REGIONAL STREAM SEDIMENT RECONNAISSANCE AND TRACE ELEMENT CONTENT OF ROCK, SOIL AND PLANT MATERIAL IN EASTERN YUKON TERRITORY

by

PATRICK J. DOYLE

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ABSTRACT

Multi-element stream sediment reconnaissance in the Hess River region of the Eastern Yukon has outlined an extensive area characterized by anomalously high molybdenum values. An accessible region in the Hess Mountains, within the high molybdenum zone, was selected for detailed study of trace element levels in stream sediment, rock, soil and vegetation. In view of the frequently observed relationship between high forage molybdenum concentrations and the incidence of copper deficiency in cattle, molybdenum concentrations in plant species likely to be consumed by caribou and moose were of particular interest.

High sediment molybdenum values are characteristic of catchments underlain by dark shales and less commonly dark limestone. These rocks and associated soils are rich in molybdenum. Concentrations in vegetation growing on anomalous shaly soils are characteristically low, while most plants growing on soils derived predominantly from limestone are molybdenum-rich. The Mo-Cu status of vegetation on limey soils is typically within the range associated with molybdenum induced hypocuprosis in cattle.

Low molybdenum uptake by plants on soils derived from shales likely reflects the unavailability of the molybdate anion, resulting from its adsorption onto clay minerals

and sesquioxides under acidic conditions prevalent in these soils. In neutral to mildly basic environments, typical of dark limestone soils, molybdenum adsorption is greatly decreased, and therefore molybdenum is relatively available to plants.

In the detailed study area soil pH values are typically similar to pH levels in associated stream water. Therefore by combining stream sediment molybdenum concentrations with stream pH data, catchments likely to contain molybdenum-rich vegetation can be predicted. Unfortunately stream pH values were not obtained in the regional survey.

In view of the apparent rarity of dark limestone throughout the Eastern Yukon, however, molybdenum-rich vegetation is not likely to be particularily widespread. Wildlife in this area, therefore, is probably not significantly affected by molybdenum induced copper deficiency.

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CHAPTER ONE

INTRODUCTION

NUTRITIONAL SIGNIFICANCE OF CRUSTAL TRACE ELEMENT ABUNDANCES

According to V. M. Goldschmidt

> "Modern geochemistry studies the amounts and the distribution of the chemical elements in minerals, ores, rocks, soils, waters and in the atmosphere" (Goldschmidt, 1954).

Many elements are essential to both plant and animal life. Of the minor or trace elements for example, adequate supplies of iron, copper, cobalt, manganese, zinc, molybdenum, selenium, chlorine and iodine are considered essential to mammals (Schutte, 1964). Other trace elements such as lead, mercury and arsenic are well known for their potentially toxic effects.

If ingested in sufficient amounts however, even the essential elements can be toxic. For example, a high dietary intake of molybdenum, in the presence of inorganic sulfate, may induce a state of copper deficiency in ruminants (Underwood, 1962). Knowledge of the regional distribution of the elements, therefore, is of considerable importance in nutritional studies and epidemiology.

Trace elements in most soils and vegetation are ultimately derived from the underlying bedrock. Acidic igneous, and coarse sedimentary rocks tend to contain relatively low concentrations of the trace elements associated with nutrition. For example, the coastal plain sands of the Eastern United States support crops which are commonly deficient in such elements as copper, iron, manganese and cobalt (Cannon, 1969).

Metal toxicities, on the other hand, are commonly associated with shales. In Co. Limerick, Ireland, for example, toxic levels of selenium and molybdenum are present in soils and herbage overlying the Clare Shales, which contain up to 30 p.p.m. selenium and 150 p.p.m. molybdenum (Webb and Atkinson, 1965). Similarily, wheat crops grown in the north-central plains of the United States contain toxic amounts of selenium, derived from selenium-rich volcanic ash layers within the underlying shales (Cannon, 1969).

APPLICATION OF STREAM SEDIMENT SURVEYS TO THE DETECTION OF TRACE ELEMENT IMBALANCES IN AGRICULTURE

A stream sediment approximates a composite sample of weathered rock and soil material upstream from the sampling point (Webb, 1968). Soluble products of weathering may be incorporated into the sediment by either absorption or precipitation. The trace element content of a stream sediment sample therefore, may reflect to some extent, that of the soils, rocks and even vegetation in the catchment as a whole.

Stream sediment sampling has been used successfully in mineral exploration programs (Webb et al, 1968). In Canada stream sediments are being utilized in pollution studies (Fortescue et al, 1971). In the British Isles they have been used extensively to detect agricultural disorders arising from trace element imbalances (Thornton and Webb, 1969).

In Co. Wicklow, Ireland, the cobalt content of stream sediments has been related to the occurrence and severity of cobalt deficiency in sheep and cattle on soils derived from granite (Webb, 1964). On the Vale of Clwyd, Wales, low manganese levels in sediments (<500 p.p.m.) have been associated with low levels in herbage and unthriftiness in livestock (Thornton and Webb, 1969).

Drainage reconnaissance over part of Co. Limerick, Ireland, has outlined large areas characterized by high molybdenum values (up to 200 p.p.m.) related to an outcrop of marine black shale (Webb and Atkinson, 1965). Detailed studies have shown the anomalies to be associated with molybdeniferous soils and rocks. Though symptoms of molydenum toxicity have been reported in cattle in the molybdenum-anomalous region, the sediment pattern defined large areas where previously unsuspected sub-clinical molybdenum induced copper deficiency is significantly inhibiting agricultural productivity.

THESIS OBJECTIVES

During the course of a mineral exploration program undertaken by Spartan Explorations Ltd., Vancouver, in the Hess Mountains, Yukon Territory, an area of over 100 square miles, characterized by stream sediments with anomalously high molybdenum contents (up to 50 p.p.m.), was recognized. Black shales, which were thought to be the source of the molybdenum, are common over a total area of more than 8,000 square miles in the Eastern Yukon.

In view of the possible existence of extensive regions characterized by enhanced molybdenum levels in rock, soil and forage materials, this study was undertaken

(1) to investigate, using sediment samples collected during a mineral exploration program, the regional extent of anomalous molybdenum levels in an area of over 6,000 square miles in the Eastern Yukon.

(2) to determine, on a local scale, trace element contents of bedrock, soil and vegetation in molybdenum-anomalous and non-anomalous regions.

SECTION A

REGIONAL STUDY

CHAPTER TWO

DESCRIPTION OF REGIONAL STUDY AREA

LOCATION AND ACCESS

The regional survey area in the Eastern Yükon extends from approximately 130° to 135° west longitude and 62° to 64° north latitude (Figure 1).

It is accessible by air from the town of Ross River. The Canol Road, which traverses the southeastern half of the area (Figure 1), is open between Ross River and the MacMillan Pass during the summer months.

GEOLOGY

The distribution of the five major geological units within the regional study area is indicated in Figure 1. The geology has been described by Bostock (Map 890A, 1947), Roddick and Green (Maps 12 - 1961, 13 - 1961), Campbell (G.S.C. Memoir 352, 1967), Campbell and Wheeler (Map 1221A - 1967) and Blusson and Templeman-Kluit (G.S.C. Paper 70-1A, 1970).

Proterozoic to Mississippian metasedimentary and sedimentary strata underlie most of the area. These rocks are intruded by small, probably Cretaceous, granitic stocks and are locally overlain by Tertiary lavas.

The Proterozoic rocks of the Yukon Group range in composition from quartz-mica, graphite, and chlorite schists in the northwest, to quartzite and dark shales in the central and southern regions. They are overlain by a rather uniform

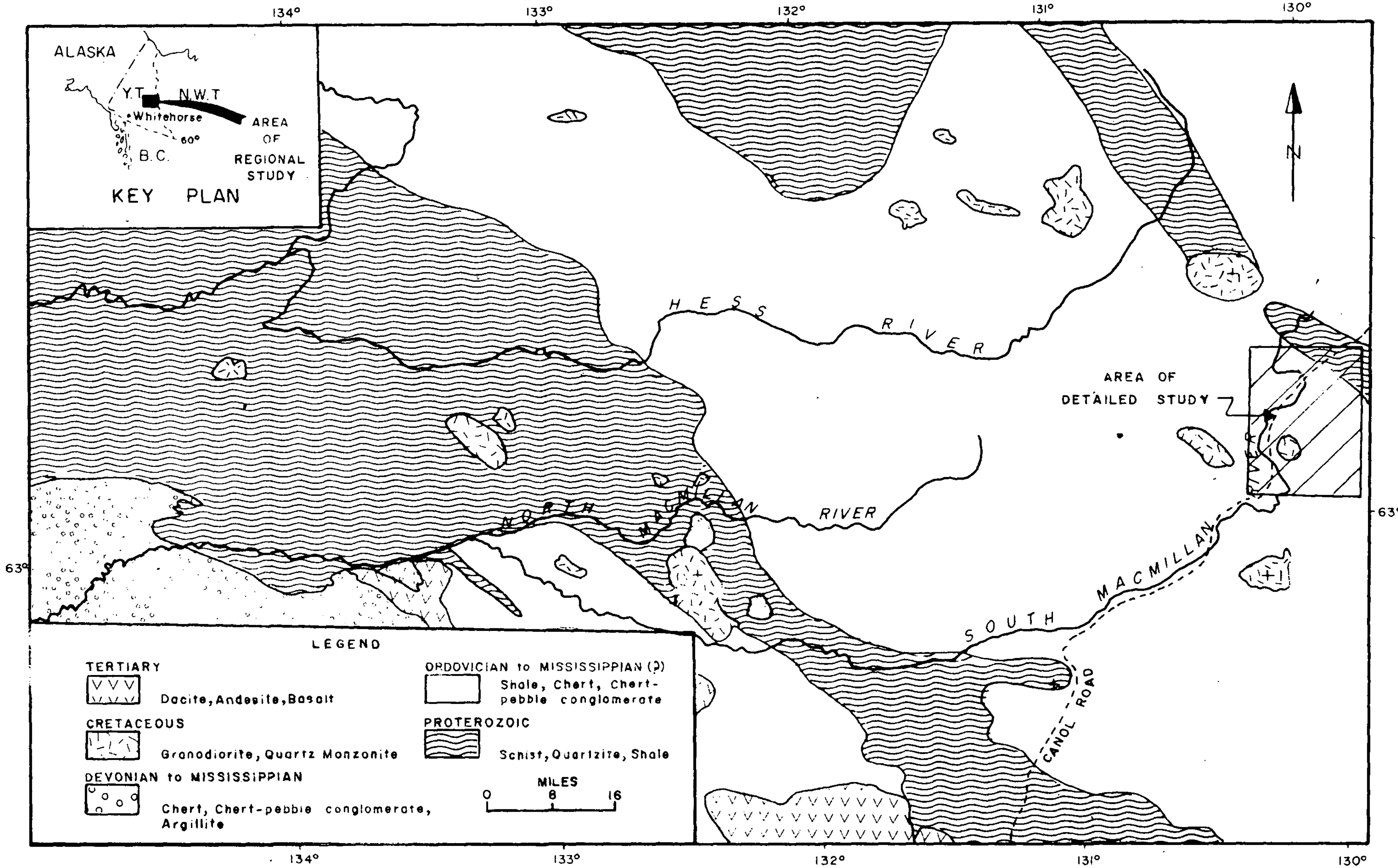


Figure 1. Distribution of the principal geological units within the regional study area.

succession of Paleozoic cherts and shales.

These dark, interbedded shales and cherts cover much of the eastern portion of the area. Their estimated aggregate thickness is 10,000 feet, with the basal portion dominated by shale and the upper portion by chert. Chert-pebble conglomerate, limestone, quartzite and phyllite are present in minor amounts. Graptolites, found in certain shaly members, suggest an Ordovician to Silurian age for part of this unit (Roddick & Green, 1961a). The rocks of the Earn Group, exposed in the southwestern corner of the area, are Devonian to Mississippian in age. They consist mainly of chert, chert-pebble conglomerate and argillite.

Massive dark lava flows, exceeding 5,000 feet in aggregate thickness, locally overlie the Paleozoic strata. The upper flows are dacitic, while the lower ones are dominantly andesitic and basaltic. Several small granodiorite and quartz monzonite stocks intrude both the Precambrian and Paleozoic rocks. Hornfels, and locally mineralized skarns, are developed near their contacts. A potassium-argon date on biotites from the Itsi Range indicates a Middle Cretaceous age for the granitic rocks (Roddick and Green, 1961a).

Several lead-zinc-copper vein and skarn deposits have been reported in the area, and tungsten and molybdenum mineralization is associated with the granitic intrusives (Findlay, 1969). At present the most promising deposits are the Tom Property (Hudson Bay Exploration and Development

Company Ltd.), comprising stratabound galena and sphalerite in Paleozoic shales, and the MacTung Property (American Metal Climax Incorporated), with pyrrhotite-scheelite mineralization in a skarn zone surrounding a small stock. Both properties are located in the northeast, near MacMillan Pass.

GLACIATION

Evidence of the most recent Pleistocene glaciation, the McConnell advance, is abundant within the study area (Hughes et al, 1968). During the McConnell glaciation ice accumulated in the Hess Mountains up to an elevation of 5,000 feet (Bostock, 1948), and flowed westward onto the Yukon Plateau. Ice movement was controlled to a great extent by the main drainage channels, which as a result were considerably deepened, especially on the Stewart Plateau.

In the MacMillan River valley the total thickness of glacial drift generally ranges from 400 to 500 feet. Normally it consists of a basal boulder clay unit, overlain by an irregular sequence of silts, sands and gravels (McConnell, 1903).

TOPOGRAPHY AND DRAINAGE

The regional study area is divided into two major physiographic regions (Figure 2), the Hess Mountains in the northeast, and the Eastern Yukon Plateau in the southwest (Bostock, 1948). The Hess Mountains comprise a group of

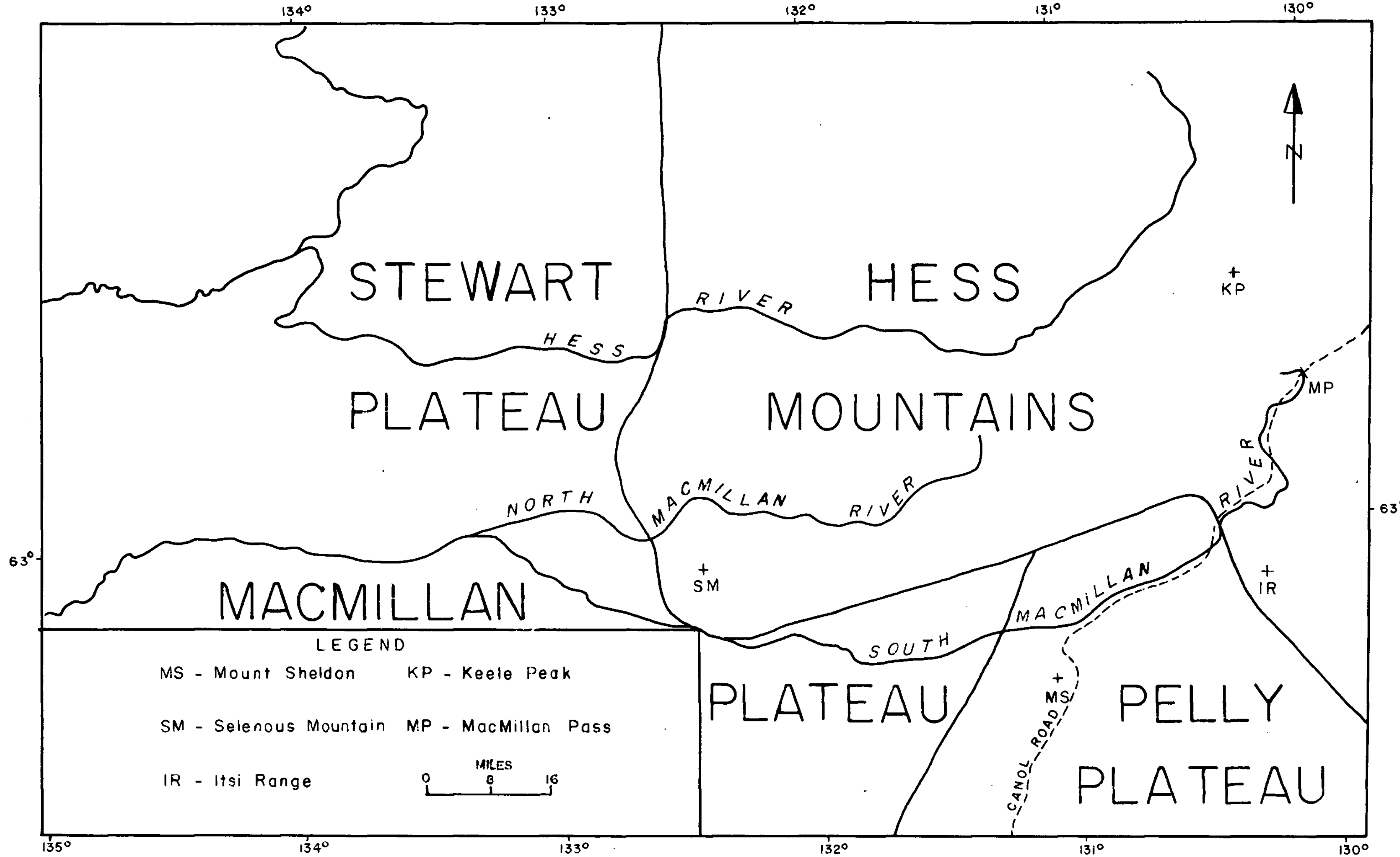


Figure 2. Physiographic subdivisions of the regional study area.

irregular, somewhat subdued ranges, underlain predominantly by Paleozoic sediments. The highest peaks, in excess of 7,000 feet, are generally cored by granitic intrusives. The Eastern Yukon Plateau is subdivided from northwest to southeast, into the Stewart, MacMillan and Pelly Plateaus.

Within the study area both the Stewart and MacMillan Plateaus consist of tablelands, 4,000 to 5,000 feet in elevation, dissected by a well developed network of structurally controlled valleys. Small mountain ranges, rarely exceeding 7,000 feet in elevation, commonly crown these tablelands. The Pelly Plateau, on the other hand, is only mildly dissected, with a few small mountains separated by broad relatively shallow valleys.

The Hess and MacMillan Rivers drain most of the region. Both head in the Hess Mountains and flow westward across the plateau.

CLIMATE

Cut off from the prevailing westerly winds by the peaks of the Saint Elias Range, the climate is predominantly continental, characterized by relatively little rainfall and extreme temperature ranges (Kendrew and Kerr, 1955). The mean daily temperatures range from approximately -20°F during the winter months, to about 60°F in the summer. The high summer mean is in part due to the nearly continuous sunlight experienced at that time. There is no pronounced rainy season, though most of the precipitation falls in late summer and early fall. The total annual precipitation increases from west to east, from about twelve inches on the plateau to over twenty inches in the mountains.

SOIL

Topography is one of the primary factors controlling the distribution of soil types. Regosols, and to a lesser extent Brunisols, are common on the well drained upland regions, whereas flat poorly drained valley bottoms are characterized by Gleysols and Organic soils. Because of the cold climate, relatively rugged topography and recent glaciation the depth of the solum of mineral soils seldom exceeds two feet. Permafrost is distributed discontinuously throughout the area.

A one to two inch layer of volcanic ash underlies the organic surface horizon in most areas. Capps (1915) has suggested that the ash was derived from a major volcanic eruption in the Saint Elias Range approximately 1,500 years ago.

VEGETATION

The distribution of plant species is chiefly topographically controlled. Dense forests occupy the bottoms of the major river valleys. The predominant species is white spruce (Picea glauca), though several other species including black spruce (Picea mariana), aspen (Populus tremuloides), and alpine fir (Abies lasiocarpa) are present (McConnell, 1903). The lower parts of the valley slopes, up to the treeline at about 4,500 feet, are covered with spruce and locally willow (Salix) and alder (Alnus). Dwarf birch and caribou moss range between the treeline and scree slopes at the highest altitudes in mountainous regions.

WILDLIFE

A wide variety of mammalian species are known to inhabit the region. Of the larger mammals the grizzly bear (Ursus horribilis), caribou (Rangifer arcticus) and mountain sheep (Ovis dalli) roam chiefly above timerline, while the black bear (Ursus americanus) and moose (Alces americana) occupy the forested valley bottoms. Mountain sheep and caribou consume mainly grasses, sedges and willows (Rand, 1945b). In the winter, however, caribou subsist almost entirely on caribou moss. Moose consume willows and assorted aquatic plants, while grasses, berries and roots are the major food sources for the bear population.

CHAPTER THREE

REGIONAL GEOCHEMICAL RECONNAISSANCE

SAMPLE COLLECTION AND PREPARATION

Atlas Explorations Limited, Vancouver, contributed nearly 600 minus-80 mesh stream sediment samples. They were collected during the summers of 1968 and 1969, originally for mineral exploration purposes, over an area of approximately 7,000 square miles in the Eastern Yukon.

Sample density ranges from about one sample per 5 square miles to approximately one sample per 50 square miles. Catchment areas upstream from sample sites are normally from two to five square miles.

SAMPLE ANALYSIS

Stream sediments were analyzed by a semi-quantitative DC-arc spectrographic procedure (Fletcher, pers. comm.) for fifteen elements: Sr, Ba, Cr, Co, Ni, Ag, Ti, Cu, V, Mo, Bi, Ga, Sn, Pb and Mn.

Pre-Analytical Treatment

A small amount of minus-80 mesh stream sediment material was ignited at 550°C for three hours. One hundred milligrams of ignited sample were then mixed with an equal weight of graphite, containing indium as an internal standard, and homogenized by shaking in a Spex "Mixer/Mill" for three minutes. The mixture was then packed into the cavity of a graphite anode and sealed with one drop of sugar solution

(20 gm. sucrose dissolved in 75 ml. of ethanol and 25 ml. of distilled water).

Analytical Method

The equipment and operating conditions for stream sediment analysis are given in Table I. Metal concentrations were estimated by visual comparison of the sample spectra with those of synthetic standards as described by Nichol and Henderson-Hamilton (1965). The spectral lines used and approximate detection limits are indicated in Table II.

Table I Spectrographic equipment and operating conditions.

Spectrograph	Hilger-Watts automatic quartz spectograph		
Source	Electro-Matic Products (ARL), Model P6KS, Type 2R41		
Arc/Spark Stand	Spex Industries #9010		
Microdensitometer	ARL Spectroline Scanner #2200		
Anode	Graphite, National L3709SPK		
Cathode	Graphite, National L3803AGKS		
3-Step Neutral Filter	Spex Industries #1090, 5% 20% and 100% transmitance		
Neutral Filter	Spex Industries #9022, 20% transmitance		
Emulsion	Spectrum Analysis #1		
Wavelength Range	2775-4800 Å		
Mask	17 mm.		
Slit Width	15 μ.		
Arc Current	12a		
Plate Processing	developer	Kodak D-19	3 min. at 23°C
	stopbath	Kodak	30 sec.
	fixer	Kodak	5 min.
Arc Gap	4 m.m.		
Exposure Time	20 sec.		

Table II Wave lengths and approximate detection limits for spectral lines used to estimate element abundances in stream sediments.

Element	Wavelength (Å)	Detection Limit (p.p.m.)
Sr	4607.33	50
Ba	4554.04	1
Cr	4254.35	1
Co	3453.51	5
Ni	3414.77	5
Ag	3382.89	1
Ti	3372.80	20
Cu	3273.96	10
In	3256.09	1
V	3185.40	20
Mo	3170.35	2
Bi	3067.72	10
Ga	2943.64	1
Sn	2839.99	5
Pb	2833.07	2
Mn	2801.06	1

Table III Analytical precision for spectrographic analysis of stream sediment at the 95% confidence level, calculated from 50 separate analyses of U.B.C. Standard Rock.

Element	Mean Concentration (p.p.m.)	Precision (at 95% confidence level)
Sr	1285	85
Ba	1320	85
Cr	8	90
Co	9	80
Ni	8	85
Ag	n.d.*	-
Ti	1410	60
Cu	15	50
In	25	45
V	55	60
Mo	n.d.*	-
Bi	n.d.*	-
Ga	15	30
Sn	n.d.*	-
Pb	4	95
Mn	275	85

*n.d. = not detected

Analytical Control

Analytical precision was estimated by replicate analysis of a standard rock sample included in each analytical batch (Fletcher, pers. comm.). Precision, at the 95% confidence level, is indicated, for each element, in Table III. Samples with less than 10 p.p.m., or greater than 50 p.p.m. of the internal standard indium, were re-analized.

PRESENTATION OF DATA

Range and geometric mean trace element values for stream sediments derived from each of the principal geological units are indicated in Table IV. Figures 3 to 11 show the regional distributions of Mo, V, Ni, Cr, Cu, Pb, Sr, Mn and Co. Ag, Bi and Sn, which were detected in only a few samples, Ba and Ti, which were commonly present in concentrations above that of the highest standard, and Ga, which is very uniformly distributed over all rock types, are not considered.

