.03318
Residual	0.026365	0.02825	0.02507	0.02277	0.0147
SSE-sum	0.793462	0.69968	0.56578	0.52154	0.378
Total dige	0.052544	0.02251	0.00637	0.00464	0.00361
Total dige	0.772417	0.69706	0.48821	0.49759	0.34944

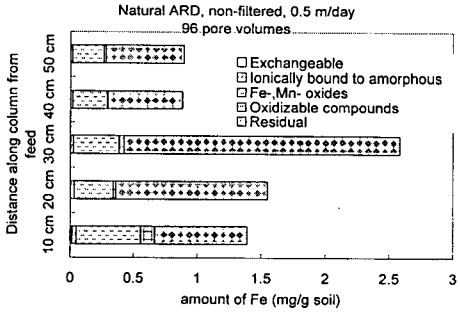
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	-0.03542	-0.0356	-0.0353	-0.0343	-0.0155
Exchange	0.015395	0.00305	0.00156	0.00142	0.00108
Ionically b	0.032684	0.02854	0.02126	0.01753	0.01563
Fe-,Mn- o	0.508985	0.3083	0.36277	0.27051	0.24841
Oxidizable	0.109552	0.01901	0.03908	0.00892	0.01531
Residual	0.725831	1.19133	2.15844	0.58602	0.6169
SSE-sum	1.392447	1.55023	2.5831	0.88441	0.89733
Total dige	-0.05641	-0.0617	-0.0615	-0.0558	-0.0361
Total dige	-0.05402	0.63698	0.51162	0.28447	0.0873

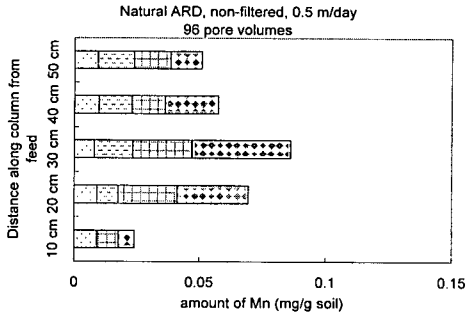
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.000363	-0.0005	-0.001	-0.0011	-0.0007
Exchange	0.009149	0.0091	0.00797	0.00982	0.00935
Ionically b	-0.00551	-0.0052	-0.0081	-0.0068	-0.0077
Fe-,Mn- o	-0.00645	0.00848	0.01551	0.01323	0.01446
Oxidizable	0.008588	0.02363	0.02359	0.01326	0.01461
Residual	0.006504	0.02835	0.03915	0.02122	0.01251
SSE-sum	0.012279	0.06441	0.07812	0.05075	0.04324
Total dige	0.001443	-0.0012	-0.0031	-0.0029	-0.0022
Total dige	-0.02359	-0.0048	-0.0146	0.0431	0.0161

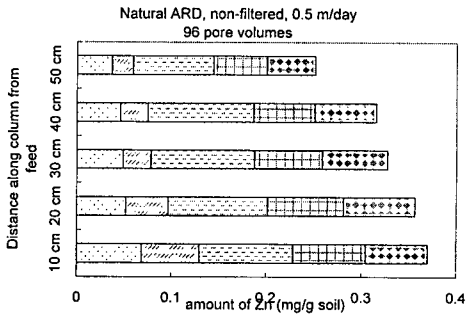
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	0.00298	0.00084	0.00037	0.00013	0.00017
Exchange	0.068781	0.05199	0.04914	0.04639	0.03725
Ionically b	0.061102	0.04501	0.0295	0.02903	0.0224
Fe-,Mn- o	0.098606	0.10474	0.10923	0.11153	0.0849
Oxidizable	0.075948	0.0796	0.07114	0.06403	0.05634
Residual	0.065408	0.07523	0.06849	0.06488	0.05073
SSE-sum	0.369846	0.35657	0.3275	0.31586	0.25162
Total dige	0.009863	0.00489	0.00173	0.00048	0.00046
Total dige	0.256331	0.22519	0.1569	0.16556	0.19484

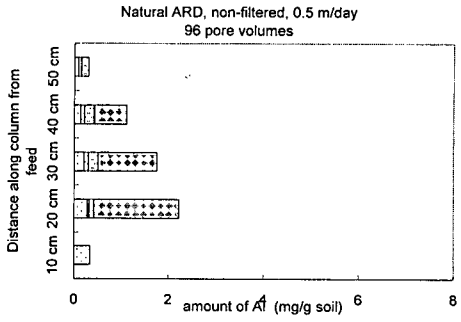
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Initial Rins	-0.04479	-0.0463	-0.0458	-0.0458	-0.0092
Exchange	0.338864	0.27834	0.20926	0.13246	0.07732
Ionically b	-0.00347	0.04056	0.09166	0.08353	0.06173
Fe-,Mn- o	0.00774	0.102	0.20447	0.19691	0.15733
Oxidizable	-0.2511	-0.1362	-0.1333	0.01477	-0.1507
Residual	-0.11186	1.80536	1.25044	0.68509	-1.7025
SSE-sum	-0.01982	2.09006	1.62257	1.11277	-1.5568
Total dige	-0.22609	-0.2318	-0.2329	-0.225	-0.215
Total dige	-0.95059	-1.0608	-0.8533	0.57341	-1.3941











CPA1 minus conc leached by bulk clinoı (%)

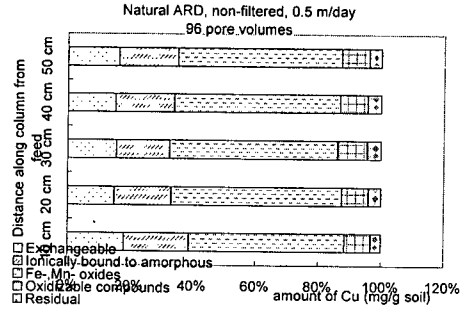
Cu	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	18.10%	14.92%	15.60%	15.30%	16.38%
Ionically b	20.78%	18.29%	17.05%	18.76%	18.90%
Fe-,Mn- o	49.49%	54.28%	53.43%	52.76%	52.06%
Oxidizable	8.31%	8.48%	9.50%	8.81%	8.78%
Residual	3.32%	4.04%	4.43%	4.37%	3.89%
SSE-sum	100%	100%	100%	100%	100%
Total dige	0.0272	0.0100645	0.006336	0.005103	0.003023
Total dige	0.501398	0.5113945	0.396896	0.352674	0.29728

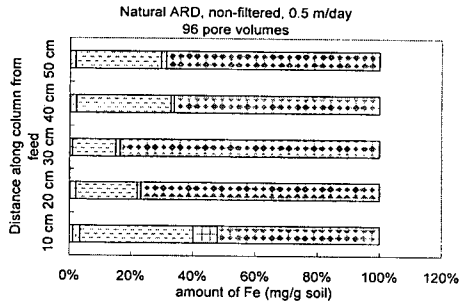
Fe	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	1.11%	0.20%	0.06%	0.16%	0.12%
Ionically b	2.35%	1.84%	0.82%	1.98%	1.74%
Fe-,Mn- o	36.55%	19.89%	14.04%	30.59%	27.68%
Oxidizable	7.87%	1.23%	1.51%	1.01%	1.71%
Residual	52.13%	76.85%	83.56%	66.26%	68.75%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.03728	-0.037911	-0.03801	-0.03571	-0.03408
Total dige	-1.4017	-0.661033	-0.39904	-0.21189	-1.8256

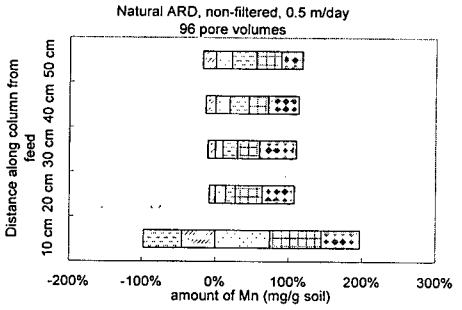
Mn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	74.51%	14.13%	10.20%	19.34%	21.62%
Ionically b	-44.88%	-8.00%	-10.36%	-13.36%	-17.80%
Fe-,Mn- o	-52.54%	13.17%	19.85%	26.06%	33.45%
Oxidizable	69.94%	36.68%	30.20%	26.14%	33.79%
Residual	52.97%	44.01%	50.11%	41.82%	28.94%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.00146	-0.002248	-0.00261	-0.00261	-0.00306
Total dige	-0.10556	-0.082915	-0.07687	-0.0557	-0.05724

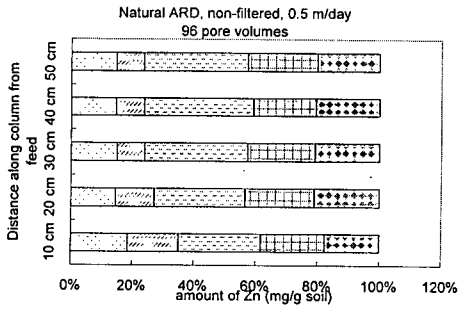
Zn	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	18.60%	14.58%	15.01%	14.69%	14.80%
Ionically b	16.52%	12.62%	9.01%	9.19%	8.90%
Fe-,Mn- o	26.66%	29.37%	33.35%	35.31%	33.74%
Oxidizable	20.54%	22.32%	21.72%	20.27%	22.39%
Residual	17.69%	21.10%	20.91%	20.54%	20.16%
SSE-sum	100%	100%	100%	100%	100%
Total dige	0.003918	0.0018417	0.0013	0.001023	0.000404
Total dige	0.163527	0.1866525	0.178546	0.172424	0.186624

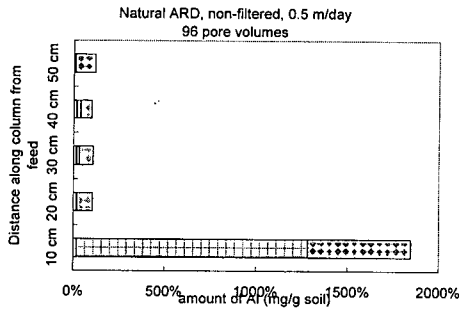
Al	10 cm	20 cm	30 cm	40 cm	50 cm
Exchange	-1709.4%	13.32%	12.90%	11.90%	-4.97%
Ionically b	17.5%	1.94%	5.65%	7.51%	-3.96%
Fe-,Mn- o	-39.0%	4.88%	12.60%	17.70%	-10.11%
Oxidizable	1266.6%	-6.52%	-8.21%	1.33%	9.68%
Residual	564.3%	86.38%	77.07%	61.57%	109.36%
SSE-sum	100%	100%	100%	100%	100%
Total dige	-0.01468	-0.016125	-0.01694	-0.01406	-0.01345
Total dige	0.057913	0.5830768	-0.40038	2.606505	1.053072