Distribution maps were compiled by computing the geometric mean trace element levels within the 10,000 meter squares of the National Topographic Series map sheets (Fletcher, pers. comm.). These mean values were then grouped according to specific class intervals, the limits of which correspond to the midpoints between the spectrographic standards.

This method of data presentation has the advantage

Table IV Range† and geometric mean trace element content (p.p.m.) of minus-80 mesh fraction of stream sediments associated with each of the major bedrock units within the regional study area.

ELEMENT	BEDROCK				
	YUKON GROUP Proterozoic schist, quartzite, phyllite shale	EARN GROUP Paleozoic chert, quartzite	UNIT 3 Paleozoic dark shale, chert	GRANITIC ROCK Cretaceous granodiorite	VOLCANIC ROCK Tertiary dacite, andesite basalt
Mo*	2 2-3	3 2-6	11 3-35	2 2-4	2 2-5
V	110 75-170	200 120-360	480 250-930	80 40-170	170 85-350
Ni	65 50-85	70 50-100	140 60-320	35 15-90	45 30-75
Cr	140 100-190	120 90-150	180 120-270	60 25-130	95 65-150
Cu	50 30-80	60 35-95	90 50-160	25 15-45	45 25-90
Pb	18 11-28	18 8-20	15 8-29	17 13-21	20 14-29
Sr	270 150-470	330 210-520	200 100-420	310 210-470	720 500-1030
Mn	770 390-1550	970 630-1500	430 170-1090	370 220-620	860 530-1390
Co	35 25-55	30 20-45	35 15-65	20 10-35	30 20-50
Number of Samples	123	28	295	18	17

† Range = geometric mean ± log standard deviation
* Values less than 2 p.p.m. taken as 1 p.p.m.

of emphasizing the regional patterns by smoothing over local irregularities. However, because of the uneven distribution of sample sites, the number of sediment samples used to calculate each map value ranges from one up to about ten. Consequently, in this case, isolated anomalous values could give a false indication of local background levels.

TRACE ELEMENT PATTERNS IN STREAM SEDIMENTS

Regional distribution patterns of the various elements may be subdivided into two relatively distinct groups. In the first, which includes molybdenum, vanadium, nickel, copper and chromium, the highest concentrations occur in the northeast, chiefly underlain by the dark shales and cherts of Unit 3. In the second, comprising lead, strontium, manganese and cobalt, high values are most common in the southwest.

Distribution of Mo, V, Ni, Cr and Cu

As indicated in Table IV, sediments associated with Unit 3 typically contain enhanced molybdenum values (11 p.p.m.). Concentrations in sediments derived from other units are generally low and often below the 2 p.p.m. detection limit. High concentrations, up to 100 p.p.m., are most common in the central portion of Unit 3 (Figure 3). Molybdenum levels over the small lens of Unit 3 rock in the south-central

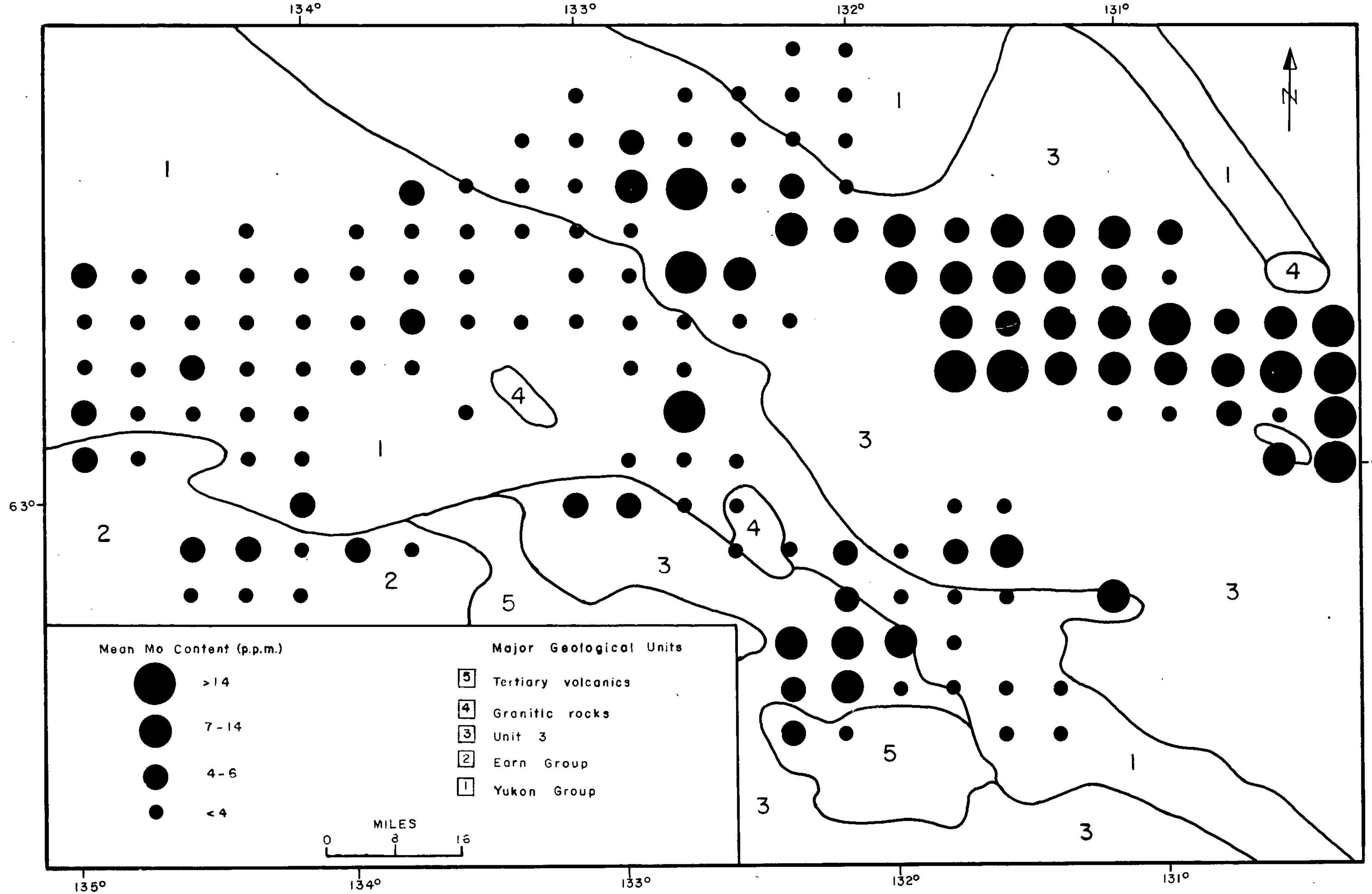


Figure 3. Regional distribution of Mo in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

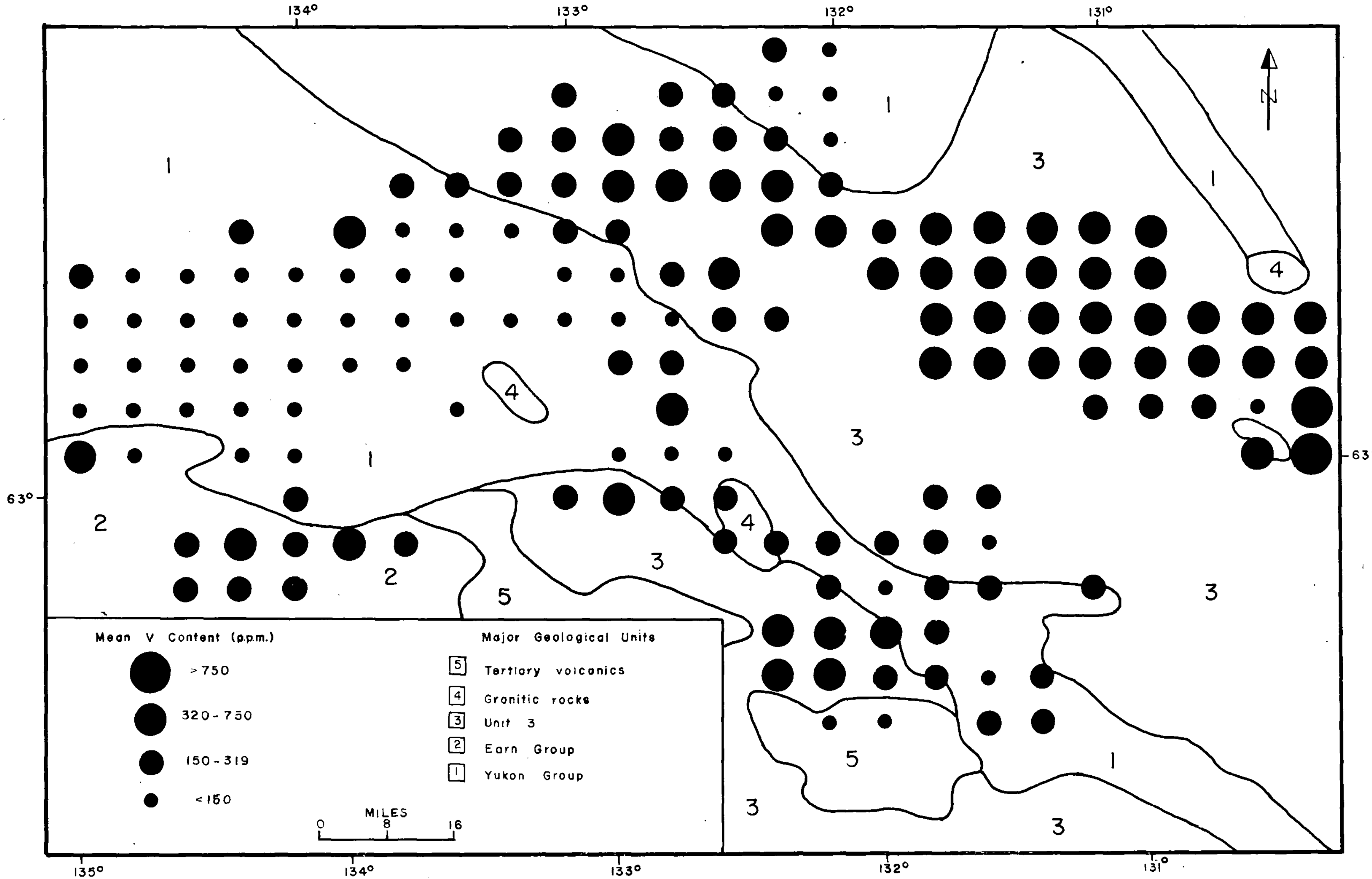


Figure 4. Regional distribution of V in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

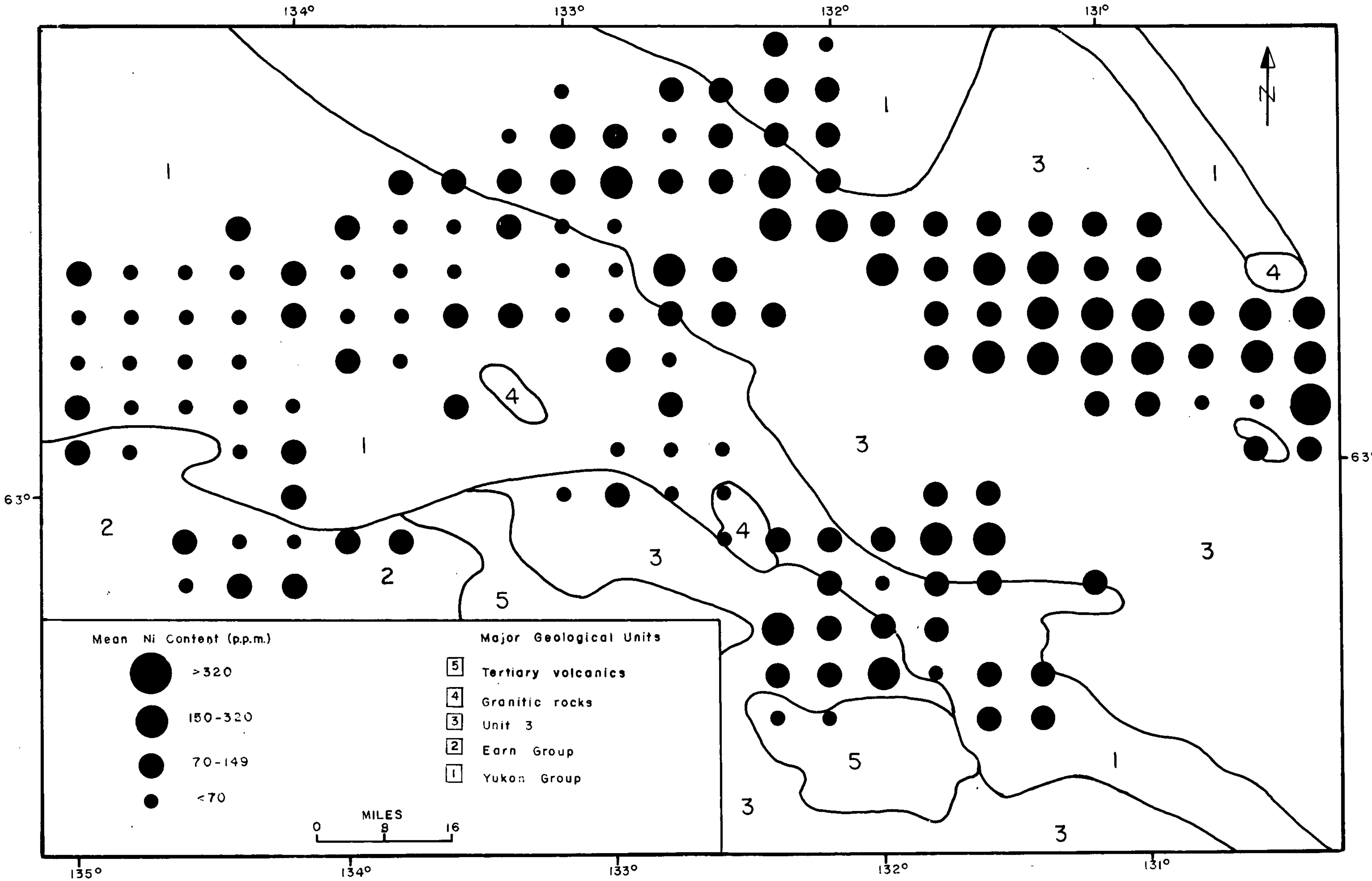


Figure 5. Regional distribution of Ni in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

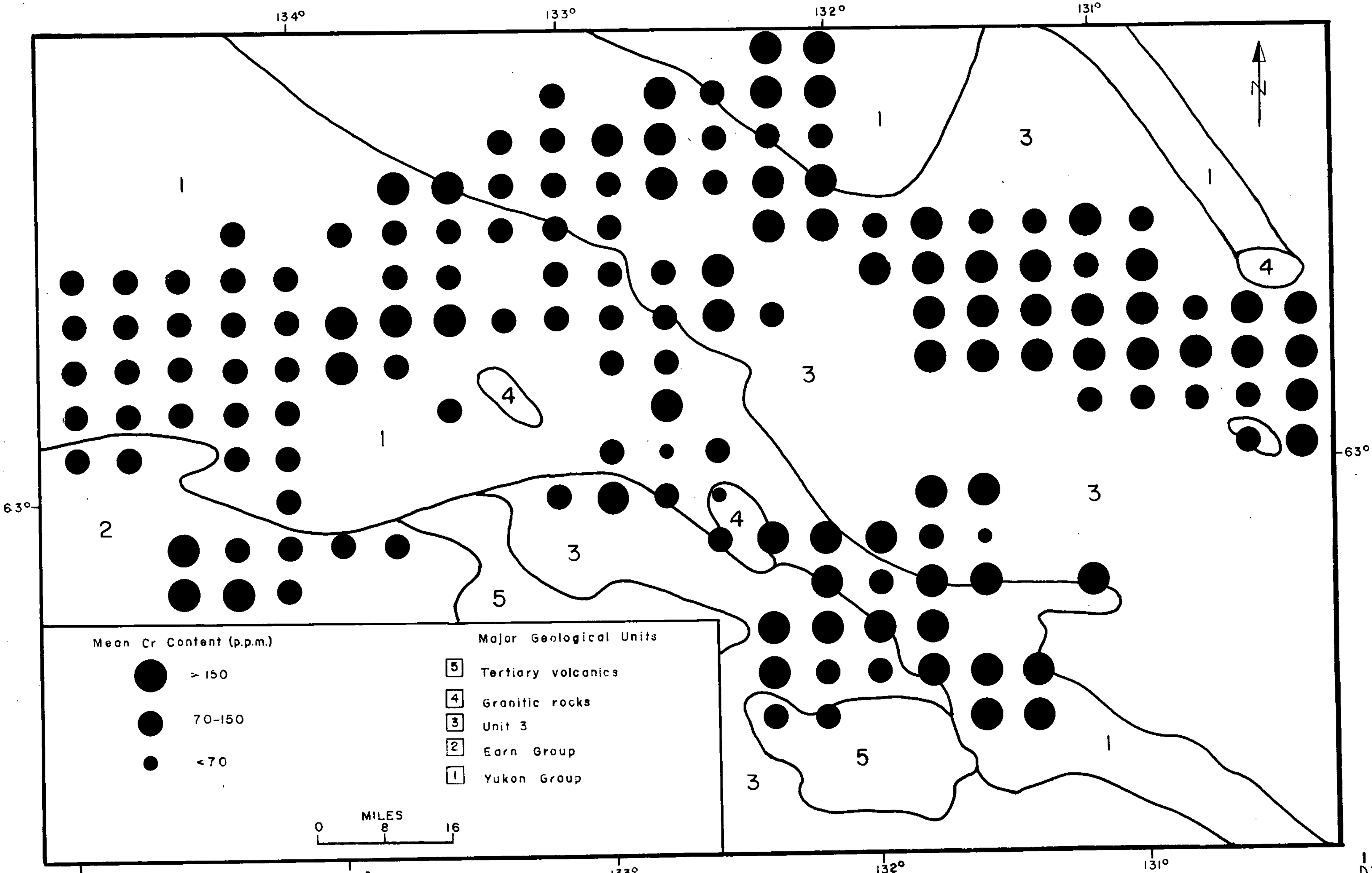


Figure 6. Regional distribution of Cr in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

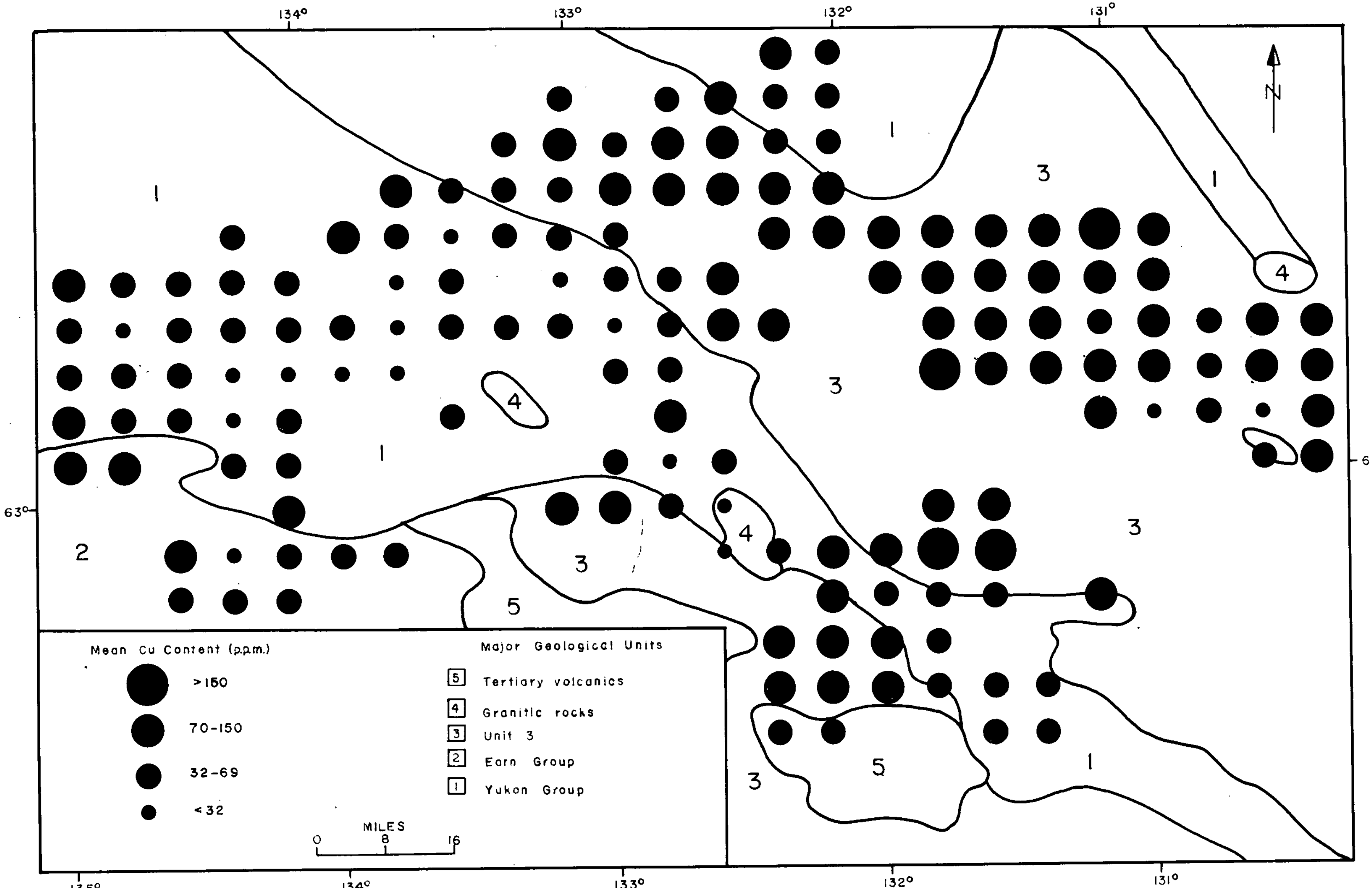


Figure 7. Regional distribution of Cu in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

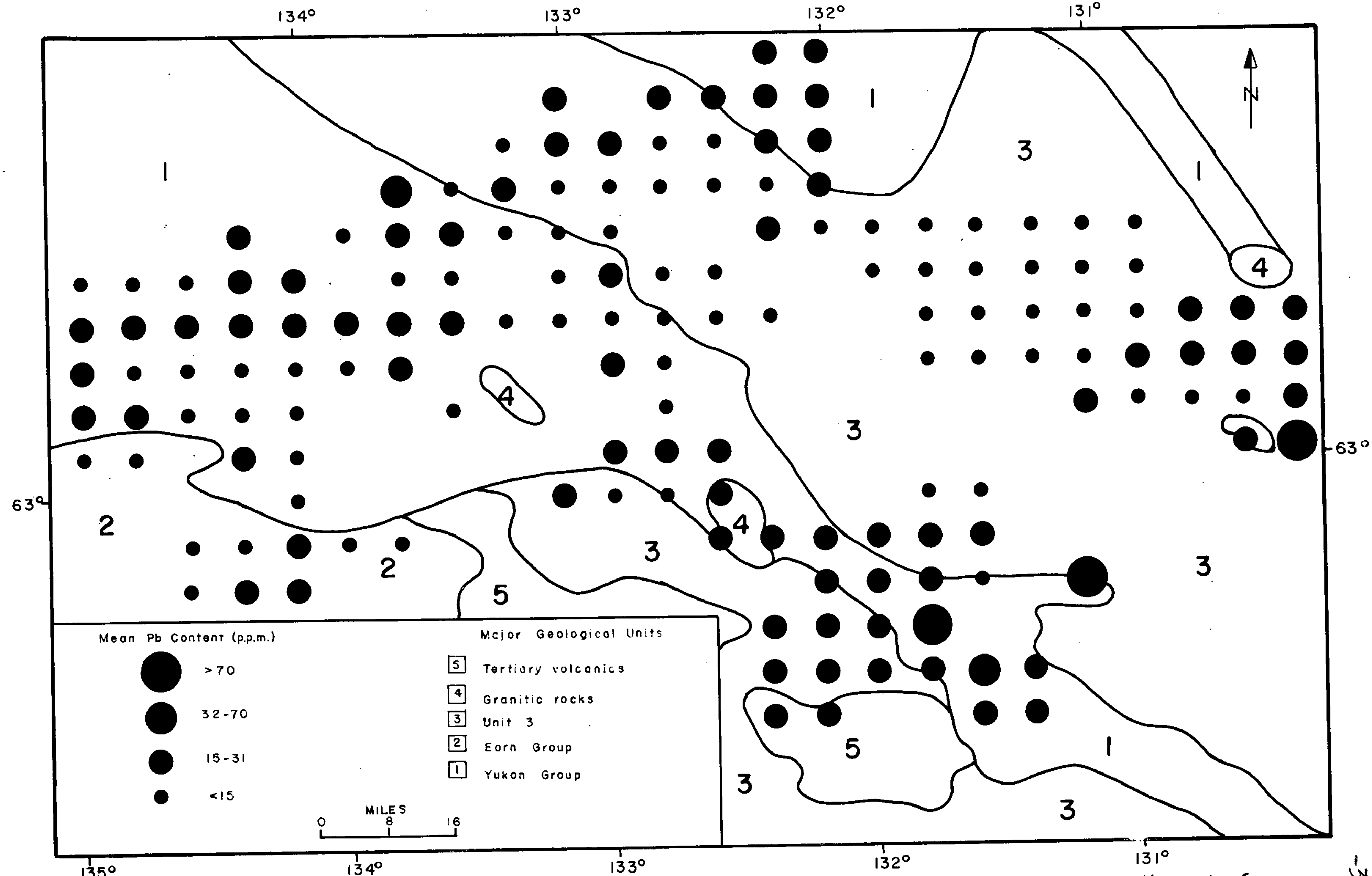


Figure 8. Regional distribution of Pb in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

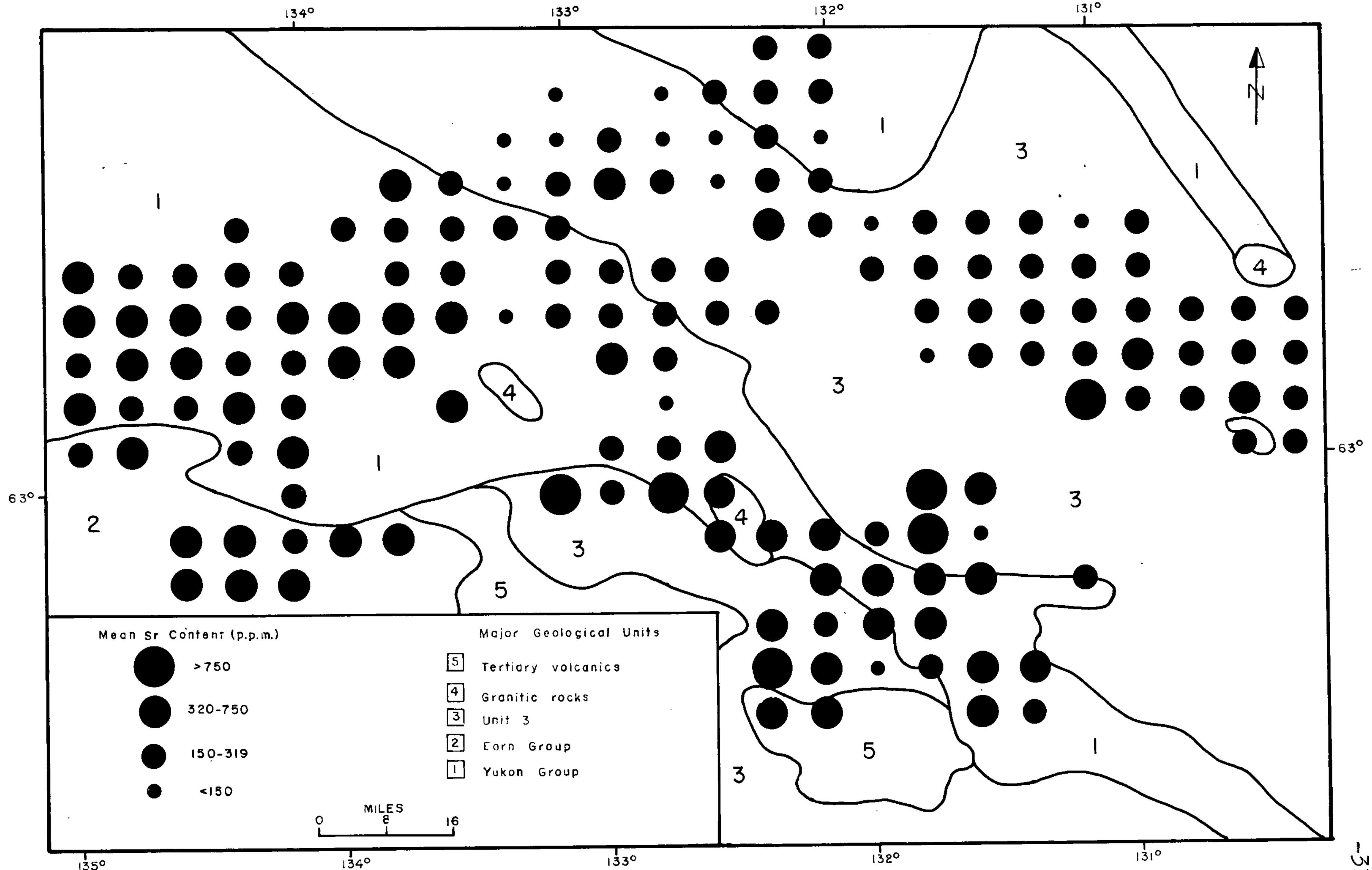


Figure 9. Regional distribution of Sr in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

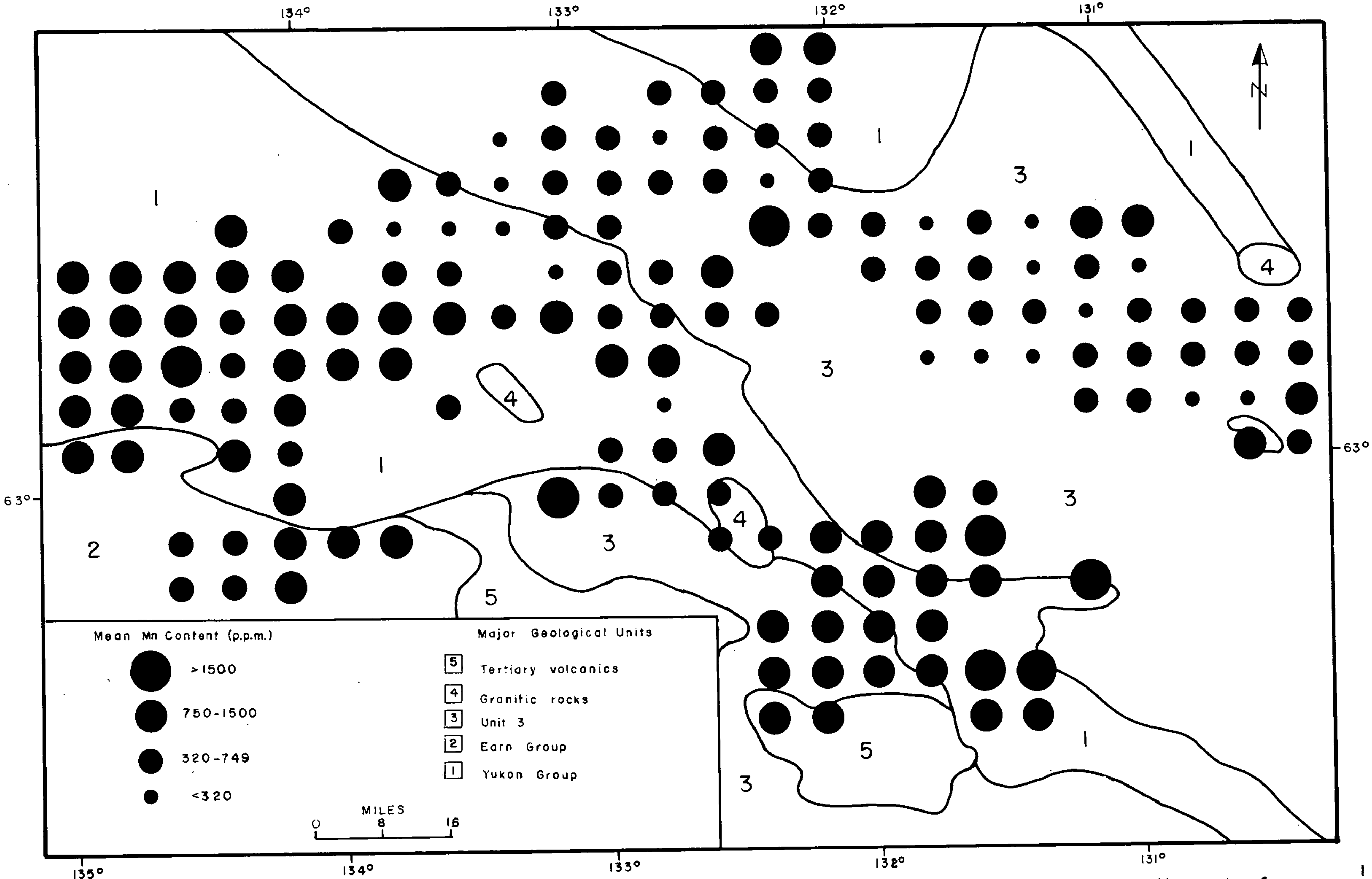


Figure 10. Regional distribution of Mn in minus-80 mesh fraction of stream sediment from 10,000 meter squares

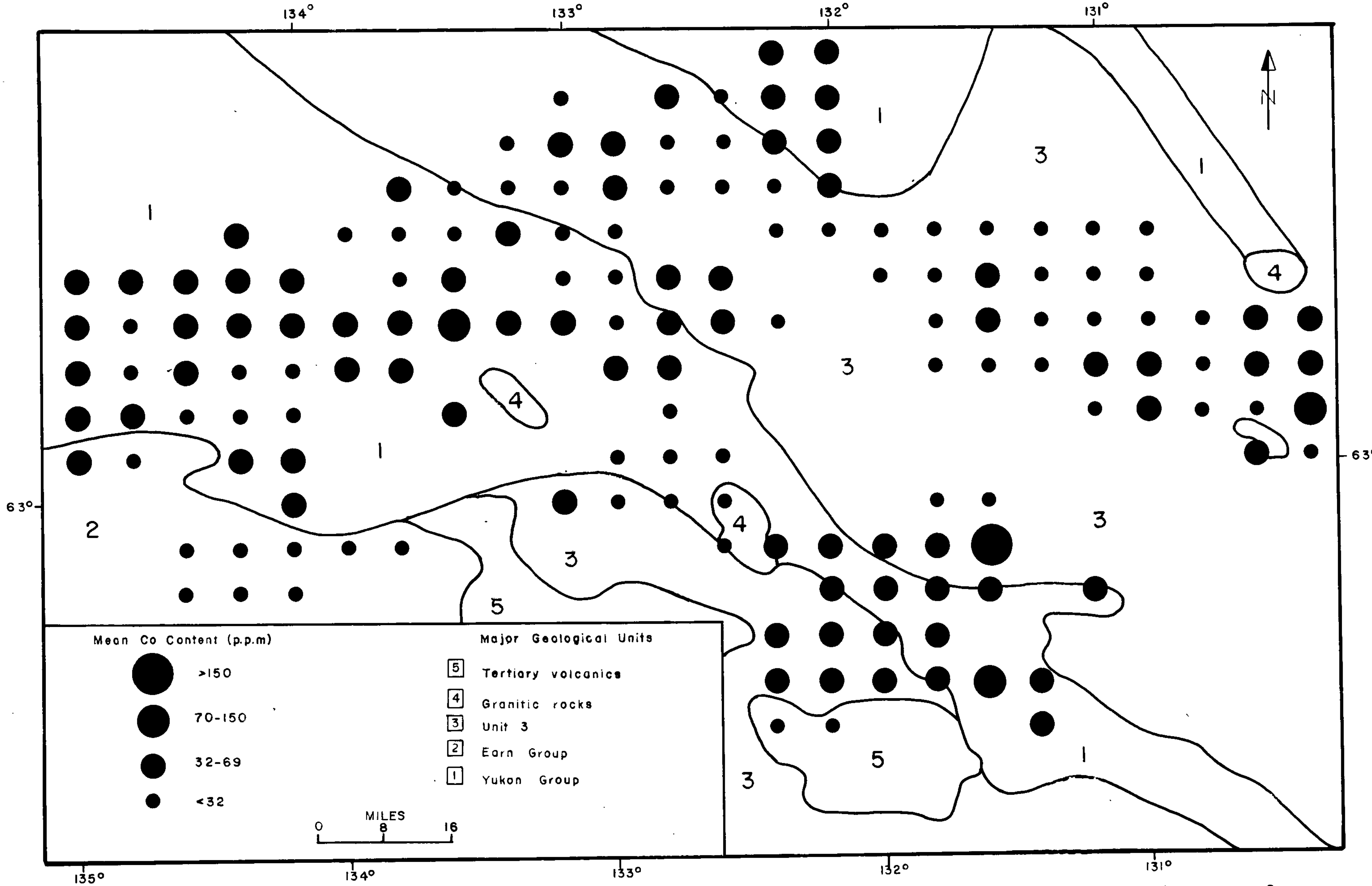


Figure 11. Regional distribution of Co in minus-80 mesh fraction of stream sediment from 10,000 meter squares.

portion of the study area are somewhat lower than those associated with the main body of this unit to the northeast.

Sediments from each geological unit are characterized by relatively distinct vanadium levels (Table IV). Consequently, the positions of all major geological contacts are clearly evident in the vanadium distribution pattern (Figure 4). The northern contact of the Earn Group with the Yukon Group for example, which is indistinguishable in the distribution patterns for the other elements, is defined by an abrupt change in concentration from approximately 250 p.p.m. over the Earn Group to about 100 p.p.m. over the Yukon Group. The highest vanadium concentrations, up to 1,500 p.p.m., are associated with Unit 3, and the lowest with the granitic rocks.

The distribution of nickel (Figure 5) resembles that of vanadium, though the locations of the major geological contacts are only vaguely reflected. Nickel concentrations over the small lens of Unit 3 southwest of Selenous Mountain (Figure 2) are relatively erratic, with adjacent values differing by as much as 140 p.p.m.

As indicated in Figure 6, the chromium pattern is subdued in comparison with those of the previously mentioned elements. This uniformity is reflected in the similar mean chromium levels (120 to 180 p.p.m.) associated with the three most abundant rock types (Table IV).

The highest mean copper contrations (90 p.p.m.) are associated with Unit 3, while the lowest (25 p.p.m.), occur in sediments derived from granitic rocks. A few strikingly high copper values, up to 500 p.p.m., occur over Unit 3 (Figure 7).

Large scale regional variations in the trace element content of stream sediments over both Unit 3 and the Yukon Group are apparent for many of these elements. For example, relatively high molybdenum (>8 p.p.m.), vanadium (>320 p.p.m.), nickel (>150 p.p.m.) and chromium (>150 p.p.m.) values in the central portion of the main body of Unit 3 contrast with moderate to low values over the narrow northwestern arm of this unit. Similarily, over the Yukon Group, relatively enhanced vanadium (>150 p.p.m.), chromium (>150 p.p.m.) and to a lesser extent nickel (>70 p.p.m.) values are more abundant in the southeast than in the northwest.

Certain isolated anomalous values over both Unit 3 and the Yukon Group may reflect the presence of small inclusions of foreign bedrock. The position of a granitic stock, for example, about twenty miles northwest of the Itsi Range (Figure 2), is clearly indicated by anomalously low trace element levels (Figures 3 to 7). Isolated high molybdenum (>14 p.p.m.) and vanadium (>320 p.p.m.) values (Figures 3 and 4), situated about twenty miles northwest of Selenous Mountain (Figure 2) over the Yukon Group, strongly suggest the presence of a small unmapped outlier of Unit 3.

Distribution of Pb, Sr, Mn and Co

Concentrations of these elements in stream sediments derived from Unit 3 are not particularly enhanced. With the exception of cobalt, their distribution patterns typically display little geological control.

Range and mean lead values associated with all five major geological units are remarkably similar (Table IV). Consequently the distribution pattern for lead is very uniform (Figure 8). Five anomalously high values (up to 180 p.p.m.) are indicated in Figure 8, four of which occur over Yukon Group rocks. High lead values in sediments draining Tertiary volcanic rocks, about twenty-five miles south of Selenous Mountain, are not apparent in Figure 8 due to dilution of the anomalous samples with surrounding ones, in the same U.T.M. square, with low lead contents.

Strontium levels in stream sediments are particularly erratic over Unit 3 (Figure 9). Both abnormally high (>750 p.p.m.) and low (<150 p.p.m.) values are confined, with few exceptions, to regions underlain by Unit 3. As indicated in Table IV, the mean strontium concentration in sediment derived from Tertiary volcanics (720 p.p.m.) is substantially higher than mean levels associated with other rock types.

Relatively wide manganese concentration ranges are associated with each of the major geological units (Table IV). As a result, the distribution pattern for manganese (Figure 10), like that of strontium, is erratic. High manganese values are typically associated with the Yukon Group, Earn Group and Tertiary volcanic rocks.

The relatively uniform distribution of cobalt values (Figure 11) is reflected in the narrow range of mean cobalt concentrations (20 to 35 p.p.m.) in sediments derived from the various bedrock units. Nevertheless, the positions of the boundaries of both the Earn Group and the Tertiary volcanics are clearly reflected in the cobalt distribution pattern.

DISCUSSION OF DISTRIBUTION PATTERNS

Relationship to Bedrock Composition

Data are available only on the regional distribution of molybdenum within the granitic rocks. Garrett (1971a) has reported that the mean molybdenum concentration in all major stocks is characteristically less than 2 p.p.m. and never exceeds 6 p.p.m. Low molybdenum levels in stream sediments derived from these rocks (Table IV) are in excellent agreement with Garrett's figures.

Gleeson (1967) has noted enhanced molybdenum values (occasionally $>$ 10 p.p.m.) in stream sediments associated with graphite and pyrite-rich phyllites in the Keno Hill region, Yukon Territory. These findings are consistent with the high mean molybdenum level (11 p.p.m.) in sediments derived from the Unit 3 rocks, which include significant amounts of organic-rich, occasionally pyrite bearing, shales.

Depending upon the influence of secondary environment, trace element levels in stream sediment should reflect, to some extent, concentrations in associated bedrock (Webb et al., 1968). Thus, Table IV suggests that the dark cherts and shales of Unit 3 are likely enriched, relative to the other geological units, in molybdenum and vanadium, and to a lesser extent nickel, copper and chromium. Similarly, the Tertiary volcanics likely contain large amounts of strontium, while the levels of both cobalt and lead are probably very similar in all of the major bedrock types.

Relationship to Glaciation

As previously noted, during the Pleistocene, glacial ice accumulated in the Hess Mountains (Figure 2) and flowed westward across the Yukon Plateau. Interpretation of stream sediment patterns in terms of bedrock geology could therefore be complicated by the presence of exotic drift over geological units in the west. The generally sharp change in sediment molybdenum, vanadium and nickel values (Figures 3, 4 and 5) across the contact between Unit 3 and the main body of the Yukon Group however, suggests that the influence of glaciation on regional sediment patterns has been relatively slight.

Possible Relationship to Animal Nutrition

In Ireland and the United Kingdom molybdenum levels of over 10 p.p.m. in stream sediment have delineated regions wherein abnormally high molybdenum concentrations in soils and herbage give rise to molybdenum induced hypocuprosis and molybdenosis (Thornton and Webb, 1969). Comparably high values are common over large areas underlain by Unit 3, especially in the east.

A detailed study was therefore undertaken to relate the regional geochemical patterns to molydenum levels in bedrock, soils and vegetation. Particular attention was given to sampling those plant species likely to be consumed by moose and caribou.

SECTION B

DETAILED STUDY

CHAPTER IV

DESCRIPTION OF DETAILED STUDY AREA

LOCATION AND ACCESS

Detailed geochemical investigations were undertaken in an area of approximately 100 square miles, near the crestline of the Hess Mountains, in the vicinity of MacMillan Pass (Figure 1). Access is provided by both the Canol Road, which is open between the village of Ross River and MacMillan Pass during summer months, and a small air strip which is situated in the valley of the South MacMillan River, a few miles southwest of the pass.

GEOLOGY

Unit 3 rocks are most abundant of the three major geological units within the detailed study area (Figure 12). Much of the northern regions, however, are underlain by the Yukon Group. A few granitic stocks, typically less than three miles in diameter, intrude both Unit 3 and the Yukon Group.

Lithological characteristics of rock material sampled are summarized in Table V. Of particular interest is the wide variety of rock types comprising Unit 3, including light to dark colored shale, siltstone, chert-pebble conglomerate and limestone. No cherts, reported by Roddick and Green (1961a) to be common within this unit were noted, though the light grey shales are typically very siliceous. Styliolina, observed in certain limestone samples (Best, pers. comm.), suggest a Middle Silurian to Upper Devonian age for at least a portion of Unit 3. Tight folding, complex faulting and

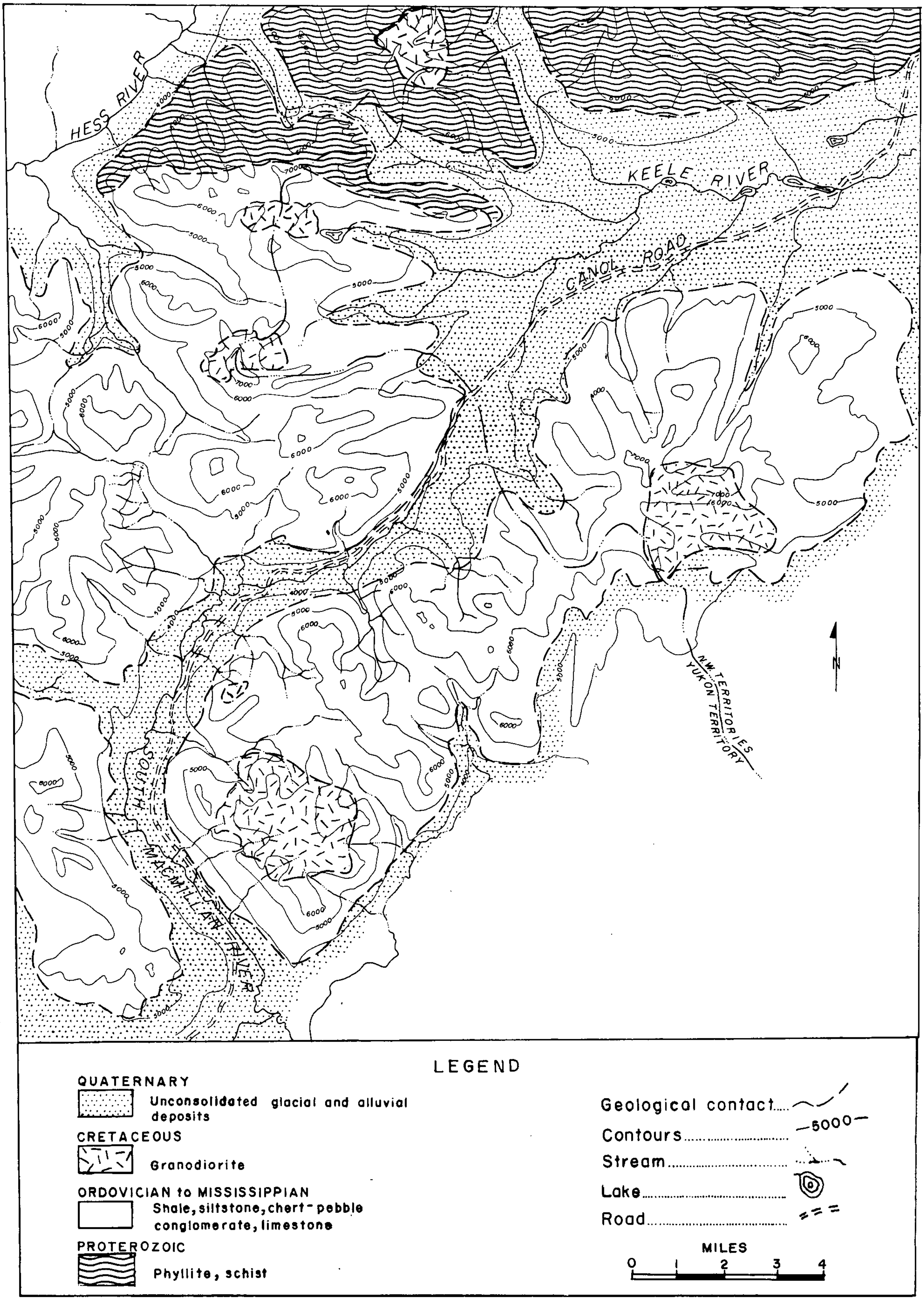


Figure 12. Distribution of principal geological units within the detailed study area.

Table V Lithological characteristics of major bedrock units within the detailed study area.