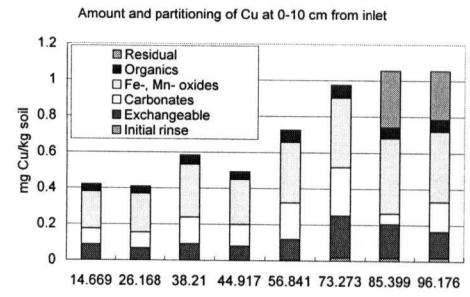


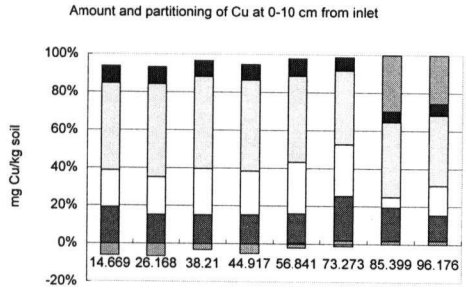


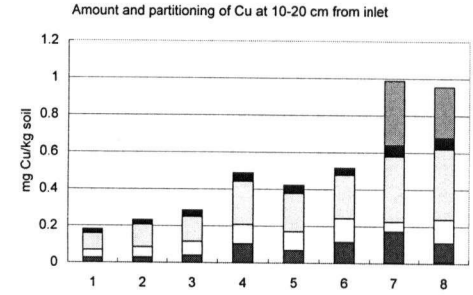


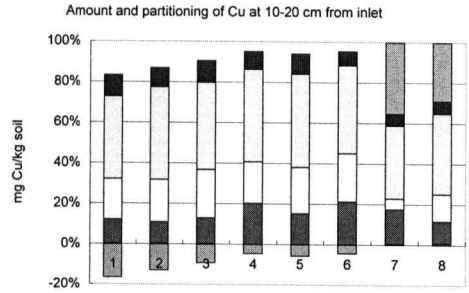
Appendix J. Results of soil analyses on tested clinoptilolite from Critical Path Analysis leaching column cells

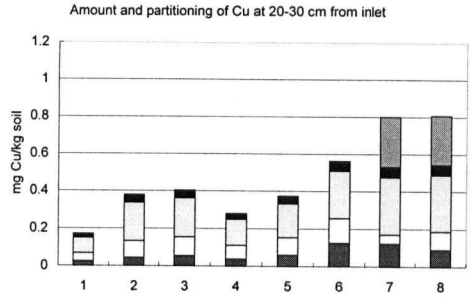
J-3. Changes of the amount and percentage partitioning of metals (Cu, Fe, Mn, Zn, Al)

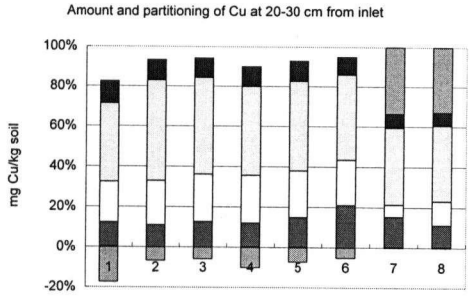

Amount and partitioning of Cu at 0-10 cm from inlet
Residual
Organics
Fe-, Mn- oxides
Carbonates
Exchangeable
Initial rinse
mg Cu/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

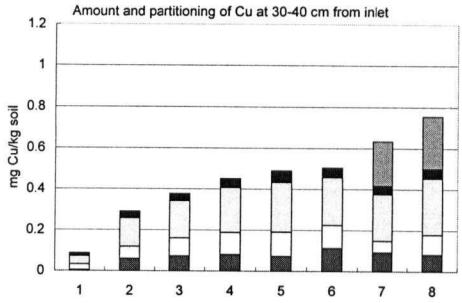

Amount and partitioning of Cu at 0-10 cm from inlet
mg Cu/kg soil
100%
80%
60%
40%
20%
0%
-20%
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

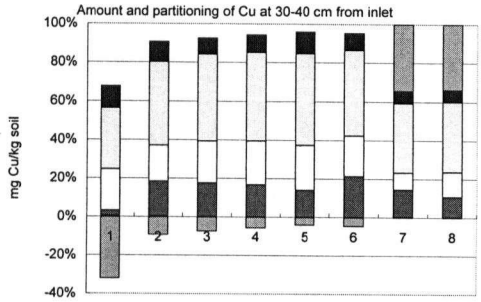

Amount and partitioning of Cu at 10-20 cm from inlet
mg Cu/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8

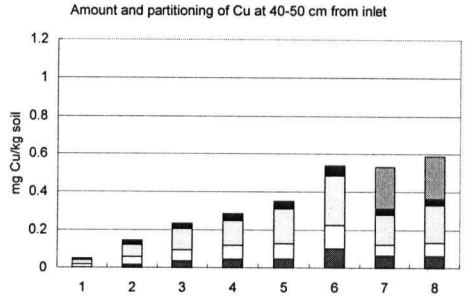

Amount and partitioning of Cu at 10-20 cm from inlet
mg Cu/kg soil
100%
80%
60%
40%
20%
0%
-20%
1 2 3 4 5 6 7 8

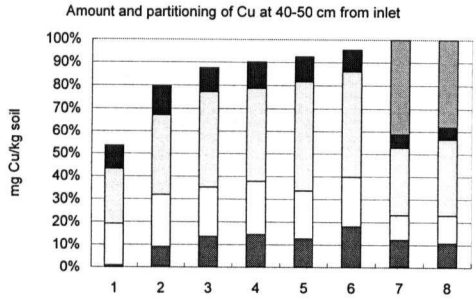

Amount and partitioning of Cu at 20-30 cm from inlet
mg Cu/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8

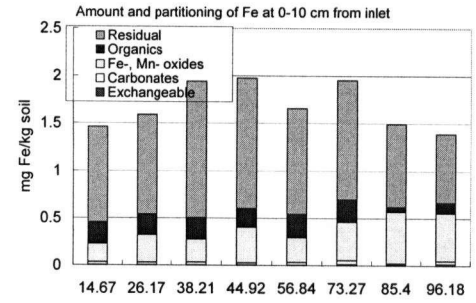

Amount and partitioning of Cu at 20-30 cm from inlet
mg Cu/kg soil
100%
80%
60%
40%
20%
0%
-20%
1 2 3 4 5 6 7 8

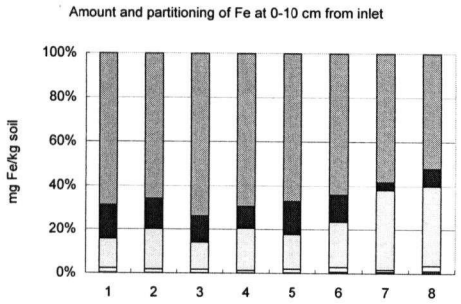

Amount and partitioning of Cu at 30-40 cm from inlet
mg Cu/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8

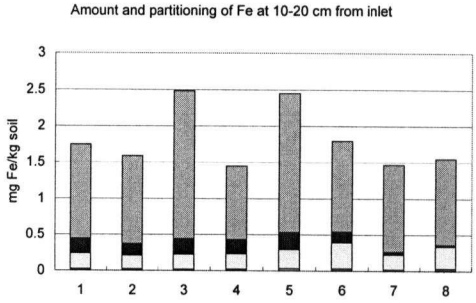

Amount and partitioning of Cu at 30-40 cm from inlet
mg Cu/kg soil
100%
80%
60%
40%
20%
0%
-20%
-40%
1 2 3 4 5 6 7 8

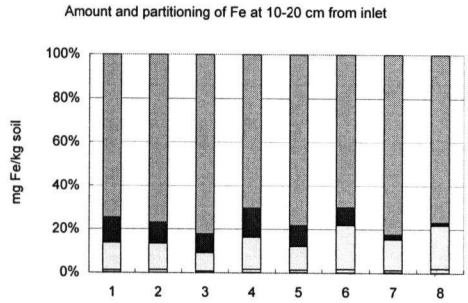

Amount and partitioning of Cu at 40-50 cm from inlet
mg Cu/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8

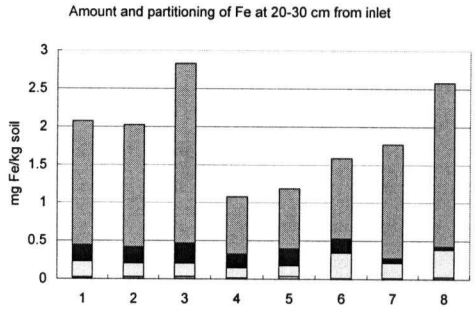

Amount and partitioning of Cu at 40-50 cm from inlet
mg Cu/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

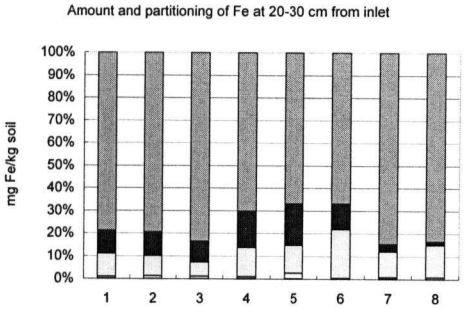

Amount and partitioning of Fe at 0-10 cm from inlet
Residual
Organics
Fe-, Mn- oxides
Carbonates
Exchangeable
mg Fe/kg soil
2.5
2
1.5
1
0.5
0
14.67 26.17 38.21 44.92 56.84 73.27 85.4 96.18

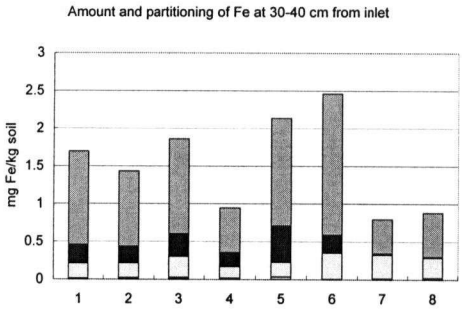

Amount and partitioning of Fe at 0-10 cm from inlet
mg Fe/kg soil
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8