AGE	GEOLOGICAL UNIT		DESCRIPTION
MESOZOIC (Cretaceous?)	GRANITIC ROCK		Biotite Granodiorite: disseminated sulfides relatively rare.
PALEOZOIC (Middle Silurian to Upper Devonian in part)	UNIT 3	SILICEOUS	Dark grey to black Shale: (50%)* organic carbon abundant; small spherical silica grains(<.5m.m. in diameter) resembling diatoms (Best, pers. comm.) common in siliceous varieties; locally euhedral pyrite crystals occupy cores of silica spheres.
			Medium to light grey Shale: (10%)* organic carbon less common than in black shale; certain varieties are very rich in silica; no true cherts,with conchiodal fracture, were noted.
			Dark Siltstone: (30%) * chiefly interbedded silty, shaley and sandy laminations; individual laminations range from less than one to a few millimeters in thickness; silty laminations are most common and sandy ones least common; organic carbon is abundant in shaley and silty layers.
			Conglomerate: (5%) * associated with siltstones; angular chert pebbles (up to 10 m.m. in length) are common; black shale and quartzite pebbles are relatively rare; gradded bedding may be present.
		CALCAREOUS	Dark grey to black Limestone: (5%)* fine grained; organic carbon common; locally fossiliferous; contains <u>Styliolina</u> (Best, pers. comm.) which ranges from Middle Silurian to Upper Devonian (Moore, 1962).
PROTEROZOIC	YUKON GROUP		Chlorite Schist: mainly chlorite with some quartz. Quartz Phillite: mainly quartz with minor muscovite and chlorite.

* relative abbundance of Unit 3 rock material sampled for analysis

the absence of distinctive marker horizons combine to make determination of relative stratigraphic positions of various Unit 3 lithologies difficult.

SOIL

Each of nearly 100 soil profiles examined was classified to the subgroup level according to the classification system of the Canadian Department of Agriculture (1970). Members of the Regosolic (Figure 13), Brunisolic (Figure 14), Gleysolic (Figure 15) and Organic Orders are recognized.

Regosols are the most abundant Order, comprising nearly seventy percent of the soils examined. They are distributed throughout a wide variety of environments ranging from the floors of the MacMillan and Ross River valleys, to the mountainous uplands above timerline.

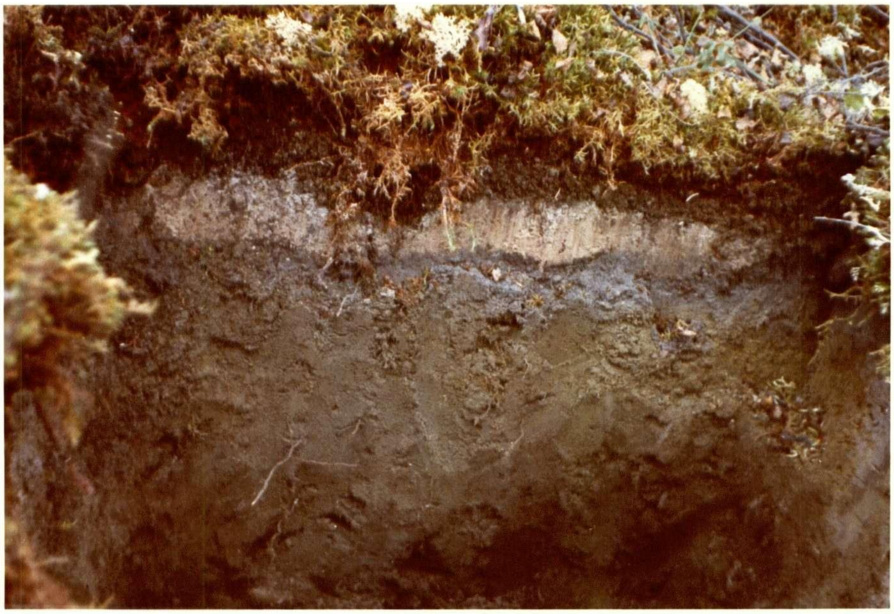
Brunisols, Gleysols and Organic soils are generally confined to main valley bottoms. Both Gleysols and Organic soils, characteristic of poorly drained environments, are commonly saturated with water within one foot or less of the soil surface. Brunisols develop on porous, well drained parent materials. Their virtual absence in upland regions may be due to rapid erosion in these areas.

A discontinuous ash layer, generally less than two inches thick, separates the L-H from the underlying mineral horizon in many soils (Figures 13 and 14). Permafrost was encountered at a variable depth in about ten percent of the soils examined.

Figure 13. Regosol in grassland environment northeast of MacMillan Pass (Site 33).

Note lack of profile development. (Scale in inches)

Figure 14. Brunisol on a dwarf birch and caribou moss covered knoll in the main valley of the South MacMillan River (Site 19).



Horizon	Thickness
L-H	3"
Ash	2"
Ae	2"
Bm	5"
C	

Note leached Ae horizon overlying yellowish-brown Bm horizon.

Figure 15. Gleysol developed on dwarf birch flats north-east of MacMillan Pass (Site 29).

Horizon	Thickness
L-H	1"
Cg	18"
Cz	

Note mottled Cg horizon overlying permafrost zone, Cz (scale in inches).

It is common beneath dwarf birch flats northeast of MacMillan Pass and in the densely forested regions of the MacMillan and Ross River valleys. The absence of permafrost in upland regions may be due to relatively sparse vegetation and rapid drainage in these areas.

VEGETATION

Distribution of plant types in the detailed study area is controlled primarily by topography and drainage. Grasses and willow characterize much of the flat wet floor of the South MacMillan River valley. Comparatively well drained knolls, scattered near the margins of the valley floor, are covered chiefly by dwarf birch (*Betula glandulosa*) and caribou moss (*Cladonia alpestris*). Near the head of the valley, in the vicinity of MacMillan Pass, these knolls merge into extensive dwarf birch-caribou moss flats.

With the exception of certain lichens such as *Umbilicaria*, summits of most mountains are essentially devoid of vegetation. At lower elevations lichens and dwarf birch become abundant. At about 4,000 ft. alpine fir (*Abies lasiocarpa*) replaces dwarf birch as the dominant woody species. Mixed stands of alpine fir and white spruce (*Picea glauca*) blanket the lower portions of valley walls in the southwestern corner of the detailed study area.

Shrubs such as white heather (*Cassiope tetragona*) and crowberry (*Empetrum nigrum*) are common on knolls in valley floors and at lower elevations along valley walls. Forbs, including fireweed (Epilobium latifolium) and lupin (Lupinus arcticus), and various grasses are characteristic of alpine meadows, which occur near the heads of many tributary streams draining into the main valley of the South MacMillan River.

Certain meadows and adjacent uplands, underlain by dark Unit 3 limestone, characteristically support a strikingly wide variety of plant types. Caribou moss and dwarf birch however are conspicuously absent in these calcareous environments.

CHAPTER V

SAMPLE COLLECTION, PREPARATION AND ANALYSIS

SAMPLE COLLECTION AND PREPARATION

Between June 15th and July 31st, 1971, approximately 1,100 samples were collected within the detailed study area and along the Canol Road. Of these approximately 120 were stream sediments, 350 soil, 350 vegetation, 250 rock and 30 animal faeces.

STREAM SEDIMENT

Stream sediment sample sites are indicated in Figures 16 and 18. Fine, active, organic free sediment was collected where possible. At each sample site brief descriptions were made of the stream and its load, and stream water pH was measured with BDH Liquid Universal Indicator. Samples were collected in kraft paper bags and oven dried in the field.

A porcelain mortar was used to disaggregate samples in the laboratory. After thorough mixing, a 10 to 15 g. sub-sample was passed through a minus-80 mesh nylon sieve, and fines were retained for spectrographic analysis.

ROCK

Rock sample locations are shown in Figure 16. Most samples were collected as continuous chips taken perpendicular to bedding of selected rock sections. Each sample consisted of a mixture of small, lithologically similar chips, collected over an interval of ten stratigraphic feet. A few random chip samples were also obtained, chiefly from small stream exposures. A representative specimen of each major lithology sampled was taken for thin section examination.

Initially rock chips were passed through a jaw crusher and then between ceramic plates. After thorough mixing a 10 g. sub-sample was ground in a Spex "Shatterbox" to minus-100 mesh. Between runs the jaw crusher and ceramic plates were cleaned with compressed air and brushes, and the dish of the Shatterbox was rinsed in tap water and dried with acetone. Samples were ground in numeric order to ensure that, if contamination occurred, its source could be readily identified.

SOIL

Figures 17 and 18 show locations of the nearly 100 soil profiles examined. At each soil site a small pit was dug and each soil horizon identified and its morphology noted. Vegetation, drainage and parent material, as well as other important variables in the soil environment were also described. Samples of each soil horizon were collected in kraft bags and oven dried in the field. Coarse rock chips from C horizons were collected separately.

Mineral and organic horizons selected for trace element analysis were disaggregated in the laboratory with a porcelain mortar. Because in agriculture, trace element content of soil is typically expressed in terms of the minus-2 m.m. fraction, disaggregated samples were passed through a 2 m.m. nylon sieve. Fines were then mixed and a 10 g. sub-sample ground to minus-100 mesh in a "Shatterbox". Organic horizon material, intended for pH measurement, was initially ground in a rotary blender.

VEGETATION

Plant material was collected in a roughly 10 x 10 m. perquadrat in the vicinity of each soil pit. Species common over a wide range of soil parent materials and altitudes were sampled preferentially. Sampling procedures for various plant types collected are indicated in Table VI. Samples, in large paper bags, were air dried as soon as possible in the field and again at 70°C in the laboratory, before being ground in a Wiley mill.

FAECES

Where available, samples were taken of both caribou and moose faeces. A few grams of dried sample were ground in a small blender prior to digestion.

SAMPLE ANALYSIS

Stream sediment and rock samples were analyzed by a semiquantitative DC-arc spectrographic procedure for Sr, Cr, Co, Ni, Cu, V, Mo, Pb and Mn. Atomic-absorption spectrophotometry was used to measure Cu, Mn and Zn levels in soil, vegetation and faeces, and Zn in selected sediment and rock samples (Fletcher, pers. comm.). Mo was determined colormetrically in soil, vegetation and faecal material. Glass electrodes were used to measure soil pH.

Table VI Plant species and parts sampled for trace element analysis.

Plant Type	Plant Species	Sampling Procedure
Trees	Abies lasiocarpa (Fir) Picea glauca (white spruce)	First and second year leaves and twigs taken to include flowers and fruits, where present
Shrubs	Betula glandulosa (dwarf birch) Salix alexensis (willow) Salix phylicifolia (willow)	
	Cassiope tetragona (white heather) Empetrum nigrum (crowberry) Potentilla flabeliformis (shrubby cinguefoil)	Terminal 2 inches taken to include flowers and fruits
Forbs	Senecio triangularis Lupinus arcticus (lupine) Epilobium latifolium (fireweed) Epilobium angustifolium (fireweed) Valarian sitchensis Veratrum viride (false hellibore) Polygonum alaskanum	Cut 1 inch above soil to include flowering parts: old growth excluded
Grasses	Festuca altaica (rough fescue) Carex aquatalis (sedge) Calamagrostis canadensis Carex microshaeta	Cut 1 inch above soil surface to include clums; old growth excluded
Lichens	Cladonia alpestris (caribou moss) Stereocaulon Alectoria	Sampled above pigment line
	Umbilicaria	Stripped from rock surfaces

SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSIS

Procedures used for stream sediment material are identical to those described for the regional study (pages 17 to 22). For rock material however, changes were made in operating conditions (Table VIIA) and in wavelengths used to estimate copper and manganese abundances (Table VIIB). Precision for rock analyses, at the 95% confidence level, is indicated in Table VIII.

ATOMIC-ABSORPTION ANALYSIS

Pre-Analytical Treatment

Soil and Vegetation: Either a 0.5 g. sample of minus-100 mesh soil material or 1 g. of dried and milled plant material was weighed into a 100 ml. beaker. After adding 10 ml. of 4:1 nitric-perchloric acid, the sample was refluxed for one hour at low heat. The solution was then evaporated to dryness and the residue taken up with 10 ml. 6 M. hydrochloric acid. After standing, a 5 ml. aliquot of clear solution was set aside for colorimetric determination of molybdenum. The remaining 5 ml. were diluted to 20 ml. with distilled water and this solution reserved for determination of copper, zinc and manganese.

Rock and Stream Sediment: A 0.5 g. sample of minus-100 mesh rock, or minus-80 mesh stream sediment material was digested in 10 ml. of 4:1 nitric-per-

Table VII Changes in spectrographic procedure Tables I and II) introduced for analysis of rock material.

A. Operating Conditions

	Changed	
	from	to
Arc Gap	4 m.m.	6 m.m.
Exposure Time	20 sec.	30 sec.
Plate Development	3 min.	5 min.

B. Spectral Lines

	Wavelength (Å) Changed		Detection Limit (p.p.m.) Changed	
	From	to	From	to
Cu	3273.96	3247.55	10	2
Mn	2801.06	2794.82	1	1

Table VIII Analytical precision for spectrographic analysis of rock material, at the 95% confidence level, calculated from 25 replicate analyses of U.B.C. Standard Rock.

Element	Mean Concentration (p.p.m.)	Precision % (at 95% confidence level)
Sr	685	30
Cr	5	50
Co	4	30
Ni	7	95
Cu	25	60
In	25	40
V	35	75
Mo	n.d.*	-
Pb	8	65
Mn	145	65

* n.d. = not detected.

chloric acid and evaporated to dryness. The residue was taken up in 20 ml. of 1.5 M hydrochloric acid for the determination of zinc.

Faeces: A 1 g. sample of ground faecal material was ignited in a porcelain crucible for twelve hours at 550° C. The ash was treated with 1 ml. of 6 M hydrochloric acid and evaporated to near dryness. The residue was taken up in 10 ml. 6 M hydrochloric acid and treated as described for soil and plant materials.

Analytical Method:

Calibration standards were prepared in 1.5 M hydrochloric acid. Samples and standards were aspirated into the air-acetylene flame of a Techtron AA-4 spectrophotometer. Operating conditions for hollow-cathode lamps are shown in Table IX.

Analytical Precision:

Each analytical batch contained at least one standard and one pair of duplicate samples. Precision at the 95% confidence level, calculated from analytical results for both standard and paired samples (Fox, pers. comm.) is indicated in Table X. The technique of precision calculation using paired samples is described by Garrett (1969).

Generally precision values obtained by different methods compare favourably. Low precision for copper in the standard moss sample is attributable to the fact that copper concentrations in this material are very near to the anal-

Table IX Operating conditions for the Techtron A A-4 Spectrophotometer

Element*	Current (μa)	Air Pressure (psi)	Slit Width (μ)	Wavelength (Å)
Cu	3	21	50	3247.5
Mn	10	20	100	2795
Zn	6	20	100	2138.6

* Standard settings for all elements:

flame height	2.3
fuel guage	2.5

Table X. A. Analytical precision (%) for Cu, Mn and Zn in soil and plant material, at the 95% confidence level, calculated from results of atomic-absorption analysis of both standard and paired samples

Element	Vegetation			Soil	
	Paired Analyses	Replicate Analyses		Paired Analyses	Replicate Analyses
		U.B.C. Standard Moss	U.B.C. Standard Grass		U.B.C. Standard Rock
Cu	25	45	20	15	20
Mn	12	10	10	9	9
Zn	10	14	12	8	25
No. of samples	18 pairs	18	17	15 pairs	6

B. Arithmetic mean Cu, Mn, and Zn concentrations* (p.p.m.) in U.B.C. standard samples.

Element	U.B.C. Standard		
	Moss	Grass	Rock
Cu	4	13	25
Mn	75	165	210
Zn	14	35	20

* $HNO_3/HClO_4$ extractable metal content

ytical detection limit.

COLORIMETRIC ANALYSIS

Molybdenum was determined colorimetrically by the method of Stanton and Hardwick (1967). Sample digestion procedures are described in the section on atomic-absorption analysis (page 56).

Briefly the method involves extraction of a green molybdenum-dithiol complex into a layer of petroleum spirits, and visual comparison of the color of this layer with that of standards. Because of high iron concentrations in certain soil samples the standard procedure was modified slightly. An additional 1 ml. of iron solution was used to prepare standards, and an extra 2 ml. of reducing solution was added to both standards and samples before addition of zinc dithiol.

Analytical precision calculated from paired sample analysis is indicated in Table XI.

Table XI Analytical precision for molybdenum in plant and soil material, at the 95% confidence level, calculated from the results of colorimetric analysis of paired samples

Material	Number of Pairs	Precision % (at 95% confidence level)
Plant	7	30
Soil	15	25

MEASUREMENT OF pH

Soil pH determinations were made on dried samples in the laboratory. Organic samples were initially ground in a blender and a 10 g. sub-sample mixed with 50 ml. of distilled water (Lavkulich, pers. comm.). For mineral horizons a 1:1 mixture by weight of minus-2 m.m. soil material and distilled water was used. Soil-water mixtures were allowed to equilibrate for at least one hour with regular stirring (Jackson, 1958) before pH measurement with a glass electrode meter. Electrodes were calibrated periodically, between sample measurements, in buffer solutions of pH 4.0 and 9.0.

CHAPTER VI

TRACE ELEMENT CONCENTRATIONS IN ROCK MATERIAL

PRESENTATION OF DATA

Range and geometric mean trace element levels for rock samples from Unit 3, the Yukon Group and granodiorite are listed in Table XII. Concentrations within the various lithologies of Unit 3 are indicated in Table XIII. Overall levels for Unit 3 were calculated assuming that the number of samples of each rock type reflects its relative abundance within the unit. Appendix A lists analytical results for individual rock samples.

It should be noted that, because of the limited number and distribution of rock sample sites, and generally low precision for rock analyses (Table VIII), values in Tables XII and XIII must be considered only approximations to the mean metal content of the various rock types. Furthermore, in situ leaching of many of the exposures sampled may, to some extent, have altered primary rock composition.

TRACE ELEMENT CONCENTRATIONS IN BEDROCK

As Table XII indicates, Unit 3 is strikingly enriched in both molybdenum (10 p.p.m.) and vanadium (435 p.p.m.), and relatively poor in manganese (15 p.p.m.) and to a lesser degree strontium (70 p.p.m.). Relatively wide concentration ranges for most elements reflect the chemical heterogeneity of this unit.

Molybdenum concentrations in both Yukon Group phyllites and schists and granitic rocks are low (1 p.p.m.). High

Table XII Range[†] and geometric mean trace element levels (p.p.m.) for major bedrock units within detailed study area.

ELEMENT	BEDROCK		
	UNIT 3	YUKON GROUP	GRANODIORITE
Mo*	10 3-29	1 <1-3	1 -
V	435 180-1075	80 50-130	80 15-470
Ni	30 10-85	45 30-60	6 1-8
Cr	75 40-140	55 30-105	18 12-25
Cu	30 10-90	30 15-60	7 2-20
Pb	15 7-25	16 11-25	19 17-21
Sr	70 20-225	145 100-210	300 -
Mn	15 5-65	485 275-855	175 130-240
Co	4 2-8	14 9-25	7 5-8
Zn**	18 3-90		5 -
Number of Samples	213	13	5

† Range = geometric mean ± log standard deviation

* Values <2p.p.m. taken as 1 p.p.m.

** Number of zinc analysis: Unit 3 = 46, Granodoirite = 1.

Table XIII Range† and geometric mean trace element levels (p.p.m.) for various rock types within Unit 3.

ELEMENT	ROCK TYPE					
	SILICIOUS					CALCAREOUS
	dark grey to black shale	medium to light grey shale	dark siltstone	chert-pebble conglomerate	siliceous rock combined	dark limestone
Mo*	17 8-35	12 6-20	4 2-5	2 <2-4	9 3-25	45 13-165
V	645 315-1320	340 155-730	260 160-430	55 30-95	410 170-995	1095 560-2135
Ni	25 13-45	10 4-30	60 35-95	15 5-55	30 10-65	190 90-415
Cr	60 35-105	45 25-75	115 90-140	25 18-40	70 35-125	215 130-350
Cu	18 6-50	55 30-105	70 35-140	45 30-70	30 10-90	45 25-80
Pb	16 10-30	6 2-16	13 10-18	10 6-15	13 7-25	7 5-11
Sr	55 20-180	55 25-120	90 45-175	20 -	60 20-170	680 310-1480
Mn	8 4-15	5 2-15	75 25-150	30 10-95	15 4-55	140 55-175
Co	<5 -	<5 <5-5	9 5-20	<5 <5-10	4 2-8	<5 <5-7
Zn**	8 2-30	5 3-9	100 50-195	55 -	35 1-200	185 170-200
Number of Samples	112	20	59	9	205	13

† Range = geometeric mean ± log standard deviation
* Values <2p.p.m. taken as 1 p.p.m.
** Number of zinc analyses: black shale = 26, grey shale = 5, siltstone = 12, conglomerate = 1, limestone = 2.

manganese concentrations (485 p.p.m.) characterize Yukon Group while granodiorite is distinguished by low copper, nickel and chromium values.

A wide range of molybdenum and vanadium values occur within the individual rock types of Unit 3 (Table XIII). Molybdenum levels are low in siltstones and conglomerate ($\leq$5 p.p.m.), relatively high in shales (up to 35 p.p.m.) and strikingly high in dark limestone (up to 165 p.p.m.). The distribution of vanadium resembles that of molybdenum, with mean concentrations ranging from an average of 55 p.p.m. in conglomerate up to 1095 p.p.m. in limestone.

High concentrations for most elements are found in dark limestone, while low values are typical in chert-pebble conglomerate. For example the mean strontium content of limestone is 680 p.p.m. while that of conglomerate is only 20 p.p.m.

Concentrations in dark and light colored shales are remarkably similar. Both rock types are strikingly low in cobalt ($<$5 p.p.m.), manganese ($<$15 p.p.m.) and zinc ($<$30 p.p.m.).

COMPARISON OF CONCENTRATIONS IN BLACK SHALES FROM UNIT 3 WITH ESTIMATES OF NORMAL CONCENTRATIONS IN SIMILAR ROCK TYPES

Table XIV lists mean metal values in black shales from Unit 3, estimates of average concentrations for all types of shales, and median levels in North American black shales. It should be noted that different parameters are

Table XIV Comparison of trace element levels (p.p.m.) within dark grey to black shales of Unit 3 with estimates of average metal concentrations in shales of all kinds and median levels within North American black shales.

Element	Dark Grey to Black Shales of Unit 3 (geometric mean)	Shales* (average)	Black Shale** (median)
Mo	17	2.6	10
V	645	130	150
Ni	25	70	50
Cr	60	90	100
Cu	20	45	70
Pb	15	20	20
Sr	55	300	200
Mn	10	850	150
Co	<5	19	10
Zn	8	95	300

* Tourekian and Wedepohl (1961)

** Vine and Tourtelot (1970)

used to measure the central tendency of the analytical data in each column.

The relatively high molybdenum concentration in Unit 3 black shales (17 p.p.m.) is consistent with that of North American black shales (10 p.p.m.) and much greater than the average molybdenum value for all types of shale (<3 p.p.m.). Vanadium is far more abundant in the black shales of Unit 3 (645 p.p.m.) than in either typical North American black shale or in shales generally.

Most other elements, especially manganese, strontium and zinc are low in Unit 3 black shales. The manganese concentration in typical shales, for example, is 850 p.p.m. while the mean value in the black shales of Unit 3 is only 10 p.p.m.

POSSIBLE MECHANISMS CONTROLLING TRACE ELEMENT LEVELS WITHIN CERTAIN UNIT 3 LITHOLOGIES

Enhanced molybdenum values in black shales are generally attributed to sorption of molybdenum from sea water by sediments collecting in anaerobic, stagnant basins. This contention is supported by the presence of high molybdenum concentrations in sediments from modern land-locked marine basins where anaerobic conditions prevail.

Manheim (1961) has reported up to 80 p.p.m. molybdenum in organic rich, oxygen deficient sediment collecting in the Baltic Sea. Gross (1967) has noted molybdenum concentrations as high as 67 p.p.m. in reducing sediments in the central portion of Saanich Inlet, a small fjord near the southeastern end of Vancouver Island. He concluded that sea water was the source of the molybdenum and observed that relatively little of the total molybdenum content of the seawater in the fjord need be removed to account for levels in the sediments.

LeRiche (1959) investigating samples of black shale from the United Kingdom, and Vine and Tourtelot (1970) studying North American black shales, both found that molybdenum is strongly associated with organic matter. In Saanich Inlet sediments however, molybdenum showed no correlation with organic carbon, but was related to the reducing capacity of the sediments (Gross, 1967).

Korolev (1958) has shown experimentally that relatively large amounts of molybdenum may be coprecipitated with iron sulfide gels, such as hydrotroilite ($FeS.nH_2O$), which eventually age to pyrite. He suggests that high molybdenum concentrations in organic shales are due to the presence of molybdenum-rich sulfides in the original sediments.

Sulfides are actively forming in modern, anaerobic, molybdenum-rich basins (Gross, 1967; Dunhan 1961). Manheim (1961) has noted that molybdenum has a strong tendency to follow iron sulfide in Baltic Sea sediments.

No quantitative organic carbon or sulfide determinations were carried out during this investigation. The molybdenum-rich black shales of Unit 3 however, are obviously also rich in organic material and locally contain abundant pyrite. The dark limestone, which contains even more molybdenum than the shales, also contains considerable amounts of organic matter.

Vine and Tourtelot (1970) have noted that very high median molybdenum values (up to 300 p.p.m.) in certain North American black shales are difficult to explain, simply by extraction of molybdenum from sea water. They suggest that externally derived, metal-rich connate solutions may have penetrated and enriched certain black shales, either during or after diagenises. Such post-depositional enrichment however, is unlikely to have affected the rocks of Unit 3 since:

(i) the maximum molybdenum concentration found within Unit 3, 100 p.p.m., is not very different from the 80 p.p.m. in modern Baltic Sea sediment (Manheim, 1961).

(ii) excessively large quantities of connate fluids would be required to enrich the thousands of cubic miles of Unit 3 rock.

With the exception of molybdenum and vanadium, trace element concentrations in Unit 3 black shales are relatively low. This could be a primary feature or a result of in situ leaching of outcrops sampled. It is interesting to note that elements in which these rocks are poorest are most soluble in acidic environments such as those of streams draining the shales (Hawkes and Webb, 1962).

In addition to molybdenum, vanadium, nickel, copper, chromium and zinc are associated with the organic fraction of many black shales (Vine and Tourtelot, 1970). High levels of most of these elements in the dark limestone could therefore be a consequence of metal sorption by the organic component of these rocks.

Strontium and manganese, according to Vine and Tourtelot (1970) are characteristic of the carbonate fraction of most North American black shales. High concentrations of both of these elements are present in the dark limestone member of Unit 3. This association likely reflects the comparative ease with which both strontium and manganese can replace calcium in the calcite lattice.

CHAPTER VII

TRACE ELEMENT CONCENTRATIONS IN SOIL MATERIAL

PRESENTATION OF DATA

Because trace element concentrations in soils are primarily a function of the composition of geological parent materials (Vinogradov 1959, Swaine and Mitchell 1960, Mitchell 1964), soils in this study are grouped according to their occurrence over chemically distinctive bedrock types. Furthermore, because parent materials in upland areas are likely of residual character, while those in main valleys may have been transported relatively far from their source, valley and upland soils over the same bedrock are grouped separately. The boundary between these two environments was arbitrarily set at 4000 ft. above sea level.

Initially samples of only one horizon from each soil profile were analyzed. The C horizon was chosen since it is the only mineral horizon present in all profiles. Concentrations of molybdenum, copper, zinc and manganese in the minus-2 m.m. fraction of this horizon, grouped according to topographic position and associated bedrock, are summarized in Tables XV and XVI.

Some of the more interesting soil profiles were analyzed in their entirety. Trace element concentrations and morphological characteristics for each horizon in six of these profiles are given in Tables XVII and XVIII respectively.

Metal levels in the thin volcanic ash layer which underlies the L-H horizon in many soils are summarized in Table XIX. Appendix B lists separately trace element levels for all soil horizons analyzed.

TRACE ELEMENT CONTENT OF C HORIZONS

Variations in C horizon compositions in upland soils associated with different bedrock types are evident in Table XV. Calcareous Unit 3 soils are considerably enriched in molybdenum (30 p.p.m.), copper (65 p.p.m.) and zinc (585 p.p.m.). Granitic soils, in contrast, contain strikingly low concentrations of these elements. Somewhat enhanced molybdenum values (11 p.p.m.) occur in siliceous Unit 3 soils, while upland soils over the Yukon Group are characterized by low molybdenum levels (<1 p.p.m.) and high concentrations of manganese (690 p.p.m.).

Metal concentrations in C horizons of valley soils (Table XVI) are generally not very different from those over similar bedrock in upland regions. The mean molybdenum level in Unit 3 valley soils (7 p.p.m.) is, however, somewhat less than that of corresponding upland soils (11 p.p.m.). Relatively low manganese concentrations in valley soils over the Yukon Group are also noteworthy.

DISTRIBUTION OF TRACE ELEMENTS IN SELECTED SOIL PROFILES

Enhanced levels of manganese and zinc are typical of many L-H horizons (Table XVII). In profile no. 72, for example, the L-H horizon contains 8445 p.p.m. manganese and 500 p.p.m. zinc, while corresponding values in the underlying C horizon are only 135 p.p.m. and 130 p.p.m. respectively.

Table XV Range and arithmetic mean concentrations* (p.p.m.) of Mo, Cu, Zn and Mn in the minus-2 mm fraction of soil C horizons in upland regions within the detailed study area.

Element	Bedrock			
	Unit 3		Yukon	Granitic
	Calcareous	Siliceous	Group	Rocks
Mo	30	11	0.7	1.5
	10-48	1-26	0.2-1.6	0.8-2.4
Cu	65	35	30	5
	40-120	15-90	15-45	2-10
Zn	585	150	115	45
	355-1400	25-570	50-170	25-65
Mn	210	360	690	255
	30-305	15-2700	240-1220	180-315
pH	6.7	4.3	4.5	4.7
No. of Samples	7	23	12	3

* $HNO_3/HClO_4$ extractable metal content

Table XVI Range and arithmetic mean concentrations* (p.p.m.) of Mo, Zn, Cu and Mn in the minus-2 mm fraction of soil C horizons in major river valleys.

Element	Bedrock	
	Unit 3	Yukon Group
Mo	7	2.6
	1-24	0.8-5.2
Cu	40	30
	10-85	20-40
Zn	180	130
	10-475	70-250
Mn	155	300
	5-480	135-415
pH	4.7	5.2
No. of Samples	26	8

* $HNO_3/HClO_4$ extractable metal content

Table XVII Distribution of $HNO_3/HClO_4$ extractable metal concentrations in selected soil profiles.

Bedrock Unit	Site Number	Horizon	Mo	Cu	Zn	Mn	pH
			(ppm)				
Unit 3 Calcareous	45	L-H	20	45	305	270	6.6
		C	45	40	355	235	7.2
	48	L-H	14	55	730	415	4.2
		IC_1	17	95	570	210	5.3
		IC_2	14	45	210	280	5.5
		Ash	1	10	25	30	5.9
		Bm	14	80	495	165	5.9
		IIC	10	60	465	165	5.5
Unit 3 Acidic	50	L-H	9	55	290	120	4.4
		C_1	15	55	290	175	3.8
		C_2	15	75	570	460	4.4
Yukon Group	30	Ash	0.8	15	40	125	4.9
		Bm	2.8	25	115	450	4.5
		IC	2.0	30	190	830	4.6
		IIC	3.6	30	250	435	4.8
	72	L-H	0.4	30	500	8445	4.8
		Ash	0.4	20	15	225	5.0
		C	2.8	35	130	135	4.5
Granitic Rock	35	L-H	7	25	80	220	4.1
		Bm	0.2	5	40	295	4.6
		C	0.8	2	25	315	4.6

Table XVIII Morphological characteristics of soil proflies considered in Table XVII.

BEDROCK	SOIL SITE	HORIZON	DEPTH (inches)	MORPHOLOGY
	46	L-H	2-0	chiefly lichens
		C	0-	very dark grey (10YR 3/1); sandy loam; 50% coarse fragments; single grain; loose; slightly sticky; non-plastic.
Unit 3 calc-areous	48	L-H	5-0	chiefly lichens
		IC_1	0-4	very dark greyish brown (10YR 3/2); silty clay; no coarse fragments; fine granular; friable; sticky; plastic.
		IC_2	4-6	very dark greyish brown (10YR 3/2); shaly silty clay loam; 15% coarse fragments; fine granular; loose; slightly sticky; slightly plastic.
		Ash	6-8	light yellowish brown (10YR 4/6); silty clay loam; no coarse fragments; single grain; firm; sticky; slightly plastic.
		Bm	8-11	dark brown (10YR 4/3); loam; 30% coarse fragments; single grain ; loose; slightly sticky; non-plastic.
		IIC	11-	very dark greyish brown (10YR 3/2); sandy loam; 20% coarse fragments; fine granular; very friable; slightly sticky; slightly plastic.
Unit 3 silic-eous	50	L-H	1-0	chiefly lichens
		IC	0-5	very dark greyish brown (10YR 3/2); clay loam; 15% coarse fragments; fine granular; loose; sticky; slightly plastic.
		IIC	5-	as for IC with 20% coarse fragments.
Yukon Group	30	Ash	0-3	yellowish brown (10YR 5/4); silt loam; no coarse fragments; single grain; friable; slightly sticky; slightly plastic.
		Bm	3-6	dark brown (10YR 3/3); silt loam; no coarse fragments; fine granular; friable; sticky;slightly plastic.
		IC	6-12	yellowish brown (10YR 5/4); as for Bm.
		IIC	12-	light olive brown (2.5Y 5/4); slaty sand; 60% coarse fragments; single grain; loose; slightly sticky; non-plastic.
	72	L-H	3-0	chiefly lichens
		Ash	0-3	light grey (10YR 7/2); silty clay loam; no coarse fragments; single grain; loose; sticky; plastic.
		C	3-	brown (7.5YR 4/4); cobbly sand; 45% coarse fragments; single grain; loose; slightly sticky; non-plastic.
Granitic Rock	35	L-H	2-0	chiefly lichens
		Bm	0-6	light yellowish brown (10YR 6/4); sand; <5% coarse fragments; single grain; loose; slightly sticky; non-plastic.
		C	6-	brownish yellow (10YR 6/6); sand; <5% coarse fragments; single grain; loose; slightly plastic; slightly sticky.

Table XIX Range and arithmetic mean trace element levels* in samples of volcanic ash

Element	Concentration (p.p.m.)
Mo	1.1 0.2-6.4
Cu	11 5-18
Zn	18 5-40
Mn	65 15-225
pH	4.9
No. of Samples	9

* $HNO_3/HClO_4$ extractable metal content.

Molybdenum and copper levels in most L-H horizons are not remarkably high.

Concentrations in B horizons (profile nos. 30 and 35) are generally about equal to, or less than, those in underlying C horizons. Adjacent C horizons with different lithological characteristics may vary greatly in composition. In profile no. 50, for example, horizons C_1 and C_2 are distinguished only by the presence of slightly fewer coarse rock fragments in the former horizon. Horizon C_1 contains 175 p.p.m. manganese, while C_2 contains 460 p.p.m.

The valcanic ash layer, which separates L-H and mineral horizons in many profiles contains uniformly low concentrations of all elements (Table XIX).

FACTORS AFFECTING THE METAL CONTENT OF SOILS

Concentrations of both molybdenum and copper in soil C horizons are very similar to those in associated bedrock. As shown in Table XX, granitic soils and rock both contain about 1 p.p.m. molybdenum and siliceous Unit 3 rock and soil material contain 9 and 11 p.p.m. molybdenum respectively. Copper concentrations are equal (30 p.p.m.) in Yukon Group soil and rock.

Webb et al (1965, 1968) have noted the close association between molybdenum concentrations in soils and bedrock in both Ireland and the United Kingdom. Vinogradov (1959) has remarked on the importance of parent materials

Table XX Comparison of mean† trace element levels (p.p.m.) in soil C horizons* in upland areas with those in the associated bedrock**.

ELEMENT	UNIT 3 CALCARIOUS		UNIT 3 SILICEOUS		YUKON GROUP		GRANITIC ROCK	
	ROCK	SOIL	ROCK	SOIL	ROCK	SOIL	ROCK	SOIL
Mo	45	30	9	11	1	0.7	1	0.5
Cu	45	65	30	35	30	30	7	5
Zn	185	585	35	150		115	5	45
Mn	140	210	15	360	485	690	175	255
pH		6.7		4.3		4.5		4.7

† Rock means geometric; soil means arithmetic.
* $HNO_3/HClO_4$ extractable metal content
** Total metal content

in determining the copper content of Russian soils.

Relative zinc and manganese levels in soils are consistent with relative concentrations in associated bedrock. Absolute soil levels however are invariably above those in rock. Enrichment factors for zinc range from 3 to 8, and for manganese may be over 20.

High soil values could be due either to residual enrichment or external additions of metals. Residual enrichment could result from either high manganese and zinc concentrations in soil minerals which are particularly resistant to weathering, or from fixing of these elements in the soil after their release to the soil solution. Both processes however require extensive chemical weathering, unlikely in the pedologically young soils of the MacMillan Pass area. Extremely high manganese levels in certain soils (>2500 p.p.m.) derived from rock material low in this element suggest that some manganese is of external origin.

Bleeker et al (1969) found manganese levels in certain New Guinea soils to be substantially higher than concentrations in underlying parent materials. Enrichment is greatest in soils subject to frequent alternating periods of oxidation and reduction. They suggest that manganese is mobilized deep in the parent material under reducing conditions, and transported up profile with a rising water table, where at a later stage it is immobilized by oxidation.

A similar process could be active in the MacMillan Pass area. It is noteworthy however that Gleysols, which should be most affected by alternating oxidizing and reducing conditions, are not excessively enriched in manganese.

Enhanced concentrations of manganese and zinc in certain L-H horizons are likely a result of biocycling. This process involves removal by plant roots, of inorganic material from lower soil horizons, and its accumulation in surface organic layers (Barshad, 1964). As indicated by lack of high metal concentrations in B horizons, other soil forming processes, such as illuviation, have not noticeably altered the primary trace element distribution in most soil profiles.

POSSIBLE SIGNIFICANCE OF VARIATIONS IN COMPOSITION OF UPLAND AND VALLEY SOILS

The molybdenum content of Yukon Group valley soils (2.6 p.p.m.) is somewhat higher than that in upland regions (0.7 p.p.m.). Since several valley sample sites are located downstream from exposures of molybdenum-rich Unit 3 rocks, debris derived from Unit 3 is likely present in valley fill over parts of the Yukon Group.

Molybdenum concentrations in valley soils over Unit 3 (7 p.p.m.) are slightly lower than those in upland areas (11 p.p.m.). Examination of the geographical distribution of valley soils poorest in molybdenum (<4 p.p.m.) reveals that most such soils occur outside of the detailed study area, on the eastern edge of the Yukon Plateau. These molybdenum-poor soils may have been derived from Unit 3 lithologies low in this element, such as siltstone or conglomerate. Alternatively, parent materials for these soils could contain significant amounts of rock debris from other molybdenum-poor geological units.

CHAPTER VIII

TRACE ELEMENT CONCENTRATIONS IN PLANT MATERIAL

PRESENTATION OF DATA

Concentrations of molybdenum, copper, zinc and manganese in a few selected plant species, and overall levels in each of the five major vegetation classes (trees, shrubs, forbs, grasses and lichens) are summarized in Tables XXI to XXIV. Since upland and valley soils associated with the same bedrock are compositionally very similar (Tables XV and XVI), plants were not subdivided on the basis of their relative topographic positions. Metal concentrations and sample site numbers for all plants analyzed are listed in Appendix C.

METAL CONTENT OF PLANTS

Low molybdenum concentrations, typically less than 0.2 p.p.m., occur in nearly all species associated with Yukon Group soils (Table XXI). Plants on siliceous Unit 3 and granitic soils may contain somewhat higher molybdenum levels. Over the Yukon Group, for example, forbs contains an average of 0.2 p.p.m. molybdenum, while those associated with siliceous Unit 3 and granitic soils contain 1.2 p.p.m. and 0.7 p.p.m. respectivèly.

Of particular interest however is the remarkably high molybdenum content of nearly all species sampled over calcareous Unit 3 soils. Fireweed (*Epilobium latifolium*), for example, contains up to 44 p.p.m. molybdenum and rough fescue (*Festuca altaica*) up to 50 p.p.m. Warren and

Table XXI Range and arithmetic mean molybdenum content† of vegetation (ppm dry weight) associated with various soil types.

CLASS	SPECIES	SOIL TYPE			
		UNIT 3 CALCAREOUS	UNIT 3 SILICEOUS	YUKON GROUP	GRANITIC
TREES	Abies lasiocarpa (fir)	(*)	0.2 0.1-1.4 (11)	0.1 - (5)	0.4 - (1)
	Trees**		0.2 0.1-1.4 (16)	0.1 - (8)	0.2 0.1-0.4 (3)
SHRUBS	Betula glandulosa (dwarf birch)		0.1 0.1-0.4 (43)	0.1 - (10)	0.1 - (2)
	Salix alaxensis (willow)	4 1.2-12 (6)	0.2 0.1-1.2 (22)	0.1 - (10)	0.4 - (1)
	Shrubs**	5 0.5-12 (9)	0.2 0.1-1.2 (89)	0.1 0.1-0.5 (43)	0.2 0.1-0.4 (5)
FORBS	Senecio triangularis	9 1.6-18 (4)	0.4 0.1-1.2 (5)	0.1 - (2)	0.4 - (1)
	Epilobium latifolium (fireweed)	22 12-44 (4)	4.5 - (1)	0.5 0.1-0.8 (3)	
	Forbs**	12 1.6-44 (11)	1.2 0.1-4.5 (13)	0.2 0.1-0.8 (12)	0.7 0.1-1.2 (4)
GRASSES	Festuca altaica (rough fescue)	40 12-50 (3)	0.9 0.1-3.6 (8)	0.2 0.1-0.6 (5)	1.2 - (1)
	Calmagrostis canadensis	2.4 - (1)	0.9 0.1-3.6 (9)	0.3 - (1)	0.4 - (1)
	Grasses**	16 0.3-50 (8)	0.9 0.1-3.6 (22)	0.4 0.1-1.2 (12)	0.8 0.4-1.2 (2)
LICHENS	Cladonia alpestris (caribou moss)		0.1 0.1-2.4 (35)	0.1 - (14)	0.1 - (1)
	Lichens**		0.2 0.1-2.4 (42)	0.1 - (20)	0.5 0.1-0.8 (2)

† values less than 0.2 p.p.m. taken as 0.1 p.p.m.
* number of samples
** for various species included in this vegetation class see Table VI.

Table XXII Range and arithmetic mean manganese content of vegetation (ppm dry weight) associated with various soil types.

CLASS	SPECIES	SOIL TYPE			
		UNIT 3 CALCAREOUS	UNIT 3 SILICEOUS	YUKON GROUP	GRANITIC
TREES	Abies lasiocarpa (fir)	(*)	510 250-745 (11)	1210 270-1670 (5)	320 - (1)
	Trees**		565 65-1145 (16)	900 135-1670 (8)	310 95-515 (3)
SHRUBS	Betula glandulosa (dwarf birch)		680 70-1755 (43)	790 270-1360 (10)	395 305-485 (2)
	Salix alaxensis (willow)	60 40-85 (6)	280 30-690 (22)	430 55-865 (10)	310 - (1)
	Shrubs**	50 20-100 (9)	395 30-1755 (89)	495 55-1360 (43)	465 225-975 (5)
FORBS	Senècio triangularis	30 15-40 (4)	105 20-175 (5)	225 180-270 (2)	140 - (1)
	Epilobium latifolium (fireweed)	50 20-90 (4)	195 - (1)	120 35-215 (3)	
	Forbs **	40 10-90 (11)	125 20-300 (13)	310 35-1395 (12)	125 65-185 (4)
GRASSES	Festuca altaica (rough fescue)	55 30-70 (3)	230 115-435 (8)	400 170-780 (5)	270 - (1)
	Calmagrostis canadensis	285 - (1)	180 70-375 (9)	210 - (1)	230 - (1)
	Grasses**	100 40-285 (8)	200 50-435 (22)	290 50-780 (12)	250 230-270 (2)
LICHENS	Cladonia alpestris (caribou moss)		55 20-155 (35)	60 20-110 (14)	30 - (1)
	Lichens**		50 5-155 (42)	50 20-110 (20)	20 10-30 (2)

* number of samples

** for various species included in this vegetation class see Table VI.

Table XXIII Range and arithmetic mean copper content of vegetation (ppm dry weight) associated with various soil types.

CLASS	SPECIES	SOIL TYPE			
		UNIT 3 CALCAREOUS	UNIT 3 SILICEOUS	YUKON GROUP	GRANITIC
TREES	*Abies lasiocarpa* (fir)	(*)	5 3-10 (11)	4 3-6 (5)	5 - (1)
	Trees**		5 3-10 (16)	4 3-6 (8)	4 3-5 (3)
SHRUBS	*Betula glandulosa* (dwarf birch)		7 3-10 (43)	6 3-9 (10)	6 5-7 (2)
	Salix alaxensis (willow)	6 1-9 (6)	6 2-10 (22)	6 3-8 (10)	6 - (1)
	Shrubs **	6 3-9 (9)	7 2-15 (89)	6 4-15 (43)	6 5-7 (5)
FORBS	*Senecio triangularis*	8 5-10 (4)	14 9-17 (5)	12 6-17 (2)	9 - (1)
	Epilobium latifolium (fireweed)	6 5-6 (4)	7 - (1)	6 4-7 (3)	
	Forbs **	8 5-20 (11)	10 6-17 (13)	8 4-17 (12)	7 3-11 (4)
GRASSES	*Festuca altaica* (rough fescue)	5 4-6 (3)	6 3-7 (8)	5 4-6 (5)	6 - (1)
	Calmagrostis canadensis	12 - (1)	9 6-12 (9)	8 - (1)	8 - (1)
	Grasses **	7 5-14 (8)	7 3-12 (22)	7 4-12 (12)	7 6-8 (2)
LICHENS	*Cladonia alpestris* (caribou moss)		3 1-4 (35)	2 1-3 (14)	2 - (1)
	Lichens**		3 1-10 (42)	4 1-14 (20)	3 2-5 (2)

* number of samples

** for various species included in this vegetation class see Table VI.

Table XXIV Range and arithmetic mean zinc content of vegetation (ppm dry weight) associated with various soil types.

CLASS	SPECIES	SOIL TYPE: UNIT 3 CALCAREOUS	UNIT 3 SILICEOUS	YUKON GROUP	GRANITIC
TREES	Abies lasiocarpa (fir)	(*)	45 35-65 (11)	45 35-60 (5)	30 - (1)
	Trees**		50 35-70 (16)	55 35-130 (8)	75 35-140 (3)
SHRUBS	Betula glandulosa (dwarf birch)		180 60-310 (43)	160 80-195 (10)	165 120-215 (2)
	Salix alaxensis (willow)	220 125-330 (6)	170 100-280 (22)	150 55-250 (10)	190 - (1)
	Shrubs**	175 125-330 (9)	80 15-310 (89)	95 10-250 (43)	135 30-215 (5)
FORBS	Senecio triangularis	55 30-75 (4)	80 55-115 (5)	165 120-205 (2)	25 - (1)
	Epilobium latifolium (fireweed)	30 20-40 (4)	75 - (1)	40 20-70 (3)	
	Forbs **	45 25-75 (11)	70 55-115 (13)	45 20-205 (12)	25 20-30 (4)
GRASSES	Festuca altaica (rough fescue)	65 40-80 (3)	50 30-105 (8)	30 20-40 (5)	30 - (1)
	Calmagrostis canadensis	195 - (1)	55 30-85 (9)	25 - (1)	35 - (1)
	Grasses **	85 35-195 (8)	55 25-105 (22)	40 20-50 (12)	30 - (2)
LICHENS	Cladonia alpestris (caribou moss)		15 5-30 (35)	14 8-25 (14)	15 - (1)
	Lichens**		15 5-30 (42)	15 8-30 (20)	20 15-25 (2)

* number of samples

** for various species included in this vegetation class see Table VI.

Delevault (1965) have reported high molybdenum levels in fireweed growing over molybdenite mineralization in British Columbia.

Where molybdenum is available forbs and grasses usually contain more of this element than do woody species. Forbs growing on calcareous Unit 3 soils, for example, typically contain 12 p.p.m. molybdenum, while shrubs, such as willow (Salix alaxensis) associated with the same soil generally contain less than 5 p.p.m.

Manganese levels in plants growing on calcareous Unit 3 soils are typically low, while plants growing on Yukon Group soils are characteristically rich in manganese (Table XXII). Shrubs, including such species as willow (Salix alaxensis) and dwarf birch (Betula glandulosa), contain an average of 495 p.p.m. manganese associated with the Yukon Group and only 50 p.p.m. in more basic Unit 3 environments. Calamagrostis canadensis is exceptional in its relatively high manganese content (285 p.p.m.) associated with calcareous Unit 3 rocks.

All woody plants contain large amounts of manganese. Dwarf birch (Betula glandulosa), in particular, may contain up to 1755 p.p.m. of this element. Kubota et al (1970) found similarily high manganese levels (1120 p.p.m.) in leaves from this species in Alaska.

Variations in copper concentrations in plants associated with different soil types are slight. Overall mean levels in grasses, for example, are 7 p.p.m. associated with all four soil types (Table XXIII).

Copper concentrations also vary little between species. Mean values typically range from about 4 p.p.m. in trees up to 8 p.p.m. in forbs. Only Senecio triangularis and Calamagrostis canadensis characteristically contain copper levels of 8 p.p.m. or greater. In contrast, Kubota et al. (1970) found an average of only 3.5 p.p.m. copper in Calamagrostis canadensis from Alaska.