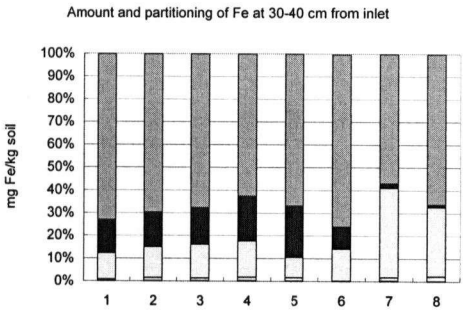

Amount and partitioning of Fe at 10-20 cm from inlet
mg Fe/kg soil
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8

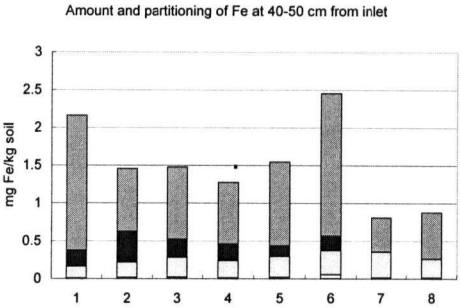

Amount and partitioning of Fe at 10-20 cm from inlet
mg Fe/kg soil
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8

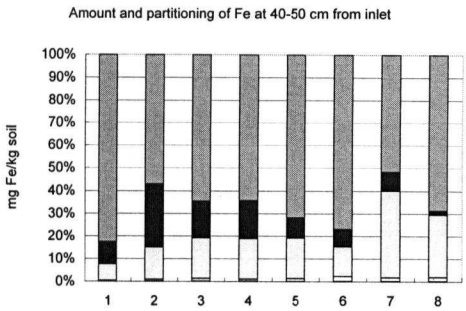

Amount and partitioning of Fe at 20-30 cm from inlet
mg Fe/kg soil
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8

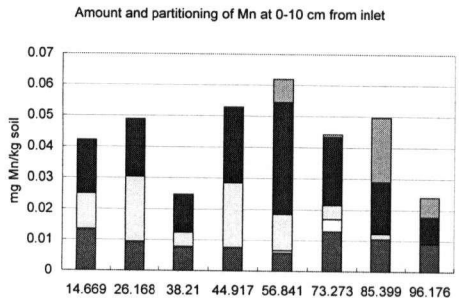

Amount and partitioning of Fe at 20-30 cm from inlet
mg Fe/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

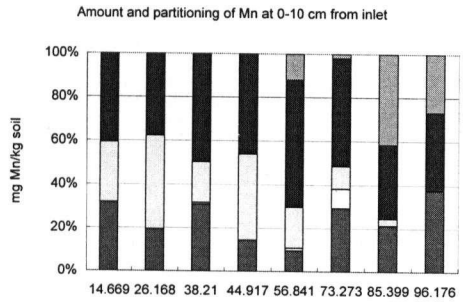

Amount and partitioning of Fe at 30-40 cm from inlet
mg Fe/kg soil
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8

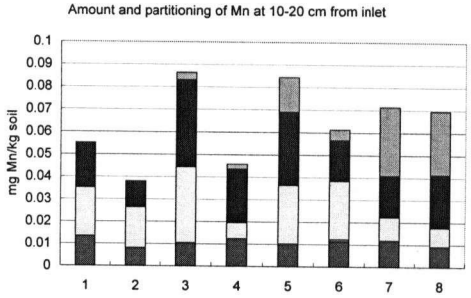

Amount and partitioning of Fe at 30-40 cm from inlet
mg Fe/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

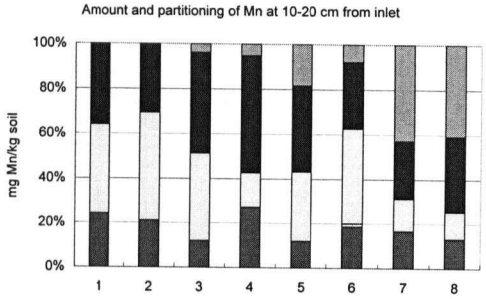

Amount and partitioning of Fe at 40-50 cm from inlet
mg Fe/kg soil
3
2.5
2
1.5
1
0.5
0
1 2 3 4 5 6 7 8

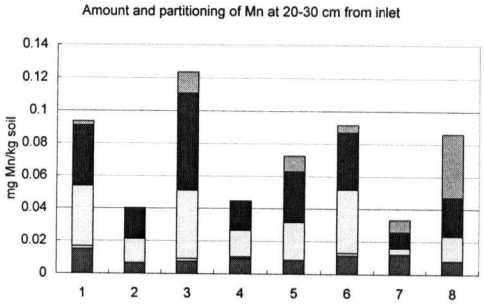

Amount and partitioning of Fe at 40-50 cm from inlet
mg Fe/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

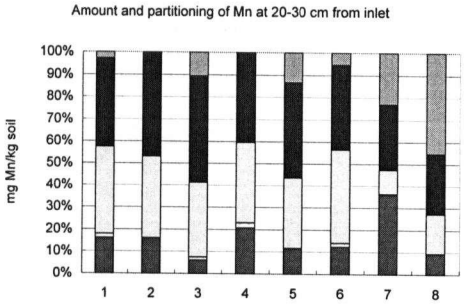

Amount and partitioning of Mn at 0-10 cm from inlet
mg Mn/kg soil
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

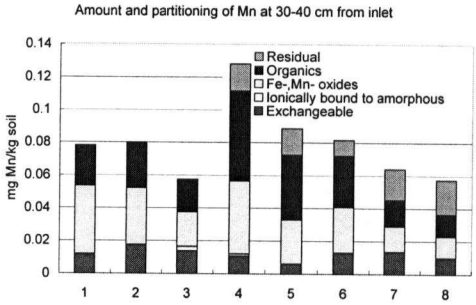

Amount and partitioning of Mn at 0-10 cm from inlet
mg Mn/kg soil
100%
80%
60%
40%
20%
0%
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

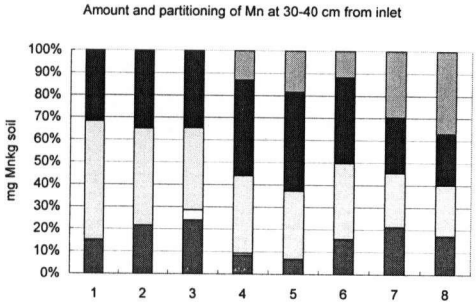

Amount and partitioning of Mn at 10-20 cm from inlet
mg Mn/kg soil
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1 2 3 4 5 6 7 8

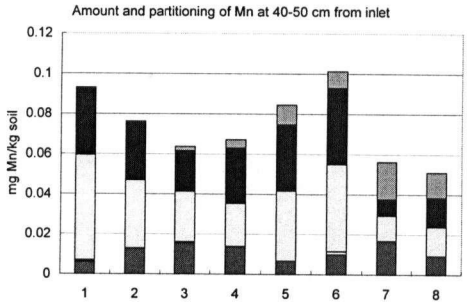

Amount and partitioning of Mn at 10-20 cm from inlet
mg Mn/kg soil
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8

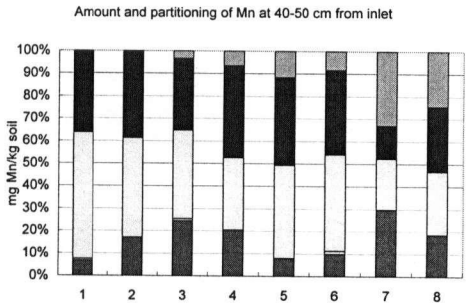

Amount and partitioning of Mn at 20-30 cm from inlet
mg Mn/kg soil
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1 2 3 4 5 6 7 8

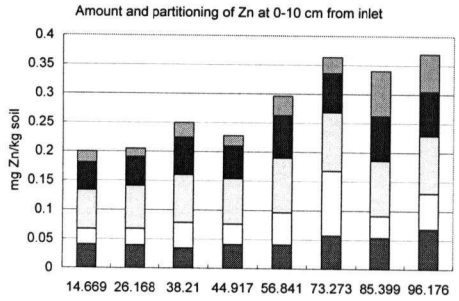

Amount and partitioning of Mn at 20-30 cm from inlet
mg Mn/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

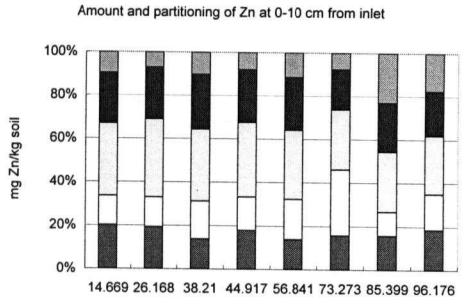

Amount and partitioning of Mn at 30-40 cm from inlet
Residual
Organics
Fe-,Mn- oxides
Ionically bound to amorphous
Exchangeable
mg Mn/kg soil
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1 2 3 4 5 6 7 8

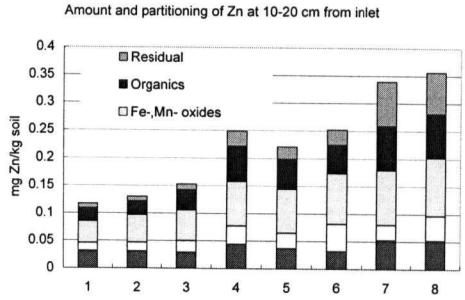

Amount and partitioning of Mn at 30-40 cm from inlet
mg Mnkg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

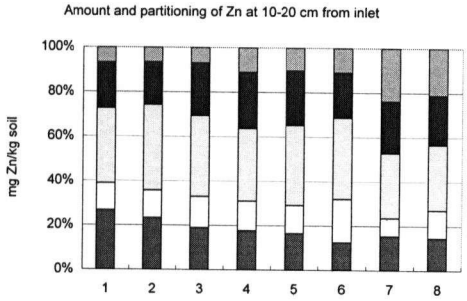

Amount and partitioning of Mn at 40-50 cm from inlet
mg Mn/kg soil
0.12
0.1
0.08
0.06
0.04
0.02
0
1 2 3 4 5 6 7 8

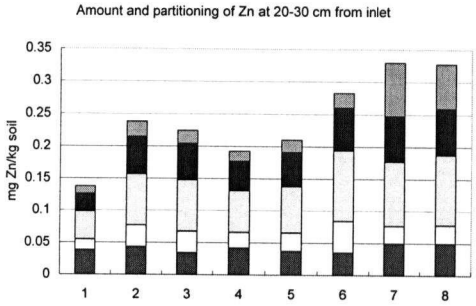

Amount and partitioning of Mn at 40-50 cm from inlet
mg Mn/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

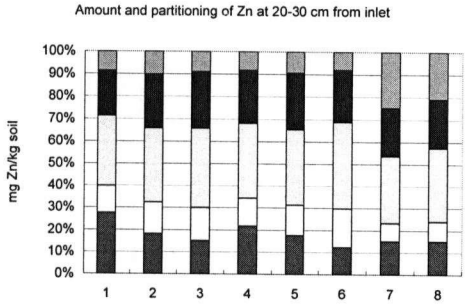

Amount and partitioning of Zn at 0-10 cm from inlet
mg Zn/kg soil
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

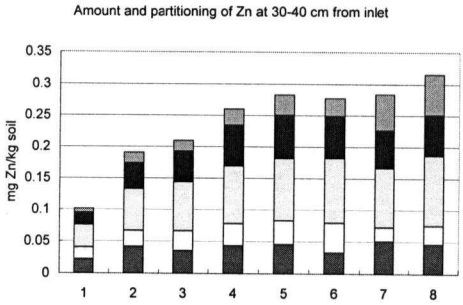

Amount and partitioning of Zn at 0-10 cm from inlet
mg Zn/kg soil
100%
80%
60%
40%
20%
0%
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

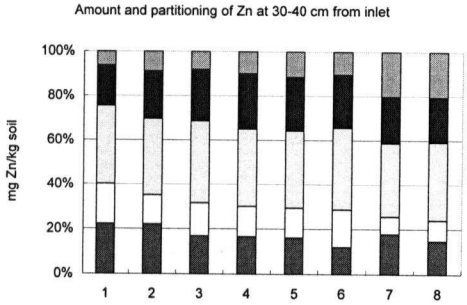

Amount and partitioning of Zn at 10-20 cm from inlet
Residual
Organics
Fe-,Mn- oxides
mg Zn/kg soil
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8

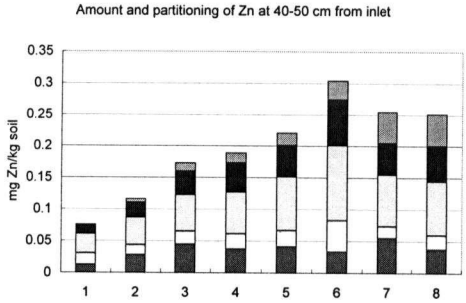

Amount and partitioning of Zn at 10-20 cm from inlet
mg Zn/kg soil
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8

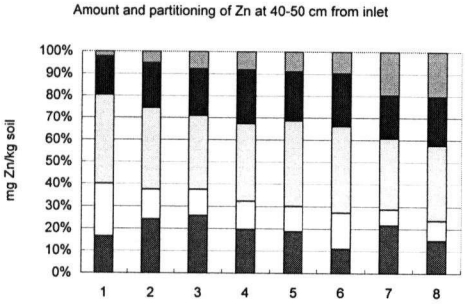

Amount and partitioning of Zn at 20-30 cm from inlet
mg Zn/kg soil
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8

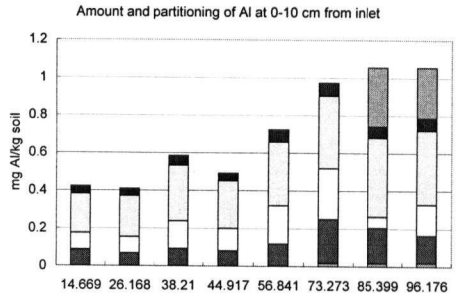

Amount and partitioning of Zn at 20-30 cm from inlet
mg Zn/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

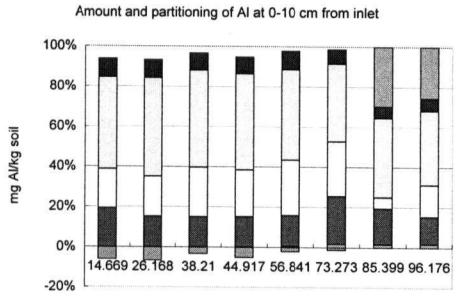

Amount and partitioning of Zn at 30-40 cm from inlet
mg Zn/kg soil
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8

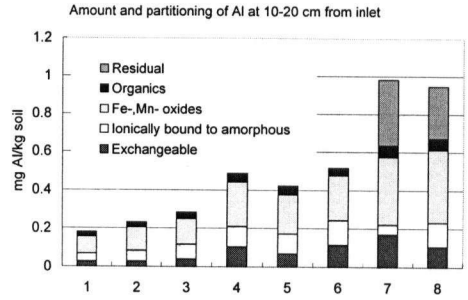

Amount and partitioning of Zn at 30-40 cm from inlet
mg Zn/kg soil
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8

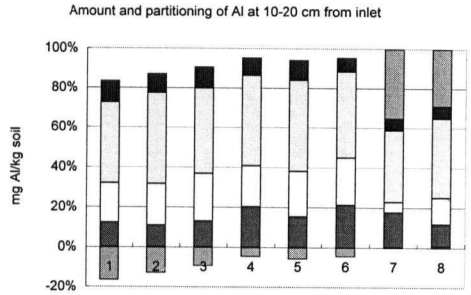

Amount and partitioning of Zn at 40-50 cm from inlet
mg Zn/kg soil
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8

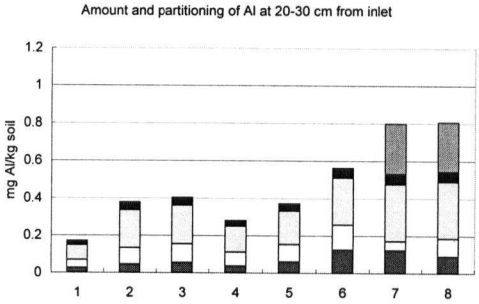

Amount and partitioning of Zn at 40-50 cm from inlet
mg Zn/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

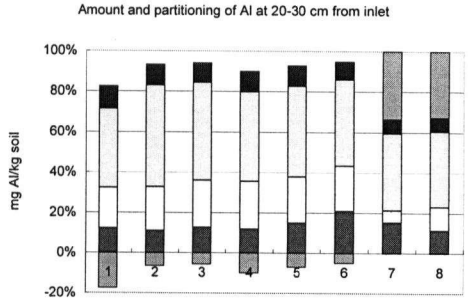

Amount and partitioning of Al at 0-10 cm from inlet
mg Al/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

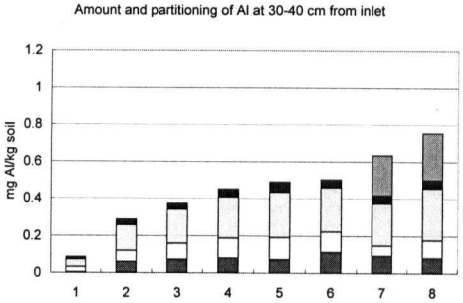

Amount and partitioning of Al at 0-10 cm from inlet
mg Al/kg soil
100%
80%
60%
40%
20%
0%
-20%
14.669 26.168 38.21 44.917 56.841 73.273 85.399 96.176

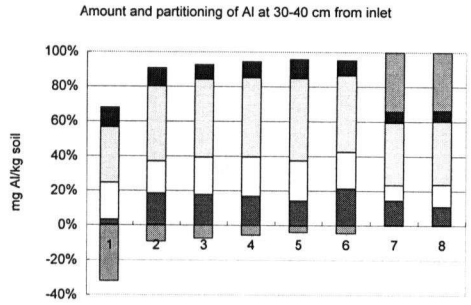

Amount and partitioning of Al at 10-20 cm from inlet
mg Al/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
Residual
Organics
Fe-,Mn- oxides
Ionically bound to amorphous
Exchangeable
1 2 3 4 5 6 7 8

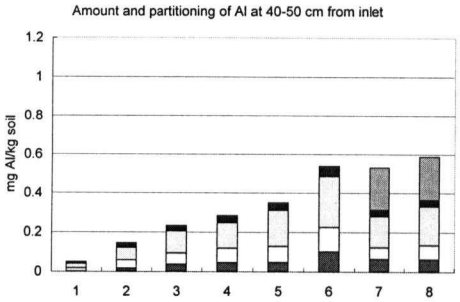

Amount and partitioning of Al at 10-20 cm from inlet
mg Al/kg soil
100%
80%
60%
40%
20%
0%
-20%
1 2 3 4 5 6 7 8

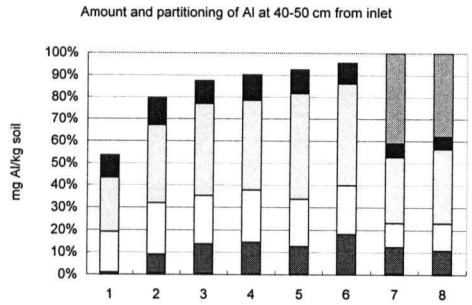

Amount and partitioning of Al at 20-30 cm from inlet
mg Al/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8


Amount and partitioning of Al at 20-30 cm from inlet
mg Al/kg soil
100%
80%
60%
40%
20%
0%
-20%
1 2 3 4 5 6 7 8


Amount and partitioning of Al at 30-40 cm from inlet
mg Al/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8


Amount and partitioning of Al at 30-40 cm from inlet
mg Al/kg soil
100%
80%
60%
40%
20%
0%
-20%
-40%
1 2 3 4 5 6 7 8


Amount and partitioning of Al at 40-50 cm from inlet
mg Al/kg soil
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8


Amount and partitioning of Al at 40-50 cm from inlet
mg Al/kg soil
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1 2 3 4 5 6 7 8