Relationships between zinc levels in plant species and soil type are often contradictory. As indicated in Table XXIV, for example, mean zinc concentrations are highest in trees growing on granitic soils (75 p.p.m.) while grasses are poorest in zinc (30 p.p.m.) when associated with the same soils.

Zinc levels in certain shrubs are particularly high. Willow (Salix alexensis) may contain up to 330 p.p.m. zinc in contrast to usual values of less than 100 p.p.m. in most other species.

Lichens generally, and Cladonia in particular, contain low concentrations of all elements. Copper concentrations do not exceed 5 p.p.m., while average zinc levels are only about 15 p.p.m. Scotter and Miltimore (pers. comm.) in the Northwest Territories, and Havre (1969) in Norway, have both reported similarly low metal values in various Cladonia species, including Cladonia alpestris.

FACTORS AFFECTING METAL LEVELS IN PLANTS

Metal concentrations in plants are influenced by both the total metal content of the soil and the form in which metals are held. Trace elements within the crystal lattice of primary and secondary soil minerals are relatively unavailable compared to ions present in the soil solution or adsorbed on either clay minerals or organic matter. The proportion of soil solution and adsorbed ions available to the plant is determined, to a large extent, by Eh and pH conditions in the soil.

Low molybdenum levels (typically $<$ 0.2 p.p.m.) in plants of most species growing on Yukon Group soils are consistent with low total molybdenum concentrations ($<$3 p.p.m.) in these soils. Relatively high molybdenum concentrations (8 p.p.m.) in siliceous Unit 3 soils, however, contrast with low values in associated woody plants and lichens. Forbs such as fireweed (*Epilobium latifolium*), and grasses such as rough fescue (*Festuca altaica*), growing on these siliceous soils may contain somewhat enhanced molybdenum levels (up to 4.5 and 3.6 p.p.m. respectively).

The average molybdenum concentration in calcareous Unit 3 soils (30 p.p.m.) is about four times greater than that of siliceous varieties. However, mean molybdenum levels for plants growing in basic soils may be, as in the case of rough fescue (*Festuca altaica*), over forty times greater than levels associated with acidic soils (Table XXI).

Barshad (1951) has reported that soil clay minerals adsorb increasing amounts of molybdenum, as $MO_4^{=}$, with decreasing pH. Similarly, Reisenaur et al (1962) have shown that the amount of molybdenum adsorbed by hydrous oxides of iron and aluminum, both common in soils, decreases with increasing pH.

Generally low concentrations of molybdenum in plants growing on molybdenum-rich siliceous Unit 3 soils therefore reflect the dominant influence of low pH (mean value 4.5) over total metal content in restricting molybdenum availability. In the calcareous soils (pH 6.7) both molybdenum and pH values are high, and hence both factors favour plant uptake.

Molybdenum-rich vegetation has also been reported growing on organic-rich acidic soils (Walsh et al, 1953, Kubota et al, 1961). In the MacMillan Pass area, however, no enhanced plant molybdenum levels were noted associated with soils of this type.

In contrast to molybdenum, availability of manganese to plants increases with decreasing pH (Hodgson, 1970). Plants growing in acidic soils, such as those derived from the Yukon Group, high in total manganese (520 p.p.m.), contain high manganese concentrations (Table XXII). Soils with similar manganese contents but different pH levels, for example calcareous and siliceous Unit 3 soils, support plants with very different manganese levels. Willow (Salix alaxensis) contains approximately 280 p.p.m. manganese on acidic siliceous soils and only 60 p.p.m. on more basic calcareous soils.

Soil type generally exerts little influence on copper concentrations in plants investigated. For example, grasses contain an average of 7 p.p.m. copper on both granitic soils, which contain 5 p.p.m. copper, and siliceous Unit 3 soils, with 35 p.p.m. copper. Furthermore mean copper values for various plant species characteristically range between only 4 and 8 p.p.m. It therefore appears that certain homeostatic mechanisms, common to most plant species studied, effectively regulate copper intake.

Copper availability, like that of manganese, reportedly decreases with increasing pH (Hodgson, 1970). This is consistent with the lack of high plant copper values associated with basic copper-rich (65 p.p.m.) Unit 3 soil. In view of the importance of plant response factors in limiting copper uptake however, the absence of enhanced plant copper concentrations is not necessarily only a pH effect.

Zinc levels in plants are often not consistent with soil pH and total zinc content. Both Yukon Group and siliceous Unit 3 soils, for example, contain similar amounts of zinc and have similar pH values (Tables XV and XVI). The mean zinc concentration in Senecio triangalaris growing on the former soils, of 165 p.p.m., is however, approximately twice that associated with the latter soils. Variations of this type could be due to soil factors such as organic matter content and the chemical form in which zinc is present, which were not investigated in this study.

Relatively high zinc levels in shrubs and grasses associated with calcareous Unit 3 soils are not in agreement with the reported low availability of zinc in basic soils (Hodgson, 1970). These high concentrations may reflect the abilities of plants concerned to absorb zinc more than the ability of soils to supply it.

POSSIBLE INFLUENCE OF METAL LEVELS IN PLANTS ON THE HEALTH OF WILDLIFE, PARTICULARLY CARIBOU AND MOOSE

The ability of an animal to tolerate molybdenum is affected by a number of factors, including its copper status and intake and the inorganic sulfate content of its diet (Underwood, 1962). Although the nature of metabolitic interactions of these elements are poorly understood, it appears that the principal toxic effect of prolonged high dietary molybdenum uptake is to induce a state of copper deficiency (hypocuprosis). A minimum amount of inorganic sulfate must however be present if this toxic action is to be effective. Cattle experiencing molybdenum induced hypocuprosis suffer severe loss of condition and scouring.

Tolerance to high dietary intakes of molybdenum varies considerably with different animal species (Underwood, 1962). Of domestic farm animals, for example, cattle are much less tolerant of molybdenum than are horses and pigs. Tolerance limits of caribou and moose have not been studied.

Nevertheless, since as ruminants, these animals share certain basic metabolitic processes with cattle, their tolerance levels could be similarly low.

Precise tolerance levels for cattle are not well established. Kubota et al (1961) have suggested that on imperfectly to poorly drained mineral soils in the western United States, molybdenum concentrations of over 15 p.p.m. in forage plants are potentially toxic to cattle, while on organic soils 2 to 3 p.p.m. in forage may be toxic. In Ireland, on the other hand, the provisional threshold level for toxic herbage is given as 5 p.p.m. in dry matter (Walsh et al., 1952).

In view of the metabolitic interaction of copper and molybdenum, the Cu/Mo ratio of forage is perhaps a more meaningful parameter of toxicity. Miltimore and Mason (1971) have observed that, in British Columbia, feeds with Cu/Mo ratios of less than 2.0 are associated with symptoms of copper deficiency in cattle.

Average Cu/Mo ratios for plants growing in all but basic Unit 3 soils are well above 2.0. With very few exceptions however, plants associated with basic soils have ratios below this limit. Overall ratios for forbs and shrubs, for example, are 0.68 and 1.25 respectively. The lowest Cu/Mo ratio for an individual species is 0.13 for rough fescue. These basic soils, derived primarily from dark limestone, are relatively rare within the detailed study area.

While little is known about the feeding habits of either caribou or moose, most plant species sampled are at least potential forage for these animals. Caribou moss (Cladonia alpestris) in particular is likely to be one of the main food sources for caribou during winter months. It is interesting to note that, while molybdenum levels in this lichen are low (<0.2 p.p.m.), concentrations of both copper (3 p.p.m.) and zinc (15 p.p.m.) are well below the minimum dietary levels of 10 and 50 p.p.m. respectively, recommended for domestic cattle (Agricultural Research Council, 1965).

An indication of the metal intake of these animals may be given by the metal content of their faeces (Table XXV). Of 30 samples analyzed, only two contained more than 2 p.p.m. molybdenum. Removal of molybdenum by digestive processes or leaching of faeces by rainwater, however, may be responsible for some of the low values.

In summary, if

(i) molybdenum-rich calcareous rock is relatively uncommon within Unit 3 as a whole, as is suggested from studies in the MacMillan Pass area and published geological reports,

(ii) molybdenum tolerance levels of caribou and moose are similar to those of cattle,

(iii) grazing habits of caribou and moose are independent of soil type,

it is unlikely that these animals suffer from molybdenum induced copper deficiency.

Table XXV Range and arithmetic mean concentration* (p.p.m.) of Mo, Cu, Zn and Mn in caribou and moose faeces.

Element	Faeces	
	Caribou	Moose
Mo	1.6 0.1-9.7	1.2 0.1-14.0
Cu	14 11-22	10 7-16
Zn	260 175-415	365 175-515
Mn	700 300-1405	465 130-1010
No. of Samples	12	18

* $HNO_3/HClO_4$ extractable metal content expressed in terms of sample dry weight.

However, if caribou moss is the principal food source for caribou in winter, the possibility of deficiency symptoms resulting from low levels of copper and zinc in this species is very real. Similar conditions may affect reindeer in Norway (Havre, 1969) and the Northwest Territories (Scotter and Miltimore, pers. comm.).

CHAPTER XI

TRACE ELEMENT CONCENTRATIONS IN STREAM SEDIMENT

PRESENTATION OF DATA

Tables XXVI and XXVII summarize metal concentrations in sediments associated with different bedrock types. Samples collected over Unit 3 were subdivided on the basis of their association with either basic, or neutral to acidic stream water. Basic streams invariably drain areas underlain, in part, by dark limestone.

Sediments from valley bottoms over the Yukon Group are considered separately since streams in these environments commonly drain areas underlain partially by Tertiary volcanics and/or Unit 3. Trace element concentrations and U.T.M. co-ordinates of all stream sediment samples collected within the detailed study area and along the Canol Road are listed in Appendix D.

METAL CONCENTRATIONS IN STREAM SEDIMENT

As shown in Table XXVI Unit 3 sediments from the MacMillan Pass region contain large concentrations of molybdenum (26 p.p.m.), vanadium (720 p.p.m.) and copper (200 p.p.m.). Molybdenum and vanadium levels in particular are considerably higher than values for Unit 3 sediments from the regional study area (11 and 480 p.p.m. respectively). Sediments associated with basic stream waters (Table XXVII A) are enriched in nickel (420 p.p.m.), molybdenum (40 p.p.m.), vanadium (905 p.p.m.) and strontium (275 p.p.m.), relative to those of acid streams.

Table XXVI Range[†] and geometric mean trace element content (p.p.m.) of stream sediment associated with major bedrock types within the detailed study area and along the Canol Road.

ELEMENT	BEDROCK		
	UNIT 3	YUKON GROUP	GRANITIC ROCK
Mo*	26 10-65	3 1-6	1 -
V	720 385-1345	115 55-230	30 20-40
Ni	100 30-345	80 45-145	11 3-20
Cr	200 130-320	165 130-215	22 15-30
Cu	110 60-210	60 35-110	8 5-12
Pb	25 15-45	20 15-35	17 15-20
Sr	145 65-320	230 145-375	175 50-300
Mn	340 95-1230	770 425-1400	200 -
Co	30 10-70	45 30-80	6 3-10
Zn**	135 35-530		
Number of Samples	69	30	2

† Range = mean ± log standard deviation
* Values less than 2 ppm taken as 1 ppm
** Number of zinc analyses = 36

Table XXVII Range[†] and geometric mean trace element content (p.p.m.) of stream sediment associated with, (A) Unit 3 subdivided on the basis of stream pH, (B) Yukon Group subdivided topographically.

A.

ELEMENT	SEDIMENTS SAMPLED OVER UNIT 3	
	Stream pH>7	Stream pH≤7
Mo*	40 15-105	24 10-55
V	905 720-1145	680 345-1345
Ni	420 265-660	75 25-220
Cr	345 240-505	180 125-260
Cu	130 85-200	105 55-210
Pb	20 10-40	25 15-45
Sr	275 130-600	125 60-225
Mn	490 170-1400	310 80-1175
Co	50 35-75	25 10-65
Zn**	375 210-680	45 15-115
Number of Samples	13	56

B.

ELEMENT	SEDIMENTS SAMPLED OVER YUKON GROUP	
	Uplands	Valleys
Mo*	1 <1-1.5	3.5 1.5-8.5
V	65 55-80	145 70-290
Ni	70 60-85	90 45-175
Cr	190 170-210	160 120-210
Cu	75 60-110	55 30-105
Pb	30 20-40	20 10-30
Sr	250 190-320	225 130-390
Mn	1020 640-1625	685 370-1260
Co	75 65-85	40 25-65
Number of Samples	9	21

† Range = mean ± log standard deviation
* Values less than 2p.p.m. taken as 1p.p.m.
** Number of zinc analyses: stream pH>7 = 19
stream pH≤7 = 17

Yukon Group sediments are generally low in molybdenum (3 p.p.m.) and rich in manganese (770 p.p.m.). A few high molybdenum and vanadium values (greater than 10 and 480 p.p.m. respectively) occur in valley sediments over the Yukon Group. Overall concentrations in sediments associated with the Yukon Group from both regional and detailed study areas are remarkably similar.

Both sediment samples derived from a biotite granodiorite stock southwest of MacMillan Pass are strikingly low in all elements (Table XXVI). Metal levels in granitic sediments from the regional study are typically higher, by factors of from two to three, than concentrations in these granodioritic sediments. Furthermore, low molybdenum levels (<2 p.p.m.) in the sediments near MacMillan Pass contrast with enhanced concentrations (up to 16 p.p.m.) reported in sediments associated with granitic intrusions in the Keno Hill region (Gleeson, 1966).

COMPARISON OF METAL CONTENT OF STREAM SEDIMENT WITH THAT OF ASSOCIATED ROCK AND SOIL

Trace element concentrations in rock, soil and stream sediment material are summarized in Tables XXVIII and XXIX.

Low concentrations of molybdenum in granitic and Yukon Group sediment and relatively and high values in calcareous Unit 3 sediment are clearly reflected in associated rock and soil. Calcareous sediment, for example, contains

Table XXVIII Molybdenum, copper and manganese concentrations (p.p.m.) in stream sediment and associated soil material.

ELEMENT	BEDROCK	STREAM SEDIMENT*	SOIL**
Mo	Unit 3 Calcareous	40 15-105	30 10-50
	Unit 3 Siliceous	24 10-55	8 1-26
	Yukon† Group	1 <1-1.5	0.7 0.2-1.6
	Granitic Rock	1 -	1.5 0.2-2.4
Cu	Unit 3 Calcareous	130 85-200	65 45-120
	Unit 3 Siliceous	105 55-210	40 10-90
	Yukon† Group	75 60-110	30 15-45
	Granitic Rock	8 5-12	5 2-10
Mn	Unit 3 Calcareous	490 170-1400	210 30-305
	Unit 3 Siliceous	310 80-1175	250 5-2695
	Yukon† Group	1020 640-1625	690 240-1220
	Granitic Rock	200 -	255 180-315

* Total analysis by emission spectroscopy; geometric mean values quoted.

** $HNO_3/HClO_4$ extractable metal content determined by atomic-absorption spectrophotometry; arithmetic means.

† Sediment values refer to upland areas only.

Table XXIX Geometric mean trace element concentrations (p.p.m.)* in rock and associated stream sediment.

ELEMENT	CALCAREOUS UNIT 3		SILICEOUS UNIT 3		YUKON GROUP		GRANITIC ROCK	
	ROCK	SEDIMENT	ROCK	SEDIMENT	ROCK	SEDIMENT	ROCK	SEDIMENT
Mo	45	40	9	24	1	1	1	1
V	1095	905	410	680	80	65	80	30
Ni	190	420	30	75	45	70	6	11
Cr	215	345	70	180	55	190	18	22
Cu	45	130	30	105	30	75	7	8
Pb	7	20	13	25	16	30	19	17
Sr	680	275	60	125	145	250	300	175
Mn	140	490	15	310	485	1020	175	200
Co	<5	50	4	25	14	75	7	6
Zn**	185	375	35	45	–	–	5	–
Number of Samples	13	13	205	56	12	9	5	2

* total analysis by emission spectroscopy (except for zinc)

**$HNO_3/HClO_4$ extractable Zn measured by atomic-absorption spectrophotometry an average of 40 p.p.m. molybdenum, while concentrations in associated rock and soil are 45 and 30 p.p.m. respectively. Mean molybdenum concentration in siliceous Unit 3 sediment (24 p.p.m.) however, is approximately three times greater than rock and soil values. Similar relationships exist for vanadium concentrations in rock and stream sediment material.

Sediments derived from both Unit 3 and the Yukon Group contain two to three times more copper than associated rock and soil. Manganese levels are also relatively high in sediments, though the enrichment factor is more variable than that of copper. The mean manganese concentration in siliceous Unit 3 sediment, for example, is 310 p.p.m. while those of associated bedrock and soil are 15 and 250 p.p.m. respectively. Concentrations of all other elements in Unit 3 and Yukon Group stream sediment are similarly enhanced relative to rock values, with the single exception of strontium in calcareous Unit 3 environments (Table XXIX).

Metal levels in sediments derived from granodioite, in contrast to levels of most elements in sediments from other bedrock types, are typically very similar to concentrations in rock and soil material. For example, granitic stream sediment contains 8 p.p.m. copper, while levels of 5 and 7 p.p.m. characterize associated soil and rock respectively. Vanadium and strontium concentrations in granitic sediment are exceptional in that levels are less than those of the source rock.

FACTORS AFFECTING TRACE ELEMENT LEVELS IN STREAM SEDIMENT

Since stream sediments approximate a composite sample of rock and soil material upstream from the sample site, their composition is controlled, to a considerable extent, by compositions of these materials. Processes active in the stream channels however, such as leaching or adsorption, may alter sediment composition to some extent.

A comparison of Tables XXVIII and XXIX indicates compositions of rock and soil material in the MacMillan Pass area, are generally not very different. Relatively large differences are common however, between the composition of these two materials and the associated sediment.

The extent to which sediment composition is modified in stream channels is determined by a number of factors including Eh and pH values in the channel and the associated soil, the amount and nature of dissolved material in stream water, the grain size and mineral composition of the sediment, and the nature of the element being considered.

Metals may be dissolved in soil or stream water as either cations or complex anions. Of the elements considered in Table XXIX only two, molybdenum and vanadium, are mobilized as anions (Hawkes and Webb, 1962). Eh and pH changes affect these two groups of ions in opposite fashions.

Soil and stream pH values are summarized in Table XXX. Stream pH values are typically one or more units above soil levels. Though no Eh measurements were made stream channels are likely to be more oxidizing than soil environments.

Considering the elements mobilized as cations, concentrations are typically much higher in sediments than in the associated rock (Table XXIX). The magnitude of this enrichment is variable, ranging from less than 2 to greater than 20. Only granitic sediments are not enriched in this fashion.

Table XXX Mean pH values of soils and stream waters associated with various bedrock units.

Bedrock		pH	
		Soils	Stream waters
Unit 3	Calcareous	6.7	7.8
	Acidic	4.5	5.3
Yukon Group		4.8	6.7
Granitic Rocks		4.7	6.7

Iron oxide precipitates are common on sediment in many of the more acidic streams draining Unit 3 lithologies, particularly pyrite bearing dark shale. According to Stumm and Morgan (1970) oxidation of pyrite releases both ferrous and hydrogen ions. Ferrous ions may subsequently be oxidized to the ferric state and precipitated as ferric hydroxide in stream channels. Precipitation of ferric hydroxide releases more hydrogen ions thus accounting for very low stream pH values associated with iron precipitates.

Iron and manganese precipitates may scavenge considerable amounts of such trace elements as nickel, cobalt, copper and zinc from stream water (Theobald et al., 1962, Hornsnail et al. 1969). Chemical analysis of precipitates in the MacMillan Pass area however (Table XXXI) reveal low values for most elements with the exception of molybdenum and zinc.

An alternative and more likely mechanism for enrichment of sediment relative to rock and soil material is cation adsorption. This involves adsorption of positively charged ions by the clay-size fraction of stream sediment, such as clay minerals and organic matter. Since the effectiveness of cation adsorption increases with increasing pH (Hawkes and Webb, 1962), cations mobilized in the relatively acidic soils of the MacMillan Pass area should tend to be adsorbed in the more basic stream channels (Table XXX).

Lack of enrichment in granitic sediment is somewhat surprising in view of relatively large pH differences between soils and stream channels (4.7 vs. 6.7). Sediment in these channels however is composed chiefly of sand-size grains of quartz and mica, whereas, as previously noted, adsorption occurs principally on the clay-size component

Table XXXI Range and arithmetic mean trace element content* (p.p.m.) of iron oxide precipitates from acidic stream channels

Element	Concentration (p.p.m.)
Mo	20
	<0.2-70.0
Ni	5
	3-12
Cu	45
	15-115
Pb	11
	3-45
Mn	14
	6-35
Co	6
	4-8
Zn	75
	30-200

* 6M HCl extractable metal concentration determined by atomic-absorption spectrophotemetry.

of the sediment.

Anions of molybdenum and vanadium (MoO_4^{-2} and VO_4^{-3}), in contrast to cations, should be most mobile in the relatively basic oxidizing stream channels. Since molybdenum and vanadium concentrations in sediment are typically similar to associated rock and soil levels, these elements however are not likely being leached from sediments to any great extent.

Siliceous Unit 3 sediments are exceptional in that they contain more molybdenum and vanadium than the associated rock. As previously noted however, hydrous iron oxide precipitates which are common as crusts on these sediments may contain large amounts (up to 70 p.p.m.) of molybdenum. Jones (1957) has shown that hydrous iron oxides are superior to clay minerals in their ability to sorb molybdenum. Vanadium concentrations in these precipitates are unknown, but it seems probable that, like molybdenum, they are relatively high.

COMPARISON OF METAL CONCENTRATIONS IN STREAM SEDIMENT WITH THOSE OF ASSOCIATED VEGETATION

Low molybdenum concentrations in stream sediment derived from both Yukon Group and granitic rock are clearly reflected in low mean molybdenum concentrations in vegetation growing over these rocks (Table XXXII). However high concentrations typical of Unit 3 sediments are not always associated with enriched vegetation. The mean molybdenum concentration in siliceous Unit 3 sediment, for example,

Table XXXII Mean molybdenum, copper and manganese concentrations in stream sediment and vegetation, and associated mean stream pH values.

ELEMENT	BEDROCK	CONCENTRATION (ppm)		STREAM pH
		Stream Sediment*	Vegetation**	
Mo	Unit 3 Calcareous	40	10	7.8
	Unit 3 Siliceous	24	0.4	5.3
	Yukon† Group	1	0.2	6.7
	Granitic Rock	1	0.4	6.8
Cu	Unit 3 Calcareous	130	7	7.8
	Unit 3 Siliceous	105	6	5.3
	Yukon† Group	75	6	6.7
	Granitic Rock	8	5	6.8
Mn	Unit 3 Calcareous	490	60	7.8
	Unit 3 Siliceous	310	330	5.3
	Yukon† Group	1020	380	6.7
	Granitic Rock	200	260	6.8

* Total analysis by emission spectroscopy; geometric means.

** $HNO_3/HClO_4$ extractable metal content determined by atomic-absorption spectrophotometry; arithmetic means; concentration expressed in terms of dry weight.

† Sediment values refer to upland areas only.

is 24 p.p.m. while that of associated vegetation is only 0.4 p.p.m.

As previously noted, low molybdenum values in vegetation growing over siliceous Unit 3 rock are primarily an effect of low pH values in soils derived from these rocks. As Table XXXII indicates these low soil pH values are reflected in low pH levels in associated stream water. Similarly high stream pH values associated with calcareous Unit 3 sediment (7.8) are consistent with high values in the calcareous soils, which typically support molybdenum enriched vegetation. Thus by considering both stream sediment concentrations and stream pH values, prediction of areas likely to contain enhanced molybdenum levels in vegetation should be possible.

Soil pH is also an important factor in determining the availability of manganese to plants. Consequently, as in the case of molybdenum, both sediment concentrations and stream pH values must be known if estimates are to be made of plant molybdenum levels. For example, in view of the relatively high concentrations of manganese in the sediment of streams draining Unit 3 limestone (Table XXXII), low vegetation values would not be expected unless these environments were known to be relatively basic, as indicated by stream pH levels.

In contrast to molybdenum and manganese, plant copper concentrations are apparently unrelated to either pH levels or metal concentrations in sediment. This situation is not surprising, since as Table XXIII indicates, copper concentrations in vegetation are to a large extent independent of soil type, including soil copper content and pH.

CHAPTER X

SUMMARY, CONCLUSIONS

AND

SUGGESTIONS FOR FURTHER RESEARCH

SUMMARY AND CONCLUSIONS

A regional stream sediment reconnaissance survey was undertaken in the Eastern Yukon, using sediment samples originally collected by Atlas Explorations Ltd. Vancouver, for mineral exploration purposes. A total area of over 6,000 square miles was covered, chiefly within the drainage basins of the Hess and MacMillan Rivers.