Appendix K Geochemical model development

Appendix K-1 Description of model codes

`SOLUTION_SPECIES; H2O +` `0.01e- = H2O-0.01; -log_k -9`	**SOLUTION SPECIES** *Association reaction; log K*
`TITLE clinoptilolite model`	**TITLE** *comment*
`SOLUTION 0 ARD`	**SOLUTION** *[number] [description]* Infilling solution for column; this data block define the temperature and chemical composition of the infilling solution
`Temp 20`	**Temp** *temperature* – Temperature of leaching solution
`pH 3.28`	**pH** *pH*, the negative log of the activity of hydrogen ion
`pe 13.22`	**pe** *pe value*, conventional negative log of the activity of the electron *[(charge or phase name [saturation index])]* $pe = \frac{F}{\log_{10} RT} \bullet Eh(Volts)$ F = Faraday constant, 96.485 Columb/mol R = Gas Constant, 0.0083147 KJ mol^{-1} K^{-1} T = Temperature, Kelvin E_h = voltage potential of the normal hydrogen electrode = $E + E_R$ Where E = the voltage potential observed with the Redox electrode E_R = standard potential of the reference electrode, E_R = 202 mV @25°C
`units ppm`	**Units** *concentration units* Units defined in terms of concentration per liter ("/L") and is defined as parts per million (ppm or mg/L)
`Ca 356.6`	*Element list* *concentration, [units]*
`Cu 37.8`	
`Mg 64.7`	
`Al 24.6`	
`Fe 3.031`	
`Mn 3.829`	
`Na 8.8`	
`S(6) 1140 as SO4`	

S(-2) 560.9 as S	
Zn 24.2	
F 2.1	
END	
SOLUTION 1-5 initial solution	**SOLUTION** *[number] [description]* Define the temperature and chemical composition of the initial solutions.
Temp 25.0	**Temp** *temperature* – Temperature of initial solution
pH 7.58 charge	**pH** *pH value*, the negative log of the activity of hydrogen ions *[(charge or phase name [saturation index])]* **charge** – indicates pH is to be adjusted to achieve charge balance.
Pe 4.0	**pe** *pe value*, conventional negative log of the activity of the electron *[(charge or phase name [saturation index])]*
Na 1000	1000 mmol/L (default unit is mmol/L) in 1M NaCl
Cl 1000	1M NaCl
EQUILIBRIUM_PHASES 1-5	EQUILIBRIUM_PHASES *[number][description]* Define the amounts of assemblage of pure phases that can react reversibly with the aqueous phase. Pure phases include minerals with fixed composition.
Phillipsite	*Phase name [saturation index [(alternative formula or alternative phase)[amount]]]* added as zeolite
quartz	*Phase name [saturation index [(alternative formula or alternative phase)[amount]]]* Quartz present in the clinoptilolite
kmica	*Phase name [saturation index [(alternative formula or alternative phase)[amount]]]* Mica is present in the clinoptilolite
pyrite	*Phase name [saturation index [(alternative formula or alternative phase)[amount]]]* Added as present in ARD
jarosite-K 0 0 jarosite-Na jarositeH	*Phase name [saturation index [(alternative formula or alternative phase)[amount]]]* Let jarosite only precipitate
SAVE solution 1-5	SAVE *keyword, number*
END	

EXCHANGE 1-5	**EXCHANGE** *[number][description]* Amount and composition of exchanger in cell expressed in moles X^- per liter of pore water Sorption depends on surface area and amount of sorption "sites" and the relative attraction of aqueous species to sorption sites on mineral/water interfaces. Mineral surfaces can have permanent structural charge or variable charge. Sorption on permanent charge surfaces is referred to as "ion exchange", and occurs in clays, and zeolites. Ion exchange calculations involve small cationic species, e.g. Ca^{2+}, Na^+, NH_4^+, and Al^{3+}. The exchanger is defined having a fixed CEC.
X 3.108	*Exchange formula, amount in moles* Cation exchange capacity (CEC) of clinoptilolite is 121.52 meq/100g and specific weight of 2.00151 g/cm^3. The porosity of the clinoptilolite in the column leaching cell is n=0.439. The CEC expressed in units meq/L pore water can be calculated. 100g dry sediment contains $\frac{100}{2.00151} = 49.96ml$ "grains". Subsequently, the amount of pore water in100g sediment can be calculated. For n = 0.439, Total sediment volume is $\frac{49.96}{(1-n)} = 89.06ml$; Pore water = $89.06ml \times n = 39.1ml$; Cation exchange capacity per litre of pore water = $\frac{121.52meq}{100g} = \frac{121.52meq}{39.1ml} = 3.108\frac{meq}{ml\ pore\ water}$ $= 3.108\frac{equivalent\ X^-}{litre\ pore\ water}$ = 3.108 moles X^- per liter pore water.
SAVE solution 1-5	SAVE *keyword, number*
End	
SURFACE_MASTER_SPECIES	**SURFACE_MASTER_SPECIES**
L L	*Surface binding-site name, surface master species*

SURFACE_SPECIES	**SURFACE_SPECIES**
L = L	*Association reaction* Surface site L
log_k 0.0	**Log_k** *log K*
#Langmuir: q=(L-1)*C/K1	Langmuir adsorption model: - Fixed # of adsorption sites - Ignores speciation, pH, competing ions, and redox states Langmuir isotherm equilibrium constant = single-site surface complex formation constant Langmuir Equation (Sparks 1995) $q = \frac{kCb}{1+kC}$ k = constant related to the binding strength or the ion specific constant for reactions of type $L + C_i \xrightarrow[precipitation]{adsorption} LC_i$ b = maximum amount of adsorptive that can be adsorbed (monolayer coverage); q = amount of adsorption, adsorbate per unit mass of adsorbent in mol/kg. In some literature, the weight of the adsorbate per unit weight of adsorbed is plotted in lieu of q; C = equilibrium concentration of the adsorptive. At the limits: K>>1 → q=b; K<<1 → q=bK Rearranging to a linear form, equation becomes $\frac{C}{q} = \frac{C}{b} + \frac{1}{kb}$ Plotting $\frac{C}{q}$ vs C, the slope is $\frac{1}{b}$ and the intercept is $\frac{1}{kb}$. Langmuir equation can equally well describe both adsorption and precipitation (Veith and Sposito, 1977). Considering the reaction of species C onto the Langmuir adsorption site L. $L + C_i \xrightarrow[precipitation]{adsorption} LC_i$ The rate constant, K, for the reaction is $K = \frac{[LC_i]}{[L][C_i]}$ The ratio of site saturation, θ, is $\theta = \frac{[LC_i]}{b}$ where b is the maximum value LC can attain.

L + Cu+2 = LCu+2	*Association reaction* Surface site L
log_k 2.1186	$\log_k = \log\frac{1}{K_1}$ (K_1 from Langmuir equation)
L + Fe+3 = LFe+3	*Association reaction* Surface site L
log_k 2.301	$\log_k = \log\frac{1}{K_1}$ (K_1 from Langmuir equation)
L + Mn+2 = LMn+2	*Association reaction* Surface site L
log_k 2.0939	$\log_k = \log\frac{1}{K_1}$ (K_1 from Langmuir equation)
L + Zn+2 = LZn+2	*Association reaction* Surface site L
log_k 2.5382	$\log_k = \log\frac{1}{K_1}$ (K_1 from Langmuir equation)
L + Al+3 = LAl+3	*Association reaction* Surface site L
log_k 2.5379	$\log_k = \log\frac{1}{K_1}$ (K_1 from Langmuir equation)
Hfo_wOH + Na+ = Hfo_wONa + H+	*Association reaction* Surface site L
log_k -15	$\log_k = \log\frac{1}{K_1}$ (K_1 from Langmuir equation)
SURFACE 1-5	**SURFACE** *[number][description]* "Surface complexation" is the type of sorption on variable charge surfaces. It occurs on Fe, Mn, Al, Ti, Si oxides and hydroxides, carbonates, sulfides and clay edges. In this study, variable charge surface includes Fe, Mn, Al, Si oxides & hydroxides and carbonates.
L 3.101 63.844 2557.73	*Surface binding-site name, sites, specific_area_per_gram, mass* <u>Sites</u> Total number of surface (moles of binding sites) are calculated from CEC (meq/100g soil) $L = \frac{CEC}{\left(\frac{100}{SW}\right)\left(\frac{\theta}{1-\theta}\right)} = \frac{CEC}{100\cdot\left(\frac{\theta}{\rho_B}\right)}$ where SW = specific dry weight of soil, $\frac{kg}{m^3}soil$ =2.00151 θ = porosity

	ρ_B =bulk density, $\frac{kg}{l}$ The amount of surface binding sites, L, is $L = \frac{121.52\frac{meq}{100g}}{\left(\frac{100}{2.00151}\right)\left(\frac{0.439}{1-0.439}\right)} = 3.108\frac{eq}{L}$ $= 3.108\frac{mol\ L}{L\ pore\ water}$ <u>Specific surface area per gram</u> SSA (specific surface area) of clinoptilolite = $63.844\frac{m^2}{g}$ <u>Mass</u> Mass of solid for calculation of surface area in grams. The mass is needed for calculation of total surface area. Surface area = mass × SSA Need to find mass of solid in 1L of pore water 1L pore water = x ml sediment × n 1000 ml pore water = x ml sediment × 0.439 Volume of sediment = $\frac{1000ml}{0.439} = 2277.9ml$ of sediment total sediment volume $= \frac{y}{1-n}ml$ $2277.9ml = \frac{y}{1-0.439}ml$ $y = 1277.9ml = 1277.9cm^3$ Weight of dry sediment, z, is $\frac{z\ grams}{2.00151\frac{g}{cm^3}} = 1277.9cm^3$ Weight of dry sediment = 2557.73 grams
Hfo_s 0.00321 954.427 2.2724	*Surface binding-site name, sites, specific _area_per_gram, mass* The number of moles of Hfo is related to the number of moles of Fe present: **From soil**: From x-ray fluorescent analysis, the clinoptilolite sample contains 2.56% of Fe_2O_3. The weight of dry clinoptilolite sediment which react

with 1L of pore water is 2557.73g

2557.73g*2.56%=65.48g Fe_2O_3

$$\frac{65.48g\ Fe_2O_3}{159.69\frac{g}{mole\ Fe_2O_3}} = 0.41 moles\ Fe_2O_3$$

$$Fe_2O_3 \longrightarrow 2Fe^{3+} + 3O^{2-}$$

0.41 moles of Fe_2O_3 contains 0.82 moles of Fe

From residue: 1.5g of residue is found in every 26L of ARD → 5.77×10^{-2} g of residue per L of leachate
From x-ray fluorescent analysis, the residue contains 64.16% of Fe_2O_3

$$5.77\times10^{-2}\ g\ residue \times 64.16\% \frac{Fe_2O_3}{residue}$$

$$= 3.70\times10^{-2}\ g\ Fe_2O_3$$

$$= 3.70\times10^{-2}\ g\ Fe_2O_3 \times \frac{1\ mole Fe_2O_3}{159.69g}$$

$$= 2.32\times10^{-4}\ mole\ Fe_2O_3$$

$$Fe_2O_3 \longrightarrow 2Fe^{3+} + 3O^{2-}$$

→ 2.32×10^{-4} mole Fe_2O_3 contains 4.64×10^{-4} mole Fe

Amount of Fe from soil and residue:
0.82 moles + 4.64×10^{-4} moles = 0.821 moles Fe

Hfo_s denotes hydrous ferric oxide surface, with strong binding sites. Strong sites account for smaller set of high-affinity cation binding sites.
Site density for strong sites: $\frac{0.005 mol\ Hfo_s}{mol\ Fe}$ (range 0.001-0.1).

Number of moles of Hfo_s:

$$\frac{0.005 mol\ Hfo_s}{mol\ Fe} \times 0.821 mol\ Fe$$

$$= 4.10\times10^{-3}\ mol\ Hfo_s$$

<u>Specific surface area</u> – Specific area of surface, in m^2/g.
Dzombak & Morel (1990) defines a surface area of $5.33 \times 10^4 m^2$/mol Fe.
In terms of m^2/g,

	$5.33\times10^4 \frac{m^2}{mol\ Fe}\times\frac{1mol\ Fe}{55.845g}$ $=\frac{954.427m^2}{g\ Fe}$ Mass of Hfo_s – mass of solid for calculation of surface area, in g; (surface area = mass × specific_area_per_gram) Dzombak & Morel (1990) assume HFO to be $Fe_2O_3{\cdot}H_2O$, i.e. 89g HFO/mol Fe. $0.821mol\ Fe\times\frac{89g\ Hfo}{mol\ Fe}=73.069g\ Hfo$

`Hfo_w 0.128 954.427`
 	
`2.2724`
	Surface binding-site name, sites, specific _area_per_gram, mass
	
	Hfo_w denotes hydrous ferric oxide surface, with weak binding sites. Site density for weak sites:
	$\frac{0.2mol\ Hfo_w}{mol\ Fe}$ (range 0.1-0.3).
	The weak sites apply to sorption of protons, cations and anions.
	
	Number of moles of Hfo_w:
	$\frac{0.2mol\ Hfo_w}{mol\ Fe}\times0.821mol\ Fe$
	$=0.1641mol\ Hfo_w$
	
	Specific surface area – Specific area of surface, in m^2/g. Dzombak & Morel (1990) defines a surface area of $5.33\times10^4 m^2$/mol Fe.
	In terms of m^2/g,
	$5.33\times10^4 \frac{m^2}{mol\ Fe}\times\frac{1mol\ Fe}{55.845g}$
	$=\frac{954.427m^2}{g\ Fe}$
	
	Mass of Hfo_w – mass of solid for calculation of surface area, in g; (surface area = mass × specific_area_per_gram)
	
	Dzombak & Morel (1990) assume HFO to be $Fe_2O_3{\cdot}H_2O$, i.e. 89g HFO/mol Fe.

	$0.821 mol\ Fe \times \frac{89 g\ Hfo}{mol\ Fe} = 73.069 g\ Hfo$ Dzombak and Morel (1990) assume Hfo to b-e $Fe_2O_3H_2O$, i.e. 89g Hfo/mole Fe. These values apply to Hfo only, an amorphous solid, with significant aging. Hfo transforms to goethite (α-FeOOH), a crystalline oxide with lower and less reactive surface area. 2-10% goethite appears in Hfo after 12-15 days of aging.
`#equilibrate 0`	
`#no_edl`	
`PRINT; -reset false`	**PRINT** **-reset** [(*True* or *False*)]
`TRANSPORT`	**TRANSPORT**
`-cells 5`	**-cells** *cells* 5 cells
`-length 5*0.11`	**-lengths** *list of lengths* cell length = 0.11m in each cell model depth 5*0.11m=0.55m
`-shifts 500`	**-shifts** *shifts* 100 shifts
`-time_step 17280`	**-time_step** *time step* 1 shift=17280s, total time=shifts*time p=17280*100=20days velocity,v $v = \frac{cell\ length}{time\ step}$ $v = \frac{x}{t} = \frac{0.11m}{17280s} = 6.36 \times 10^{-6} \frac{m}{s} = 0.55 \frac{m}{day}$
`-flow_direction forward`	**-flow_direction (forward, back** or **diffusion_only)** The direction of flow

`-boundary_conditions`
 	
`constant flux`
	-boundary_conditions *first,last*
	The boundary conditions at column ends

`-diffc 0.03e-9`	**-diffc** *diffusion coefficient* m^2/s
`-dispersivity 5*0.00077`	**-dispersivities** *list of dispersivities* Dispersion coefficient Macro-dispersivity Longtitudinal dispersivity in each cell $\alpha_L = 0.1x$ $\alpha_L = 3.5 d_{10} = 3.5 \times 0.22mm = 0.00077m$
`-correct_disp true`	**-correct_disp** [(*True* or *False*)] set to true when modeling outflow from a column with

	flux boundary conditions
-punch 5	**-punch** *list of cell numbers* only punch.graph cell 5 specifies that data will be written to the selected-output file for the cell 5 at each shift
-punch_frequency 1	**-punch_frequency** *punch_modulus* indicates that data will be written to the output file for cell 5 every 1 shift
-warnings false	**-warnings** [(*True* or *False*)]
USER_GRAPH	**USER_GRAPH**
-headings PV Cu Fe Zn Al Mn pH	**-headings** *list of column headings*
-chart_title "clinoptilolite"	**-chart_title** *chart title*
-axis_titles "pore volume""ppm""pH"	**-axis_titles** *titles of x-axis, y-axis* and *secondary y-axis*
-plot_concentration_vs time	**-plot_concentration_vs** plot concentration against variable [(*time, length, or cell*)]
-start	
10 graph_x (step_no+0.5)/5	PHREEQC calculates cell-centered concentrations, so that the concentrations in the last cell arrives a half shift later at the column end. In this algorithm, one shift represents 1/5 of the column pore volume. The number of pore volumes (PV) that have been flushed from the column is therefore $PV = \frac{number\ of\ shifts + 0.5}{5}$
20 graph_y tot("Cu")*63546,tot("Fe")*55 847,tot("Zn")*65370,tot("Al")*26982,tot("Mn")*54938	
30 graph_sy -LA("H+")	
-end	

Dzombak, D. A. and F. M. M. Morel (1990). Surface complexation model: hydrous ferric oxide. New York, Wiley & Sons.

Sparks, D. L. (1995). Environmental Soil Chemistry. San Diego, CA, Academic Press, Inc.

Appendix K-2 Model output

```
------------------
Reading data base.
------------------

    SOLUTION_MASTER_SPECIES
    SOLUTION_SPECIES
    PHASES
    EXCHANGE_MASTER_SPECIES
    EXCHANGE_SPECIES
    SURFACE_MASTER_SPECIES
    SURFACE_SPECIES
    END
-----------------------------------
Reading input data for simulation 1.
-----------------------------------

    SOLUTION_SPECIES
     H2O + 0.01e- = H2O-0.01
     log_k -9
    TITLE clinoptilolite model
    SOLUTION 0 ARD
        temp    20
        pH  3.28
        pe  13.22 #O2(g)    -0.68
        units   ppm
        Ca  356.6
    Cu  35.7
        Mg  64.7
      Al 24.6
        Fe  3.031
    Mn  3.829
        Na  8.8
    S(6)    1140  as SO4
    S(-2)   560.9  as S
    Zn  24.2
        F   2.1
    END
-----
TITLE
-----

 clinoptilolite model

-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 0. ARD

-----------------------------Solution
composition------------------------------

    Elements          Molality      Moles
```

```
    Al              9.138e-04   9.138e-04
    Ca              8.917e-03   8.917e-03
    Cu              5.631e-04   5.631e-04
    F               1.108e-04   1.108e-04
    Fe              5.439e-05   5.439e-05
    Mg              2.667e-03   2.667e-03
    Mn              6.985e-05   6.985e-05
    Na              3.836e-04   3.836e-04
    S(-2)            1.753e-02   1.753e-02
    S(6)             1.189e-02   1.189e-02
    Zn              3.710e-04   3.710e-04

----------------------------Description of solution----------------------------

                                  pH  =   3.280
                                  pe  =  13.220
                      Activity of water  =   0.999
                         Ionic strength  =   3.424e-02
                     Mass of water (kg)  =   1.000e+00
                Total alkalinity (eq/kg)  =   1.523e-03
                   Total carbon (mol/kg)  =   0.000e+00
                     Total CO2 (mol/kg)  =   0.000e+00
                    Temperature (deg C)  =  20.000
                 Electrical balance (eq)  =   2.936e-03
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =   8.35
                            Iterations  =  10
                               Total H  = 1.110459e+02
                               Total O  = 5.555381e+01

---------------------------------Redox
couples---------------------------------

    Redox couple            pe  Eh (volts)

    S(-2)/S(6)          1.0094      0.0587

----------------------------Distribution of species----------------------------

                                          Log      Log        Log
    Species          Molality   Activity  Molality  Activity    Gamma

    H+              6.032e-04   5.248e-04   -3.220    -3.280    -0.060
    H2O-0.01         7.371e-10   7.371e-10   -9.132    -9.132    -0.000
    OH-             1.532e-11   1.293e-11  -10.815   -10.888    -0.074
    H2O             5.551e+01   9.994e-01    1.744    -0.000     0.000
Al              9.138e-04
    AlSO4+           5.541e-04   4.676e-04   -3.256    -3.330    -0.074
    Al+3            1.851e-04   4.019e-05   -3.733    -4.396    -0.663
    AlF+2           1.023e-04   5.187e-05   -3.990    -4.285    -0.295
    Al(SO4)2-        6.725e-05   5.676e-05   -4.172    -4.246    -0.074
    AlF2+           3.992e-06   3.369e-06   -5.399    -5.473    -0.074
    AlOH+2          1.079e-06   5.472e-07   -5.967    -6.262    -0.295
    AlHSO4+2         4.118e-08   2.089e-08   -7.385    -7.680    -0.295
    Al(OH)2+         6.173e-09   5.210e-09   -8.210    -8.283    -0.074
    AlF3            5.570e-09   5.614e-09   -8.254    -8.251     0.003
    Al(OH)3          9.912e-13   9.990e-13  -12.004   -12.000     0.003
    AlF4-           3.520e-13   2.971e-13  -12.453   -12.527    -0.074
    Al(OH)4-         3.998e-15   3.374e-15  -14.398   -14.472    -0.074
Ca              8.917e-03
    Ca+2            6.417e-03   3.358e-03   -2.193    -2.474    -0.281
```