Enhanced molybdenum values (>8 p.p.m.) are present in sediments over an area of more than 1,300 square miles. Most of these enriched sediments are derived from a thick succession of Paleozoic sedimentary rocks, consisting predominantly of dark shales and chert (Unit 3). Molybdenum levels associated with the other major bedrock units, namely the Yukon Group, Earn Group, Tertiary volcanics and granitic rocks, are typically low (<4 p.p.m.).

Stream sediments derived from Unit 3 are also noticeably enriched in vanadium (480 p.p.m.), and to a lesser extent nickel (140 p.p.m.), copper (90 p.p.m.) and chromium (180 p.p.m.). Those associated with Tertiary volcanics are relatively rich in strontium (720 p.p.m.), while granitic sediments contain low concentrations of most elements.

A detailed follow-up study of trace element concentrations in rock, soil, stream sediment and plant material was undertaken in the vicinity of MacMillan Pass, near the eastern limit of the reconnaissance study area. This region is underlain by Unit 3, Yukon Group metasediments and granitic rocks. Unit 3 is composed of a wide variety of lithologies including black and light grey shales, dark siltstones, chert-pebble conglomerate and dark limestone.

The dark grey to black shales, which in the MacMillan Pass area are the most abundant rock type within Unit 3, contain relatively large amounts of molybdenum (17 p.p.m.), as do the less common light colored shales (12 p.p.m.). Siltstones and chert-pebble conglomerates typically contain less than 4 p.p.m. molybdenum. Concentrations are highest (up to 100 p.p.m.) in the relatively uncommon dark limestone member of Unit 3. Vanadium, nickel, chromium and zinc values are also high in the limestone.

In addition to molybdenum, black shales are enriched in vanadium (645 p.p.m.), but are relatively poor in most other elements, especially strontium (55 p.p.m.), manganese (8 p.p.m.) and zinc (8 p.p.m.). Enhanced molybdenum and vanadium values are likely a consequence of sorption of these elements, by organic-rich sediments, from sea water in a large anaerobic basin. Low values for other elements could be a primary feature of the sediments, or could be a result of in situ leaching of shale exposures sampled.

The C horizons of all soils associated with Unit 3 contain high molybdenum concentrations. Soils derived from dark limestones contain an average of 30 p.p.m. molybdenum, while those associated with other rock types of Unit 3 typically contain about 10 p.p.m. Molybdenum levels in both Yukon Group and granitic soils are low ($\leq$3 p.p.m.).

Copper levels in soil C horizons are usually very close to values in the underlying rock. Both manganese and zinc however are enriched in soil relative to rock material. Soils derived from siliceous Unit 3 rocks, for example, contain an average of 360 p.p.m. manganese and 150 p.p.m. zinc while rocks themselves contain only 15 and 35 p.p.m. of these elements respectively.

Molybdenum availability to plants is chiefly controlled by soil pH. Plants are capable of absorbing molybdenum only in neutral to basic soils such as those associated with Unit 3 limestone. These molybdenum-rich calcareous soils typically support vegetation with enhanced molybdenum levels. Average concentrations in forbs and grasses, for example, are 12 and 16 p.p.m. respectively. In acidic conditions however, characteristic of molybdenum-rich Unit 3 soils, concentrations in plants are generally less than 0.2 p.p.m. Molybdenum-poor Yukon Group and granitic soils also support vegetation low in this element.

Manganese concentrations in plants are also dependent on soil pH. Restricted manganese availability in basic environments is reflected, for example, in low manganese levels in plants growing on calcareous Unit 3 soils. Copper levels, on the other hand, are remarkably uniform, and apparently independent of soil conditions. Variations of zinc concentrations in certain species often contradict estimates of zinc availability based on the total metal content and pH of associated soils.

Molybdenum levels in stream sediments are generally consistent with rock and soil values. Similarily, low sediment values typically reflect low concentrations in associated vegetation. However, either molybdenum-rich or molybdenum-poor vegetation may be associated with sediment containing enhanced amounts of molybdenum. In anomalous areas, characterized by molybdenum-poor vegetation, stream pH values are generally acidic. Neutral to basic stream water, on the other hand, is typically associated with molybdenum-rich vegetation.

Because of the absence of stream pH values from the regional study area, the distribution of molybdenum-rich vegetation cannot be predicted. However, in the vicinity of MacMillan Pass, high plant values are associated with dark molybdenum-rich limestone only. Since these limestones are apparently not common within the reconnaissance study area, it may be tentatively concluded that molybdenum-enriched vegetation is not likely to be sufficiently widespread to endanger the health of wildlife in this portion of the Eastern Yukon.

SUGGESTIONS FOR FURTHER RESEARCH

In view of the significance of trace elements to plant and animal nutrition, maps showing the regional distribution of trace metals are urgently required on a world-wide scale. Geochemical data should then be combined with epidemiological information in an attempt to assess possible causal relationships between trace element abundances and disease patterns.

Where adequate surface drainage exists, stream sediment surveys can be used to compile such maps. Basic research, however, is required into possible modifications of stream sediment reconnaissance techniques oriented toward environmental, rather than mineral exploration programs. For example, while it is standard practice in mineral exploration to measure the metal content of the minus-80 mesh fraction of sediment, other size fractions may be more meaningful in terms of regional rock and soil chemistry. Furthermore, application of various cold and hot extraction techniques to stream sediment material may prove more useful than the total metal content in assessing trace element availability to plants.

Since well developed river drainage systems are not always present in areas of geochemical interest, research is required into use of rock and/or soil material in regional surveys. Finally, possible applications of remote sensing techniques, such as measurement of metal levels in the atmosphere, to geochemical reconnaissance projects should be investigated.

BIBLIOGRAPHY

Agricultural Research Council, 1965. The nutrient requirements of farm livestock, No. 2. Ruminants, 264 pp.

Barshad, I., 1951. Factors affecting the molybdenum content of pasture plants: I. Nature of soil molybdenum, growth of plants and soil pH. Soil Science, Vol. 71, pp. 297-313.

Barshad, I., 1964. Chemistry of soil development. In Chemistry of the Soil, F.E. Bear ed., Reinhold Pub. Corp., N.Y., pp. 1-70.

Bleeker, P., and M.P. Austin, 1970. Relationships between trace element contents and other soil variables in some Papua-New Guinea soils, as shown by regression analyses. Australian Journal of Soil Research, Vol. 8, pp. 133-143.

Blusson, S.L., and D. J. Templeman-Kluit, 1970. Operation Stewart, Yukon Territory, District of MacKenzie. Report of Activities, Geological Survey of Canada Paper 70-1A, pp. 29-32.

Bostock, H.S., 1947. Mayo, Yukon Territory. Geological Survey of Canada, Map 890A.

Bostock, H.S., 1948. The physiography of the Canadian Cordillera, with special reference to the area north of the 55th parallel. Geological Survey of Canada Memoir 247.

Bostock, H.S., 1966. Notes on the glaciation of the Central Yukon. Geological Survey of Canada Paper 65-36.

Brown, R.J., 1960. The distribution of permafrost and its relation to air temperature in Canada and the U.S.S.R. Arctic, pp. 163-177.

Campbell, R. B., 1967. Glenlyon map area, Yukon Territory. Geological Survey of Canada Memoir 352.

Campbell, R. B. and J. O. Wheeler, 1967. Geology, Glenlyon, Yukon Territory. Geological Survey of Canada Map 1221A.

Canada Department of Agriculture, 1970. The system of soil classification for Canada. 249 pp.

Cannon, Helen L., 1969. Trace element excesses and deficiencies in some geochemical provinces of the United States. Proceedings of the University of Missouri's 3rd Annual Conference on Trace Substances and Environmental Health, pp. 21-43.

Capps, S. R., 1915. An ancient volcanic eruption in the upper Yukon Basin. United States Geological Survey Prof. Paper 95-D.

Collins J.F. and S. W. Boul, 1970. Effects of fluctuations in the Eh-pH environment of iron and/or manganese equilibria. Soil Science, Vol. 110, pp. 111-118.

Davies, E.B. 1956. Factors affecting molybdenum availability in soils. Soil Science, Vol. 81, pp. 209-221.

Dunham, K., 1961. Black shale, oil and sulfide ore. British Association for Advancement of Science, Sept., pp. 284-299.

Findlay, D.C., 1969. The mineral industry of Yukon Territory and Southwestern District of MacKenzie, 1968. Geological Survey of Canada Paper 69-55.

Fortescue, J., J. Dupuis, R. Winn, J. Hughes, E. Gawron, and I. Ernesaks, 1971. Preliminary study of the use of stream sediment geochemistry to detect the effect of man's activities on the environment around St. Catherines, Ontario. Brock University, Department of Geological Science, Research Report Series No. 2, Studies in Landscape Geochemistry No. 1, 22 pp.

Garrett, R.G., 1969. The determination of sampling and analytical errors in exploration geochemistry. Economic Geology, Vol. 64, pp. 568-574.

Garrett, R.G., 1971a. Molybdenum and tungsten in some acidic plutonic rocks of Southeast Yukon Territory. Geological Survey of Canada Open File 51, 3 pp.

Garrett, R. G., 1971b. Regional geochemical census of plutonic rocks in Eastern Yukon Territory. Geological Survey of Canada, Report of Activities, Part A, April to October 1970, pp. 72-75.

Gleeson, C. F., 1967. Molybdenum content of stream and spring sediments, Keno Hill area, Yukon Territory. Geological Survey of Canada Map 51-1965.

Goldschmidt, V.M., 1954. Geochemistry. Clarendon Press, Oxford, 730 pp.

Gross, M.G., 1967. Concentrations of minor elements in diatomaceous sediments of a stagnant fjord. Amer.

Assoc. Adv. Sci., Pub. No. 83, Estuaries, pp. 273-282.

Havre, G. N., 1969. The mineral composition of lichen related to studies of trace element metabolism in reindeer. Trace Element Metabolism in Animals, Proc. W.A.A.P./I.B.P. International Symposium, Aberdeen, Scotland, pp. 380-382.

Hawkes, H.E. and J. S. Webb, 1962. Geochemistry in mineral exploration. Harper and Row, New York, 415 pp.

Hodgson, J.G., 1970. Chemistry of trace elements in soils with reference to trace element concentrations in plants. Proceedings of University of Missouri's 3rd Annual Conference on Trace Substances in Environmental Health, pp. 45-58.

Horsnail, R. F., I. Nichol, and J.S. Webb, 1969. Influence of variations in secondary environment on metal content of drainage sediments. Quarterly of the Colorado School of Mines, Vol. 64, pp. 307-322.

Hughes, O.L., R. B. Campbell, J. E. Muller, and J. O. Wheeler, 1968. Glacial limits and flow patterns, Yukon Territory south of 65 degrees north latitude. Geological Survey of Canada Paper 68-34.

Jackson, M.L., 1958. Soil chemical analysis. Prentice-Hall, Englewood Cliffs, N.J., 498 pp.

Jones, L.H.P., 1957. The solubility of molybdenum in symplified systems and aqueous soil suspensions. Journal of Soil Science, Vol. 8, pp. 313-327.

Keele, J., 1910. A reconnaissance across the MacKenzie Mountains on the Pelly, Ross and Gravel Rivers, Yukon and Northwest Territories. Geological Survey of Canada Pub. No. 1097.

Kendrew, W. G. and D. P. Kerr, 1955. Climate of British Columbia and Yukon Territory. Ottawa, 222 pp.

Kindle, E.D., 1945. Geological reconnaissance along the Canol Road from Telsin River to MacMillan Pass, Yukon. Geological Survey of Canada Paper 45-21.

Korolev, D. F., 1958. The role of iron sulfides in the accumulation of molybdenum in sedimentary rocks of the reducing zone. Geochemistry, No. 4, pp. 452-463.

Kubota, J., V. A. Lazar, L. N. Langan and K.C. Beeson, 1961. The relationship of soils to molybdenum toxicity in cattle in Nevada. Soil Science Society of America, Proc., Vol. 25, pp. 227-231.

Kubota, J., V. A. Lazar, G. H. Simonson, and W. W. Hill, 1967. The relationship of soils to molybdenum toxicity in grazing animals in Oregon. Soil Science Society of America Proc., Vol. 31, pp. 667-671.

Kubota, J., S. Rieger and V. A. Lazar, 1970. Mineral composition of herbage browsed by moose in Alaska. Journal of Wildlife Management, Vol. 34, pp. 565-569.

Leahey, A., 1954. Factors affecting the extent of arable lands and the nature of soils in the Yukon Territory. Proc. 7th Pacific Science Congress 1949, Vol. 6, pp. 16-20.

LeRiche, H. H., 1959. Distribution of trace elements in the Lower Lais of Southern England. Geochimica et Cosmochimica Acta, Vol. 16, pp. 101-122.

Lewis, A. H. 1943. The teart pastures of Somerset. Journal of Agricultural Science, Vol. 33, pp. 52-63.

Manheim, F.T., 1961. A geochemical profile in the Baltic Sea. Geochimica et Cosmochimica Acta, Vol. 25, pp. 52-70.

Mason, B., 1966. Principles of geochemistry. John Wiley and Sons, New York, 329 pp.

Massey, H.F., R. H. Lowe, and H. H. Bailey, 1967. Relationship of extractable molybdenum to soil series and parent rock in Kentucky. Soil Science Society of America Proc., Vol. 31, pp. 200-202.

McConnell, R.C., 1903. The MacMillan River, Yukon District. Geological Survey of Canada Summary Report for 1902, pp. 20-36.

Miltimore, J. E., and J. L. Mason, 1971. Copper to molybdenum ratio and molybdenum and copper concentrations in ruminant feeds. Canadian Journal of Animal Science, Vol. 51, pp. 193-200.

Mitchell, R. L., 1964. Trace elements in soils. Chemistry of the Soil, F.E. Bear ed., Reinhold Publ. Corp., New York, pp. 320-368.

Moore, R. C. (ed.), 1962. Treatise on Invertibrate Paleontology, Part W, Miscellanea. Geological Society of America and University of Kansas Press.

Nichol, I., and J. C. Henderson-Hamilton, 1965. A rapid quantitative spectrographic method for the analysis of rocks, soils and stream sediments. Trans. Inst. Min. Metall. Vol. 74, pp. 955-961.

Nichol, I., R.F. Horsnail and J. S. Webb, 1967. Geochemical patterns in stream sediment related to precipitation of manganese oxides. Trans. Sect. B. Inst. Min. Metall. Vol. 76, pp. B113-B115.

Rand, A. L., 1945a. Mammal investiations on the Canol Road, Yukon and Northwest Territories, 1944. National Museum of Canada Bull. 99, Biological Series 28, 52 pp.

Rand, A. L., 1945b. Mammals of the Yukon. Canadian National Museum Bull. 100, Biological Series 29, 93 pp.

Reisenaur, H., A. Tabikh and P. Stout, 1962. Molybdenum reactions with soils and the hydrous oxides of iron, aluminum and titanium. Soil Science Society Proc., Vol. 26, pp. 23-27.

Roddick, J. A. and L. H. Green, 1961a. Geology, Sheldon Lake, Yukon. Geological Survey of Canada, Map 12 - 1961.

Roddick, J. A. and L. H. Green, 1961b. Geology, Tay River, Yukon Territory. Geological Survey of Canada Map 13-1961.

Schutte, K. H., 1964. The biology of the trace elements. Crosby, Lockwood and Sons, London, 228 pp.

Stanton, R. E., and A. J. Hardwick, 1967. The colorimetric determination of molybdenum in soils and sediments by zinc dithiol. Analyst, Vol. 92, pp. 387-390.

Stumm, W. and J. Morgan, 1970. Aquatic chemistry. Wiley-Interscience, New York, 583 pp.

Swaine, D. J., and R. L. Mitchell, 1960. Trace element distribution in soil profiles. Journal of Soil Science, Vol. 11, pp. 347-368.

Theobald Jr., P.K., H.W. Lakin and D. B. Hawkins, 1963. The precipitation of aluminum, iron and manganese at the junction of Deer Creek with the Snake River, in Summit County, Colorado. Geochimica et Cosmochimica Acta, Vol. 27, pp. 121-132.

Thornton, I., W. Atkinson, J. S. Webb and D. B. Poole, 1966. Geochemical reconnaissance and boivine hypocuprosis in Co. Limerick, Ireland. Irish Journal of Agricultural Research, Vol. 5, pp. 280-283.

Thornton, I., R. N. Moon and J. S. Webb, 1969. Geochemical reconnaissance of the Lower Lais. Nature, Vol. 221, pp. 457-459.

Thornton, I., and J. S. Webb, 1969. Geochemical reconnaissance and the detection of trace element disorders in animals. Trace Element Metabolism in Animals, Proc. W.A.A.P./I.B.P. International Symposium, Aberdeen, Scotland, pp. 397-407.

Titley, S.R., 1963. Some behavioural aspects of molybdenum in the supergene environment. Society of Mining Engineers Trans., Vol. 226, pp. 199-204.

Turekian, K. K. and K. H. Wedepohl, 1961. Distribution of the elements in some major units of the earth's crust. Geological Society of America Bull., Vol. 72 pp. 175-192.

Underwood, E.J., 1962. Trace elements in human and animal nutrition. Academic Press Inc., 429 pp.

Vine, J. D. and B. Tourtolot, 1970. Geochemistry of black shale deposits - a summary report. Economic Geology, Vol. 65, pp. 253-272.

Vinogradov, A.P., 1959. The geochemistry of rare and dispersed chemical elements in soils. Consultants Bureau, New York.

Walsh, T., M. Neenan and L. O'Moor, 1952. The importance of molybdenum in relation to some cropping and livestock problems under Irish conditions. Erie Dept. Agri, J., Vol. 48, pp. 32-43.

Walsh, T., M. Neenan, and L. O'Moor, 1953. High molybdenum levels in herbage on acid soils. Nature, Vol. 171, p. 1120.

Warren, H.V. and R. E. Delevault, 1965. Further studies in the biogeochemistry of molybdenum. Western Miner, Vol. 38, pp. 64-72.

Webb, J. S., 1964. Geochemistry and life. New Scientist, Vol. 23, pp. 504-507.

Webb, J. S., 1970. Some geological applications of regional geochemical reconnaissance.

Webb, J. S., and W. J. Atkinson, 1965. Regional geochemical reconnaissance applied to some agricultural problems in Co. Limerick, Ireland. Nature, Vol. 208, pp. 1056-1059.

Webb, J. S., I. Nichol, and I. Thornton, 1968. The broadening scope of regional geochemical reconnaissance. Proc. XXIII International Geological Conference, Vol. 6, pp. 131-147.

Webb, J. S., I. Thornton and K. Fletcher, 1968. Geochemical reconnaissance and hypocuprosis. Nature, Vol. 217, pp. 1010-1012.

Wedepohl, K. H., 1971. Geochemistry. Holt, Rinehart and Winston, New York, 231 pp.

Wheeler, J. O., 1953. A geological reconnaissance of the northern Selwin Mountains region, Yukon and Northwest Territories. Geological Survey of Canada Paper 53-7.

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APPENDIX A

PART I

RESULTS OF EMISSION SPECTROGRAPHIC ANALYSIS (METHOD 2) OF ROCK MATERIAL MACMILLAN PASS AREA PPM

WL% = WEIGHT LOSS ON IGNITION

ID NO	FEO%	WL%	SR	BA	CR	CO	NI	AG	TI	CU	IN	V	MO	BI	GA	SN	PB	MN
16	2.0	5.0	40	1000	150	2.5	10	2.0	5000	40	20	100	4		10		10	10
94	5.0	5.0	300	4000	180	8.0	100	0.5	9999	30	20	500	2		40		10	20
124	5.0	2.5	90	8000	40	2.5	40	2.0	4000	50	15	500	30		8		10	30
125	1.0	2.5	40	5000	40	2.5	30	0.5	5000	40	15	400	15		4		10	20
126	2.0	2.5	40	6000	60	2.5	40	0.5	8000	50	20	900	40		10		15	10
127	1.0	5.0	20	4000	30	2.5	20	0.5	5000	50	15	900	90		7		10	5
128	2.0	5.0	40	7000	50	2.5	50	0.5	4000	50	15	1000	50		8		15	7
129	1.0	5.0	20	5000	40	2.5	40	0.5	3000	40	15	1000	40		8		15	7
130	1.0	5.0	20	5000	40	2.5	40	0.5	4000	40	15	900	60		10		10	10
131	2.0	5.0	20	3000	50	2.5	100	2.0	4000	50	20	1000	50		8		10	10
132	2.0	5.0	50	9998	90	2.5	50	2.0	4000	50	15	900	50		10		10	10
133	1.0	5.0	20	2000	40	2.5	20	0.5	1000	20	10	100	10		5		10	7
134	1.0	2.5	20	1000	10	2.5	30	0.5	2000	20	15	1000	15		4		10	7
135	1.0	2.5	20	3000	40	2.5	20	2.0	4000	20	10	500	20		5		20	10
136	3.0	5.0	20	5000	60	2.5	20	2.0	5000	40	20	500	20		10		20	10
137	0.5	2.5	20	2000	20	2.5	80	0.5	2000	50	10	1000	10		4		10	5
138	1.0	5.0	20	5000	40	2.5	25	2.0	2000	20	15	1500	20		5		20	5
139	1.0	5.0	20	2000	30	2.5	20	1.0	4000	20	20	2000	10		5		15	5
140	2.0	5.0	20	3000	50	2.5	20	1.0	2000	20	15	1500	15		5		20	10
141	4.0	5.0	20	5000	50	2.5	20	4.0	5000	40	20	1000	25		7		20	8
142	2.0	5.0	90	5000	70	2.5	20	2.0	2000	50	20	2000	10		5		20	8
143	8.0	5.0	70	3000	50	2.5	15	2.0	5000	50	20	2000	70		7		20	5
144	2.0	5.0	20	3000	40	2.5	10	1.0	2000	50	10	1000	15		5		30	5
145	2.0	2.5	20	2000	20	2.5	10	1.0	4000	40	10	1000	20		5		20	5
154	1.0	2.5	20	1000	10	2.5	15	0.5	2000	10	10	500	10		4		15	5

155	1.0	2.5	204000	50	2.5	30	0.55000	50	10	5000	20	6	20	6
156	2.0	5.0	203000	40	2.5	20	1.03000	20	15	1500	30	6	20	8
157	1.0	5.0	202000	30	2.5	20	0.52000	15	10	2000	15	5	20	8
158	2.0	2.5	204000	50	2.5	20	2.05000	15	10	2000	20	8	30	5
159	2.0	5.0	205000	40	2.5	20	0.55000	10	15	1000	20	10	30	10
160	2.0	2.5	203000	50	2.5	20	1.07000	10	15	1000	10	10	30	15
161	0.5	5.0	204000	50	2.5	20	1.06000	10	15	2000	10	15	20	10
162	1.0	2.5	205000	60	2.5	20	1.06000	10	15	1000	10	15	20	10
163	1.0	2.5	204000	80	2.5	30	0.55000	5	20	1000	10	15	20	8
164	1.0	2.5	204000	40	2.5	20	0.55000	10	20	600	10	10	20	10
165	1.0	2.5	205000	40	2.5	20	1.05000	5	20	800	10	10	30	8
166	2.0	2.5	204000	70	2.5	15	2.04000	20	15	500	10	10	30	8
167	2.0	2.5	205000	40	2.5	10	2.04000	30	15	300	10	7	40	7
168	2.0	2.5	204000	40	2.5	30	2.02000	40	10	800	10	7	15	5
169	1.0	2.5	201500	10	2.5	10	0.52000	10	10	500	5	2	10	2
171	2.0	2.5	2002000	8	5.0	20	0.53000	15	20	10	1	20	30	100
173	4.0	2.5	1009999	50	2.5	20	0.57000	20	20	500	20	20	40	8
174	5.0	2.5	2009999	70	4.0	50	0.56000	30	20	400	20	15	50	10
175	2.0	2.5	2009999	80	2.5	20	0.56000	15	20	400	20	15	30	5
176	4.0	5.0	15009999	100	2.5	30	0.58000	15	20	400	30	15	20	7
177	2.0	5.0	1009999	100	2.5	20	0.58000	10	20	400	20	15	20	10
178	4.0	2.5	10008000	100	2.5	50	0.58000	20	20	500	20	20	15	8
179	1.0	2.5	205000	80	2.5	30	0.58000	3	15	500	10	20	10	10
180	1.0	2.5	506000	90	2.5	20	0.59000	3	15	500	20	20	15	10
181	2.0	5.0	1009998	90	2.5	20	0.58000	3	20	400	40	30	15	15
182	2.0	5.0	1008000	100	2.5	20	0.58000	3	15	400	20	20	20	10
183	2.0	2.5	1008000	50	2.5	20	0.58000	5	15	400	20	15	20	15
184	2.0	5.0	1008000	80	2.5	20	0.58000	5	30	500	20	20	20	15
185	2.0	2.5	1008000	100	2.5	20	0.58000	3	20	500	15	15	15	8
186	2.0	2.5	1006000	80	2.5	20	0.59000	3	15	500	20	15	15	8
187	2.0	5.0	1008000	80	2.5	40	0.58000	15	20	500	30	20	20	20
188	2.0	5.0	1009000	90	2.5	30	0.59000	5	20	500	20	20	20	10
189	2.0	5.0	1009000	90	2.5	50	0.59000	7	30	900	20	20	20	10
190	5.0	5.0	1009000	100	2.5	50	0.59998	20	20	900	20	20	30	15
191	2.0	2.5	1508000	90	2.5	20	0.59000	2	20	500	15	20	20	10
192	2.0	5.0	1509000	80	2.5	20	0.59000	5	20	500	20	20	20	10
193	4.0	5.0	1509998	60	2.5	30	0.59998	5	20	900	30	20	15	10
194	2.0	5.0	8009998	90	2.5	20	0.59000	5	20	1000	20	20	20	10
195	2.0	5.0	9009998	90	2.5	30	0.59000	5	20	500	20	15	20	10