CaSO4	2.491e-03	2.511e-03	-2.604	-2.600	0.003
CaHSO4+	8.620e-06	7.275e-06	-5.064	-5.138	-0.074
CaF+	4.095e-09	3.456e-09	-8.388	-8.461	-0.074
CaOH+	1.257e-12	1.061e-12	-11.901	-11.974	-0.074
Cu(1)	1.329e-23				
Cu+	1.329e-23	1.122e-23	-22.876	-22.950	-0.074
Cu(2)	5.631e-04				
Cu(HS)3-	5.631e-04	4.752e-04	-3.249	-3.323	-0.074
Cu+2	7.334e-13	3.720e-13	-12.135	-12.429	-0.295
CuSO4	2.859e-13	2.882e-13	-12.544	-12.540	0.003
CuOH+	8.394e-18	7.084e-18	-17.076	-17.150	-0.074
CuF+	1.019e-18	8.598e-19	-17.992	-18.066	-0.074
Cu(OH)2	2.796e-20	2.819e-20	-19.553	-19.550	0.003
Cu2(OH)2+2	2.613e-29	1.326e-29	-28.583	-28.878	-0.295
Cu(OH)3-	3.832e-30	3.234e-30	-29.417	-29.490	-0.074
Cu(OH)4-2	2.422e-39	1.229e-39	-38.616	-38.911	-0.295
F	1.108e-04				
AlF+2	1.023e-04	5.187e-05	-3.990	-4.285	-0.295
AlF2+	3.992e-06	3.369e-06	-5.399	-5.473	-0.074
FeF+2	2.603e-07	1.320e-07	-6.585	-6.879	-0.295
F-	1.577e-07	1.331e-07	-6.802	-6.876	-0.074
HF	9.505e-08	9.580e-08	-7.022	-7.019	0.003
MgF+	9.457e-09	7.982e-09	-8.024	-8.098	-0.074
AlF3	5.570e-09	5.614e-09	-8.254	-8.251	0.003
CaF+	4.095e-09	3.456e-09	-8.388	-8.461	-0.074
FeF2+	7.802e-10	6.584e-10	-9.108	-9.182	-0.074
MnF+	2.930e-11	2.473e-11	-10.533	-10.607	-0.074
NaF	2.419e-11	2.438e-11	-10.616	-10.613	0.003
FeF+	8.895e-13	7.507e-13	-12.051	-12.125	-0.074
AlF4-	3.520e-13	2.971e-13	-12.453	-12.527	-0.074
ZnF+	1.407e-13	1.188e-13	-12.852	-12.925	-0.074
FeF3	1.354e-13	1.365e-13	-12.868	-12.865	0.003
HF2-	5.558e-14	4.691e-14	-13.255	-13.329	-0.074
H2F2	2.836e-14	2.858e-14	-13.547	-13.544	0.003
CuF+	1.019e-18	8.598e-19	-17.992	-18.066	-0.074
Fe(2)	1.473e-06				
Fe+2	1.112e-06	5.642e-07	-5.954	-6.249	-0.295
FeSO4	3.564e-07	3.593e-07	-6.448	-6.445	0.003
Fe(HS)2	3.178e-09	3.203e-09	-8.498	-8.494	0.003
FeHSO4+	1.448e-09	1.222e-09	-8.839	-8.913	-0.074
Fe(HS)3-	1.043e-12	8.804e-13	-11.982	-12.055	-0.074
FeF+	8.895e-13	7.507e-13	-12.051	-12.125	-0.074
FeOH+	2.753e-13	2.323e-13	-12.560	-12.634	-0.074
Fe(OH)2	2.401e-21	2.420e-21	-20.620	-20.616	0.003
Fe(OH)3-	1.930e-28	1.628e-28	-27.715	-27.788	-0.074
Fe(3)	5.292e-05				
FeSO4+	3.087e-05	2.606e-05	-4.510	-4.584	-0.074
FeOH+2	1.216e-05	6.167e-06	-4.915	-5.210	-0.295
Fe(OH)2+	3.800e-06	3.207e-06	-5.420	-5.494	-0.074
Fe+3	3.116e-06	6.767e-07	-5.506	-6.170	-0.663
Fe(SO4)2-	2.602e-06	2.196e-06	-5.585	-5.658	-0.074
FeF+2	2.603e-07	1.320e-07	-6.585	-6.879	-0.295
FeHSO4+2	7.259e-08	3.683e-08	-7.139	-7.434	-0.295
Fe2(OH)2+4	1.907e-08	1.263e-09	-7.720	-8.899	-1.179
FeF2+	7.802e-10	6.584e-10	-9.108	-9.182	-0.074
Fe(OH)3	6.253e-10	6.303e-10	-9.204	-9.200	0.003
Fe3(OH)4+5	9.407e-11	1.353e-12	-10.027	-11.869	-1.842
FeF3	1.354e-13	1.365e-13	-12.868	-12.865	0.003
Fe(OH)4-	1.057e-15	8.922e-16	-14.976	-15.050	-0.074
H(0)	1.422e-36				

H2	7.109e-37	7.166e-37	-36.148	-36.145	0.003
Mg	2.667e-03				
Mg+2	1.869e-03	9.955e-04	-2.728	-3.002	-0.274
MgSO4	7.982e-04	8.045e-04	-3.098	-3.094	0.003
MgF+	9.457e-09	7.982e-09	-8.024	-8.098	-0.074
MgOH+	5.153e-12	4.348e-12	-11.288	-11.362	-0.074
Mn(2)	6.985e-05				
Mn+2	5.295e-05	2.686e-05	-4.276	-4.571	-0.295
MnSO4	1.690e-05	1.704e-05	-4.772	-4.769	0.003
MnF+	2.930e-11	2.473e-11	-10.533	-10.607	-0.074
MnOH+	1.029e-12	8.686e-13	-11.987	-12.061	-0.074
Mn(OH)3-	3.483e-30	2.940e-30	-29.458	-29.532	-0.074
Mn(3)	3.018e-17				
Mn+3	3.018e-17	6.555e-18	-16.520	-17.183	-0.663
Mn(6)	0.000e+00				
MnO4-2	0.000e+00	0.000e+00	-45.473	-45.768	-0.295
Mn(7)	0.000e+00				
MnO4-	0.000e+00	0.000e+00	-42.190	-42.264	-0.074
Na	3.836e-04				
Na+	3.764e-04	3.184e-04	-3.424	-3.497	-0.073
NaSO4-	7.196e-06	6.073e-06	-5.143	-5.217	-0.074
NaF	2.419e-11	2.438e-11	-10.616	-10.613	0.003
O(0)	3.404e-22				
O2	1.702e-22	1.715e-22	-21.769	-21.766	0.003
S(-2)	1.753e-02				
H2S	1.510e-02	1.522e-02	-1.821	-1.818	0.003
Cu(HS)3-	5.631e-04	4.752e-04	-3.249	-3.323	-0.074
Zn(HS)2	3.708e-04	3.737e-04	-3.431	-3.427	0.003
HS-	2.991e-06	2.524e-06	-5.524	-5.598	-0.074
Zn(HS)3-	1.616e-08	1.364e-08	-7.792	-7.865	-0.074
Fe(HS)2	3.178e-09	3.203e-09	-8.498	-8.494	0.003
S5-2	1.539e-12	9.350e-13	-11.813	-12.029	-0.216
Fe(HS)3-	1.043e-12	8.804e-13	-11.982	-12.055	-0.074
S6-2	1.008e-12	6.325e-13	-11.997	-12.199	-0.202
S4-2	9.218e-13	5.393e-13	-12.035	-12.268	-0.233
S-2	8.083e-16	4.100e-16	-15.092	-15.387	-0.295
S3-2	3.326e-16	1.862e-16	-15.478	-15.730	-0.252
S2-2	1.905e-17	1.027e-17	-16.720	-16.988	-0.268
S(6)	1.189e-02				
SO4-2	7.633e-03	3.930e-03	-2.117	-2.406	-0.288
CaSO4	2.491e-03	2.511e-03	-2.604	-2.600	0.003
MgSO4	7.982e-04	8.045e-04	-3.098	-3.094	0.003
AlSO4+	5.541e-04	4.676e-04	-3.256	-3.330	-0.074
HSO4-	2.135e-04	1.802e-04	-3.671	-3.744	-0.074
Al(SO4)2-	6.725e-05	5.676e-05	-4.172	-4.246	-0.074
FeSO4+	3.087e-05	2.606e-05	-4.510	-4.584	-0.074
MnSO4	1.690e-05	1.704e-05	-4.772	-4.769	0.003
CaHSO4+	8.620e-06	7.275e-06	-5.064	-5.138	-0.074
NaSO4-	7.196e-06	6.073e-06	-5.143	-5.217	-0.074
Fe(SO4)2-	2.602e-06	2.196e-06	-5.585	-5.658	-0.074
FeSO4	3.564e-07	3.593e-07	-6.448	-6.445	0.003
FeHSO4+2	7.259e-08	3.683e-08	-7.139	-7.434	-0.295
ZnSO4	5.920e-08	5.967e-08	-7.228	-7.224	0.003
AlHSO4+2	4.118e-08	2.089e-08	-7.385	-7.680	-0.295
Zn(SO4)2-2	3.908e-09	1.982e-09	-8.408	-8.703	-0.295
FeHSO4+	1.448e-09	1.222e-09	-8.839	-8.913	-0.074
CuSO4	2.859e-13	2.882e-13	-12.544	-12.540	0.003
Zn	3.710e-04				
Zn(HS)2	3.708e-04	3.737e-04	-3.431	-3.427	0.003
Zn+2	1.328e-07	6.736e-08	-6.877	-7.172	-0.295

ZnSO4	5.920e-08	5.967e-08	-7.228	-7.224	0.003
Zn(HS)3-	1.616e-08	1.364e-08	-7.792	-7.865	-0.074
Zn(SO4)2-2	3.908e-09	1.982e-09	-8.408	-8.703	-0.295
ZnF+	1.407e-13	1.188e-13	-12.852	-12.925	-0.074
ZnOH+	1.133e-13	9.563e-14	-12.946	-13.019	-0.074
Zn(OH)2	3.051e-18	3.075e-18	-17.516	-17.512	0.003
Zn(OH)3-	2.194e-26	1.852e-26	-25.659	-25.732	-0.074
Zn(OH)4-2	1.102e-35	5.588e-36	-34.958	-35.253	-0.295

----------Saturation indices----------

Phase	SI	log IAP	log KT	
Al(OH)3(a)	-5.69	5.44	11.13	Al(OH)3
Anhydrite	-0.54	-4.88	-4.34	CaSO4
Anilite	-7.43	-36.84	-29.41	Cu0.25Cu1.5S
Antlerite	-34.86	-26.57	8.29	Cu3(OH)4SO4
Basaluminite	-9.89	12.81	22.70	Al4(OH)10SO4
Bianchite	-7.82	-9.58	-1.76	ZnSO4:6H2O
Birnessite	-8.61	34.99	43.60	MnO2
Bixbyite	-14.27	36.98	51.24	Mn2O3
BlaubleiI	6.07	-11.57	-17.64	Cu0.9Cu0.2S
BlaubleiII	-0.86	-23.23	-22.38	Cu0.6Cu0.8S
Boehmite	-3.49	5.44	8.94	AlOOH
Brochantite	-47.78	-32.44	15.34	Cu4(OH)6SO4
Brucite	-13.62	3.56	17.18	Mg(OH)2
Chalcanthite	-12.18	-14.84	-2.66	CuSO4:5H2O
Chalcocite	-12.98	-46.56	-33.57	Cu2S
Chalcopyrite	12.40	-9.19	-21.59	CuFeS2
Covellite	7.82	-7.69	-15.51	CuS
Cu(OH)2	-14.70	-5.87	8.83	Cu(OH)2
Cu2SO4	-46.41	-53.70	-7.29	Cu2SO4
CuF	-37.06	-32.53	4.54	CuF
CuF2	-25.73	-26.18	-0.45	CuF2
CuF2:2H2O	-21.68	-26.18	-4.50	CuF2:2H2O
CuMetal	-27.20	-38.87	-11.67	Cu
CuOCuSO4	-32.68	-20.70	11.97	CuO:CuSO4
CupricFerrite	-4.89	27.75	32.65	CuFe2O4
Cuprite	-37.71	-44.74	-7.03	Cu2O
CuprousFerrite	-7.13	-5.56	1.57	CuFeO2
CuSO4	-18.07	-14.84	3.24	CuSO4
Diaspore	-1.74	5.44	7.19	AlOOH
Djurleite	-11.49	-43.99	-32.50	Cu0.066Cu1.868S
Epsomite	-3.23	-5.41	-2.18	MgSO4:7H2O
Fe(OH)3(a)	-1.22	16.81	18.03	Fe(OH)3
Fe3(OH)8	-12.57	33.93	46.50	Fe3(OH)8
FeS(ppt)	-4.65	-1.51	3.15	FeS
Fluorite	-5.57	-16.23	-10.66	CaF2
Gibbsite	-2.95	5.44	8.40	Al(OH)3
Goethite	4.67	16.81	12.14	FeOOH
Goslarite	-7.58	-9.58	-2.00	ZnSO4:7H2O
Greigite	17.18	26.66	9.49	Fe3S4
Gypsum	-0.30	-4.88	-4.58	CaSO4:2H2O
H2(g)	-32.95	-33.00	-0.05	H2
H2S(g)	-0.87	-1.82	-0.94	H2S
Hausmannite	-23.32	38.97	62.29	Mn3O4
Hematite	10.96	33.62	22.66	Fe2O3
Jarosite-Na	-2.31	32.28	34.60	NaFe3(SO4)2(OH)6
JarositeH	-2.22	32.50	34.72	(H3O)Fe3(SO4)2(OH)6

```
    Jurbanite        -0.29   -3.52   -3.23  AlOHSO4
    Langite         -49.73  -32.45   17.29  Cu4(OH)6SO4:H2O
    Mackinawite      -3.92   -1.51    2.41  FeS
    Maghemite         0.95   33.62   32.67  Fe2O3
    Magnetite         3.28   33.93   30.65  Fe3O4
    Manganite        -6.85   18.49   25.34  MnOOH
    Melanterite      -6.38   -8.66   -2.27  FeSO4:7H2O
    Mirabilite       -8.05   -9.40   -1.35  Na2SO4:10H2O
    Mn2(SO4)3       -36.36   10.08   46.44  Mn2(SO4)3
    MnS(Green)      -10.76    0.17   10.93  MnS
    MnSO4            -9.84   -6.98    2.86  MnSO4
    Nsutite          -7.58   34.99   42.56  MnO2
    O2(g)           -18.91   66.00   84.91  O2
    Portlandite     -19.10    4.09   23.19  Ca(OH)2
    Pyrite           34.18   29.68   -4.50  FeS2
    Pyrochroite     -13.21    1.99   15.20  Mn(OH)2
    Pyrolusite       -7.21   34.99   42.19  MnO2
    Sphalerite        2.23   -2.43   -4.66  ZnS
    Sulfur           26.18   31.18    5.00  S
    Tenorite        -13.68   -5.87    7.81  CuO
    Thenardite       -9.23   -9.40   -0.17  Na2SO4
    Wurtzite          0.26   -2.43   -2.68  ZnS
    Zincite(c)      -12.03   -0.61   11.41  ZnO
    Zincosite       -12.83   -9.58    3.25  ZnSO4
    Zn(OH)2-a       -13.06   -0.61   12.45  Zn(OH)2
    Zn(OH)2-b       -12.36   -0.61   11.75  Zn(OH)2
    Zn(OH)2-c       -12.81   -0.61   12.20  Zn(OH)2
    Zn(OH)2-e       -12.11   -0.61   11.50  Zn(OH)2
    Zn(OH)2-g       -12.32   -0.61   11.71  Zn(OH)2
    Zn2(OH)2SO4     -17.69  -10.19    7.50  Zn2(OH)2SO4
    Zn3O(SO4)2      -39.56  -19.77   19.80  ZnO:2ZnSO4
    Zn4(OH)6SO4     -39.81  -11.41   28.40  Zn4(OH)6SO4
    ZnF2            -19.57  -20.92   -1.36  ZnF2
    ZnMetal         -59.83  -33.61   26.22  Zn
    ZnO(a)          -11.92   -0.61   11.31  ZnO
    ZnS(a)           -0.39   -2.43   -2.04  ZnS
    ZnSO4:H2O        -9.14   -9.58   -0.44  ZnSO4:H2O

------------------
End of simulation.
------------------

------------------------------------
Reading input data for simulation 2.
------------------------------------

    SOLUTION 1-5 initial solution
        temp    25.0
        pH  7.58  charge
        units    ppm
        Na  10000
    Cl  10000
    end
-------------------------------------------
Beginning of initial solution calculations.
-------------------------------------------

Initial solution 1. initial solution

-----------------------------Solution
```

```
composition-----------------------------

    Elements          Molality      Moles

    Cl              2.878e-01   2.878e-01
    Na              4.439e-01   4.439e-01

---------------------------Description of solution---------------------------

                                  pH  =  13.064     Charge balance
                                  pe  =   4.000
                     Activity of water  =   0.985
                        Ionic strength  =   4.439e-01
                   Mass of water (kg)   =   1.000e+00
               Total alkalinity (eq/kg) =   1.560e-01
                  Total carbon (mol/kg) =   0.000e+00
                    Total CO2 (mol/kg)  =   0.000e+00
                  Temperature (deg C)   =  25.000
               Electrical balance (eq)  =  -8.327e-17
 Percent error, 100*(Cat-|An|)/(Cat+|An|)  =  -0.00
                            Iterations  =   7
                              Total H   = 1.111685e+02
                              Total O   = 5.566225e+01

----------------------------Distribution of species---------------------------

                                          Log      Log        Log
    Species          Molality    Activity Molality Activity    Gamma

    OH-             1.560e-01   1.141e-01   -0.807   -0.943   -0.136
    H2O-0.01         8.983e-10   8.982e-10   -9.047   -9.047   -0.000
    H+              1.124e-13   8.639e-14  -12.949  -13.064   -0.114
    H2O             5.551e+01   9.849e-01    1.744   -0.007    0.000
Cl              2.878e-01
    Cl-             2.878e-01   1.878e-01   -0.541   -0.726   -0.186
H(0)            9.541e-38
    H2              4.770e-38   5.284e-38  -37.321  -37.277    0.044
Na              4.439e-01
    Na+             4.439e-01   3.159e-01   -0.353   -0.500   -0.148
O(0)            2.615e-18
    O2              1.308e-18   1.448e-18  -17.883  -17.839    0.044

-----------------------------Saturation
indices-------------------------------

    Phase             SI log IAP  log KT

    H2(g)          -34.08  -34.13   -0.04  H2
    Halite          -2.81   -1.23    1.58  NaCl
    O2(g)          -14.95   68.24   83.19  O2

------------------
End of simulation.
------------------

-----------------------------------
Reading input data for simulation 3.
-----------------------------------

    EQUILIBRIUM_PHASES 1-5
```

```
        phillipsite  1.0 3.108   # added as zeolite  Are you sure of 30 moles
phili/L ?
        pyrite
        quartz  1.0 1.76
        kmica   1.0 1.32
        jarosite-K  0 0 # Let it only precipitate???
        jarosite-Na 0 0
        jarositeH   0 0
    SAVE solution 1-5
    END
------------------
End of simulation.
------------------

------------------------------------
Reading input data for simulation 4.
------------------------------------

    EXCHANGE 1-5
        X   3.108        # How did you get X ? X should equal phillipsite in moles
    SAVE solution 1-5
    end
------------------
End of simulation.
------------------

------------------------------------
Reading input data for simulation 5.
------------------------------------

    SURFACE_MASTER_SPECIES
        L   L
    SURFACE_SPECIES
        L = L
        log_k   0.0
        L + Cu+2 = LCu+2
            log_k   2.1186
        L + Fe+3 = LFe+3
            log_k   2.301
        L + Mn+2 = LMn+2
            log_k   2.0939
        L + Zn+2 = LZn+2
            log_k   2.5382
        L + Al+3 = LAl+3
            log_k   2.5379
    SURFACE 1-5
        L   3.101       63.844  2557.73
        Hfo_s   0.0041  954.427 73.069
        Hfo_w 0.164 954.427 73.069
        no_edl
    end
------------------
End of simulation.
------------------
------------------------------------
Reading input data for simulation 6.
------------------------------------
    PRINT
     reset false
No memory leaks
```