196	2.0	5.0	4009998	90	2.5	20	0.59000	5	20	500	20	15	20	10
199	2.0	2.5	20 400	30	2.5	20	0.52000	20	10	30	1	3	15	20
200	2.0	2.5	602000	100	2.5	30	0.58000	30	20	300	3	15	10	30
201	2.0	2.5	20 300	30	2.5	15	0.52000	40	15	100	3	5	10	20
1202	2.0	2.5	20 700	50	2.5	20	0.57000	20	20	200	5	10	5	15
2202	5.0	5.0	1003000	100	2.5	15	0.59999	40	30	400	4	30	6	40
203	2.0	5.0	20 200	20	2.5	40	0.52000	50	20	50	1	5	5	50
204	5.0	2.5	20 300	20	2.5	30	0.54000	50	15	50	1	5	5	40
205	9.0	5.0	501500	150	2.5	30	0.59999	90	30	500	4	20	10	30
206	5.0	5.0	20 300	30	2.5	30	0.53000	50	20	50	3	5	10	30
207	2.0	5.0	502000	150	2.5	20	0.59999	30	20	500	3	30	10	10
208	2.0	5.0	502000	150	2.5	15	0.59999	50	20	500	4	20	10	10
209	5.0	5.0	20 500	4050.0		2	0.52000	90	20	50	5	7	15	100
210	5.0	5.0	1003000	15015.0		50	0.59999	100	30	200	2	30	8	150
211	5.0	2.5	1003000	10020.0		100	0.59999	90	30	200	2	30	10	100
212	5.0	5.0	1504000	150	8.0	50	0.59999	50	30	200	2	40	10	100
213	5.0	5.0	1003000	100	5.0	40	4.09998	80	30	200	2	30	10	100
21410.0		2.5	20 150	20	2.5	40	0.54000	50	20	100	5	5	15	100
215	2.0	2.5	1003000	150	2.5	30	0.59998	40	30	400	3	30	20	20
216	5.0	5.0	2002000	100	5.0	40	2.09999	80	30	400	4	20	20	40
217	5.0	5.0	902000	100	8.0	50	0.59999	50	30	300	4	20	20	40
218	5.0	2.5	1003000	15010.0		100	0.59998	70	30	500	5	20	20	30
219	5.0	5.0	1002000	100	8.0	100	0.59998	90	30	300	3	20	20	100
220	5.0	5.0	1002000	100	2.5	30	0.59998	50	30	400	3	20	15	20
221	5.0	5.0	1003000	100	5.0	60	1.09998	60	20	300	5	20	15	50
222	4.0	2.5	1003000	100	5.0	50	0.59998	70	20	300	4	20	15	50
223	5.0	2.5	1504000	100	7.0	50	2.09998	70	30	300	5	20	20	80
224	5.0	5.0	1004000	100	5.0	50	1.09998	50	20	200	5	30	20	50
225	7.0	5.0	1004000	100	5.0	40	1.09998	50	20	400	5	20	20	100
226	5.0	5.0	1004000	100	5.0	50	0.59998	40	20	300	2	20	15	50
227	5.0	5.0	1504000	100	5.0	60	0.59998	50	20	200	2	30	20	50
228	5.0	5.0	1004000	100	5.0	60	0.59998	50	20	300	3	30	15	40
229	7.0	5.0	1004000	10015.0		60	0.59998	90	20	400	5	20	15	100
230	5.0	5.0	1004000	10015.0		100	0.59998	70	20	400	4	20	15	100
231	5.0	5.0	1004000	10015.0		90	0.59998	90	20	400	3	20	15	100
232	5.0	5.0	1504000	150	7.0	50	0.59999	40	40	400	5	30	15	50
233	6.0	5.0	1004000	10020.0		100	0.59999	300	30	300	5	20	15	100
234	8.0	5.0	904000	10020.0		60	0.59999	80	20	400	5	20	15	100
235	8.0	5.0	1505000	10020.0		50	0.59999	90	20	400	5	30	12	100

236	6.0	5.0	1004000	10015.0	50	0.59998	50	20	400	4	20	15	100
237	9.0	5.0	1004000	10020.0	60	1.09999	50	20	400	4	20	12	100
238	6.0	5.0	1005000	10020.0	60	0.59998	100	20	400	5	20	10	100
239	5.0	5.0	904000	10015.0	50	0.59998	50	20	400	5	20	15	100
240	8.0	5.0	1505000	10020.0	60	0.59998	50	20	400	5	20	15	100
241	5.0	5.0	1004000	10020.0	60	0.59998	50	20	300	4	20	10	100
242	5.0	5.0	1004000	10020.0	80	0.59998	60	20	400	4	20	10	100
243	5.0	5.0	1503000	10010.0	90	0.59999	70	30	300	4	30	15	100
24410.0		5.0	1504000	10020.0	150	2.09999	300	30	200	5	30	20	200
245	8.0	5.0	1504000	10030.0	150	0.59999	300	40	200	5	20	20	400
246	8.0	5.0	1504000	15010.0	90	0.59999	200	30	200	5	30	15	200
24720.0		5.0	1504000	15020.0	100	2.09999	300	30	200	5	30	15	200
248	8.0	5.0	1503000	10020.0	100	0.59999	300	20	200	5	20	10	200
249	8.010.0		2004000	15020.0	100	0.59999	200	20	200	5	30	15	100
250	7.010.0		1505000	15020.0	100	0.59999	200	20	200	4	20	15	100
251	8.0	5.0	1004000	15020.0	100	0.59999	200	20	200	5	20	15	100
252	5.0	5.0	1004000	15010.0	100	0.59999	100	20	200	4	30	10	100
253	5.0	5.0	1004000	15010.0	100	0.59999	200	30	200	4	30	15	100
254	5.0	5.0	504000	150 5.0	50	0.59999	40	30	400	5	30	10	40
255	6.0	5.0	505000	15010.0	100	0.59999	50	30	500	4	30	15	90
256	6.0	2.5	505000	15015.0	50	0.59999	50	30	400	5	20	20	20
257	5.0	5.0	1004000	200 5.0	200	0.55000	30	302000		50	8	5	50
258	2.0	5.010002000		200 4.0	100	0.51000	40	401000		50	5	5	100
259	2.0	2.510004000		200 4.0	300	0.55000	60	402000		100	5	5	100
260	2.0	5.010004000		200 3.0	300	0.54000	40	402000		100	5	5	100
261	2.0	5.010002000		200 3.0	300	0.52000	40	301000		100	5	5	100
269	5.0	2.5	300 500	20 8.0	8	0.55000	20	30	400	1	20	20	200
270	5.0	2.5	300 500	20 6.0	5	0.58000	30	30	300	1	20	20	200
271	5.0	5.0	300 500	30 9.0	5	0.58000	3	40	200	1	20	20	200
272	2.0	2.5	3001500	15 5.0	7	0.55000	3	20	10	1	20	15	100
273	3.0	2.5	202000	50 5.0	50	0.55000	50	15	100	2	6	10	50
274	5.0	2.5	1005000	10020.0	100	1.09998	90	20	500	5	30	20	50
286	8.0	5.0	7001000	15020.0	50	0.59998	30	30	100	2	10	10	200
364	5.0	5.0	209999	40 2.5	100	0.55000	50	15	600	50	7	30	5
365	2.0	2.5	207000	30 2.5	30	0.54000	20	15	800	15	5	10	10
374	5.0	2.5	3002000	815.0	20	0.59998	3	30	20	20	20	20	200
384	2.010.0		209999	30 2.5	30	0.54000	30	10	400	5	7	10	7
396	1.0	5.0	209999	80 2.5	5	0.57000	5	20	400	3	15	20	15
424	5.0	5.0	505000	80 2.5	20	0.59998	10	20	400	3	20	10	10

```
 433 5.0 5.0 1005000 100 2.5  20 0.59998  20   20 200   2      20      10  20
 469 1.0 5.025002000 150 2.5 300 0.52000  50   202000  70       4       3  50
 538 1.0 5.0  204000  60 2.5  10 0.55000   3   152000  10      10       7  15
 551 6.0 2.5  201000  90 7.0  40 0.59998  30   30 100   2      20      10 200
 585 3.0 2.5 300 800  10 6.0   7 0.54000   3   30  15   1      20      20 200
 710 9.0 5.0 150 500  7010.0  50 0.59999  20   30 100   2      30      40 500
 711 5.0 2.5 100 500  50 9.0  30 0.59999  20   30 100   1      20      15 500
 712 8.0 2.5 100 800  5020.0  50 0.59999  50   30 100   1      30      101000
 71310.0 5.0  90 800  5040.0  70 0.59998  30   40 100   1      20      201000
 714 5.0 2.5 100 800  50 9.0  40 0.59999  50   20 100   1      20      20 500
 715 5.0 5.0 150 700  5015.0  60 0.59998  50   30  50   1      20      20 200
 716 5.0 2.5 100 800  5020.0  50 0.59998  40   20  50   1      20      10 200
 717 7.0 5.0 150 500  6020.0  60 0.59999  40   30 100   1      20      10 700
 718 7.0 5.0 150 400 10020.0  40 0.59999  40   30 100   1      20      10 600
171910.0 2.5 200 400  9010.0  40 0.59999  20   30 100   1      30      20 500
271910.0 2.5 200 500 10010.0  30 0.59999  40   30 100   1      20      15 500
 72010.0 5.0 200 400 10010.0  50 0.59998  30   40 100   1      30      15 800
 795 5.0 2.5 9001000 100 8.0  30 0.55000  10   40 200   1      10      10 500
 896 1.0 5.0  20 200  15 2.5   2 0.52000  50    8  20   3       2      10   3
 897 3.0 5.0 3001500 100 2.5  15 0.59998  50   20 600   5      20      20   5
 898 2.0 5.0 3002000 100 2.5  20 0.59999  30   20 800   5      15      40   5
 899 2.0 5.0 3002000 150 2.5  30 0.59998  20   20 300   5      20      20  10
 900 6.0 5.0 3001500 100 2.5  40 0.59999  20   20 500   7      20      15 100
 901 2.0 2.5 3001000  90 2.5  30 0.55000  15   20 400   5      20      15  40
 902 2.0 2.5 4001000 100 2.5  30 0.55000  30   20 200   5      20      50  15
 903 2.0 2.5 3001000 150 2.5  40 0.55000  20   20 500   5      20      20  10
 904 1.0 5.0 4001500 150 2.5  15 1.07000  10   20 500   5      20      40   5
 905 1.0 5.0 3002000 150 2.5  15 1.05000   3   20 500  10      20      50   2
 906 1.0 2.5 3001500 100 2.5  30 0.54000   3   20 500  15      20      40   3
 907 2.0 5.0 100 800  40 2.5  20 0.52000  30   20 200  40      10      30   2
 908 1.0 2.5 2001000  70 2.5  10 0.53000  20   20 200  15      15      40   2
 909 1.0 2.5 3001000  80 2.5  10 0.54000  10   10 200  15      20      50   5
 910 1.0 2.5 200 600  50 2.5  10 0.54000   5   10 200  10      10      30   3
 911 1.0 2.5 1001500  60 2.5  10 0.52000   5   10 300  20      10      40   2
 912 1.0 2.5 1001500  60 2.5  15 0.58000   8   15 500  20      15      30   2
 913 2.0 5.0  202000  50 2.5  30 0.56000  40   20 500  90       8      20   5
 914 2.0 2.5  201000  30 2.5  20 0.58000  60   15 500  70      10      15   5
 915 2.0 2.5  202000  50 2.5  20 0.52000  20   20 800  20       8      10   5
 916 2.0 2.5  201500  50 2.5  20 0.54000  20   201000  10      10      10   5
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917 2.0 2.5  204000  40 2.5  30 2.04000  70  201000  20       10       10   5
918 1.0 5.0  205000  70 2.5  30 1.08000  20  201500  50       10        8   5
919 0.5 5.0  204000  60 2.5  30 0.55000  20  152000  50       10        7   5
920 0.5 2.5  205000  60 2.5  30 2.08000  20  204000  40       10       10   5
921 2.0 2.5  206000  40 2.5  40 0.52000 100  15 500  20        7        8   5
922 4.0 5.0  208000  50 2.5  90 0.55000 150  151000  20        6        8   8
923 5.0 5.0  209999  50 2.5 150 1.06000 200  151000  40       10       10   7
924 5.0 5.0  209998  50 2.5 100 1.05000  90  15 800  20       10       10   8
925 5.0 2.5  209998  40 2.5 100 1.09998  80  152000  60        8       10  10
927 4.0 5.0  207000  40 2.5  60 1.05000  50  101000  20        8       10   5
928 5.0 5.0  208000  50 2.5  60 0.55000  50  151000  20        8       10   5
929 3.0 2.5  205000  50 2.5  30 0.56000  40  15 500  10       10       10   5
930 1.0 2.5  204000  40 2.5  10 0.54000  40  15 600  10       10       10   3
931 2.0 2.5  201500  40 2.5  20 2.05000  30  15 500  15        8       10   4
932 2.0 5.0  609999  40 2.5  50 0.54000  50  20 900  10        8       10   5
933 3.0 2.5  509999  30 2.5  80 0.55000  60  15 500  15        5       10   5
947 2.0 2.5 1501500  80 2.5  30 4.05000  40  15 150  10       10       10   4
948 3.0 2.5 1003000  50 2.5  20 4.05000  80  15 300   7       15       15   5
949 2.0 2.5  702000  50 2.5  40 5.05000  90  20 300  10       10       20   5
950 2.0 2.5  503000  40 2.5  15 5.09999  50  15 500  15       10       10   5
951 5.0 2.5  502000  50 2.5  15 2.09998 100  15 400  15       15       20   5
952 7.0 2.5  203000  40 2.5  20 2.09999 100  20 500  15       10       15   2
953 5.0 5.0  206000  40 5.0  20 4.09998 100  15 300  10       10       20  10
954 7.0 2.5  202000  40 2.5  20 3.09998  90  15 400  15       10       20   5
955 5.0 2.5  202000  40 2.5  20 0.57000  90  20 200  15       10        8   5
956 0.5 2.5  20 800  20 2.5   5 0.51000  30  10 300  10        5        2   5
957 0.5 2.5  20 500  20 2.5   8 0.51000  30  10 400  10        5        2   3
958 1.0 2.5  20 400  20 2.5   8 5.01000  30  10 400   5        5        2   3
960 1.0 2.5 100 800  40 2.5   7 3.05000  60  20 400  15        8        2   3
961 3.0 2.5 1001000  70 2.5   9 4.03000  80  20 400  10       10        2   4
962 0.5 2.5 100 200  30 2.5  15 6.06000  40  15  70   7        3        2   2
963 1.0 2.5 100 150  30 2.5   5 5.05000  60  10  50   8        2        5   2
964 1.0 2.5 100 400  40 2.5   2 5.06000  50  15 120   8        6        8   3
965 3.0 2.5 1009998  50 2.5  20 2.05000  40  30 400  15        7       10   5
966 1.0 5.0 100 600  20 2.5   5 1.02000  35  15 300  15        3        5   2
967 0.5 2.5 100 500  50 2.5   2 1.02000  10  15 600   7        4        2   4
96810.0 5.0 1002000  50 2.5   2 0.55000 100  15 500  30        7        2   3
96920.0 5.0 1007000  80 2.5   2 0.55000 100  203000  60        7        7   2
97015.0 5.0 1501000 18030.0  50 0.59999  50  30  80   3       15       15 400
```

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    97110.0 5.0  201000 100 5.0  30 0.57000  30  20  90   3      15      15  20
    97210.0 5.0   20 800 10010.0  50 0.58000  40  20  80   4      15      10  40
    97310.0 5.0  201000 10010.0  80 0.58000  40  15 100   3      15      10  50
    97410.0 5.0  201000 15020.0 100 0.57000  40  15 100   3      20      15 100
    989 5.0 5.0 1003000 100 3.0  10 0.57000  40  20 300   3      30      10 100
    990 5.0 5.0 1003000 100 5.0  15 0.57000  30  20 300   3      30      10 100
    991 1.0 5.0 1002000  80 2.5  15 0.54000  10  15 700  10      15       5   8
   1001 8.0 5.0  501500 10010.0  30 0.57000  20  20 100   1      20      10 100
   100810.0 5.0 1001500 150 8.0  30 0.57000  30  20 150   1      30      10 150
   1024 1.0 5.0  20 400  40 2.5  20 0.53000  10  10 800  20       5       5  10
   1051 1.0 5.0  50 600 150 2.5  10 0.53000   3  15 500  10      10      20   5
   1052 2.0 5.0  401000 200 2.5  10 2.06000   3  15 700  15      15      15   5
   1053 2.010.0  501000 300 2.5  15 2.09998   3  151000  15      20      20   5
   1068 2.010.0 4001500 300 5.0 500 2.0 900 100  201000 100      10      10  80
   1078 1.010.01000 500 300 2.5 100 0.5 800  50  301000  50       5       8 100
   1079 2.010.0 7003000 800 2.5 400 0.55000 100  202000  50      10      10  50
   1082 6.0 5.0 5003000 200 8.0 300 0.56000  50  201000 100      20      10 100
   1092 5.010.0 7005000 200 7.0 100 1.04000  50  20 500  20      15      10 150
   1093 5.010.0 5009999 300 4.0  90 2.09998  50  15 500   3      30      10  20
   1097 7.010.0 3003000 150 5.0 150 0.59998  40  201000  60      20      15 100
```

* BLANK = NOT DETECTED
** 9998 = 10,000
9999 = >10,000

PART II

HNO3/HCLO4 EXTRACTABLE ZN CONTENT OF SELECTED SAMPLES DETERMINED BY ATOMIC-ABSORPTION SPECTROPHOTOMETRY

ID NO			ZN(PPM)
124	0	0	43.119
128	0	0	14.277
132	0	0	17.161
136	0	0	6.489
140	0	0	1.875

144	0	0	8.220
156	0	0	2.452
160	0	0	2.019
164	0	0	2.163
168	0	0	39.513
171	0	0	149.978
174	0	0	12.546
178	0	0	7.932
182	0	0	4.903
186	0	0	8.220
190	0	0	13.123
194	0	0	15.430
209	0	0	56.530
213	0	0	21.487
217	0	0	37.350
221	0	0	122.578
225	0	0	157.188
229	0	0	197.567
233	0	0	186.030
237	0	0	148.765
241	0	0	100.726
245	0	0	113.123
249	0	0	94.702
253	0	0	178.208
257	0	0	199.903
261	0	0	168.910
269	0	0	5.269
900	0	0	50.828
904	0	0	2.634
908	0	0	1.550
912	0	0	1.550
916	0	0	1.395
920	0	0	2.015
924	0	0	66.324
928	0	0	45.404
932	0	0	113.123
948	0	0	6.354
952	0	0	6.973
956	0	0	2.634

473				
474				
475				
476				
477				
478				
479				
480				
481				
482				
483	960	0	0	3.564
484	964	0	0	2.015
485	968	0	0	9.918
486	972	0	0	91.429

END OF FILE

$SIGNOFF

CNTR XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

RFS NO. 023793 UNIVERSITY OF B C COMPUTING CENTRE MTS(AN192) 01:39:28 THU MAY 04/72

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$SIGNON AWKF PRIO=L COPIES=2
**LAST SIGNON WAS: 01:38:38   THU MAY 04/72
 USER "AWKF" SIGNED ON AT  01:39:31 ON THU MAY 04/72
$LIST *SOURCE*
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APPENDIX B

RESULTS OF ATOMIC-ABSORPTION ANALYSIS OF SOIL MATERIAL

MACMILLAN PASS AREA

HNO3/HCLO4 EXTRACTABLE METAL CONTENT

PPM

C=CLASSIFICATION 1 REGOSOL
2 BRUNISOL
3 ORGANIC
4 GLEYSOL

S = SOIL SITE NUMBER

ID NO			CU	FE	MN	ZN	MO	PH	C	S
7	0	0	14.128	0.547	20.754	29.432	1.2	4.0	1	2
9	0	0	53.687	2.108	87.167	117.128	4.0	4.6	1	2
12	0	0	5.415	0.261	21.858	11.311	0.4	4.1	2	3
13	0	0	32.487	0.730	21.858	131.891	12.0	3.8	2	3
14	0	0	33.570	2.711	77.814	99.767	12.0	3.7	2	3
15	0	0	48.035	2.468	147.353	186.204	10.4	4.5	2	3
23	0	0	50.861	2.889	213.766	198.217	8.8	4.5	2	4
31	0	0	67.815	0.984	6.226	12.013	2.4	4.2	1	5
36	0	0	21.192	1.000	45.659	78.085	7.2	4.2	1	6
42	0	0	77.704	4.217	233.482	285.312	3.2	4.5	1	7
51	0	0	39.559	1.952	35.282	87.696	9.6	4.8	2	8
55	0	0	56.512	3.014	31.131	285.312	18.4	4.5	4	9
65	0	0	28.256	2.108	53.960	117.128	5.2	4.9	4	11
70	0	0	45.210	3.670	210.653	336.368	6.0	5.5	4	12
75	0	0	26.843	1.952	195.087	160.676	3.2	5.0	1	13
80	0	0	7.064	0.937	36.319	69.076	1.2	4.3	1	14
85	0	0	31.082	3.280	378.760	267.292	2.8	4.5	1	15
91	0	0	42.384	4.061	97.544	426.467	8.8	5.4	4	16
96	0	0	6.497	0.483	28.852	10.633	0.2	3.9	2	17
97	0	0	17.327	1.077	32.350	28.731	1.6	4.1	2	17
98	0	0	15.161	2.092	56.831	58.593	2.4	4.1	2	17
99	0	0	14.128	2.218	65.375	72.079	2.8	4.7	2	17

107	0	0	16.954	1.874	89.242	96.706	2.4	4.3	2	18
110	0	0	19.779	1.843	157.730	180.197	2.4	4.6	4	19
114	0	0	18.366	1.015	44.621	57.062	1.6	4.4	1	20
266	0	0	55.228	2.364	245.683	726.193	33.0	5.8	1	22
278	0	0	38.433	1.410	152.032	213.942	2.8	4.8	1	23
283	0	0	68.512	2.850	95.374	177.415	2.8	4.4	1	24
297	0	0	55.144	2.625	254.961	152.629	2.0	5.4	4	27
301	0	0	25.065	2.220	228.521	70.966	1.2	4.6	1	28
307	0	0	25.065	3.451	264.404	129.580	2.8	5.5	4	29
312	0	0	15.161	1.003	126.776	37.780	0.8	4.9	2	30
313	0	0	27.073	3.355	450.273	116.055	2.8	4.5	2	30
314	0	0	28.156	4.122	830.601	187.769	2.0	4.6	2	30
315	0	0	31.749	3.000	434.379	250.469	3.6	4.8	2	30
324	0	0	33.420	3.781	290.845	195.679	2.6	5.5	4	31
328	0	0	41.775	3.376	307.842	140.889	5.2	4.8	1	32
334	0	0	25.065	2.250	481.594	86.099	7.2	4.4	1	33
366	0	0	23.233	2.316	221.762	79.557	7.0	4.1	2	35
368	0	0	1.671	1.380	316.341	22.699	0.8	4.6	2	35
3671	0	0	5.415	1.770	292.896	37.328	0.2	4.6	2	35
3672	0	0	4.332	1.349	298.142	29.183	0.4	4.4	2	35
375	0	0	18.342	0.528	90.004	102.221	3.4	3.9	1	36
376	0	0	15.039	0.675	15.109	33.918	15.2	4.2	1	36
401	0	0	15.039	1.830	14.165	44.354	22.0	4.1	1	38
406	0	0	5.415	0.272	20.109	7.466	0.2	4.0	1	39
407	0	0	10.829	1.275	11.366	32.577	16.8	4.2	1	39
408	0	0	16.710	2.130	15.109	39.136	22.0	4.0	1	39
419	0	0	18.342	0.528	84.436	71.295	1.4	3.2	1	41
420	0	0	24.907	0.817	14.863	36.423	6.0	3.5	1	41
421	0	0	31.749	1.275	15.109	35.222	12.8	3.8	1	41
430	0	0	91.906	3.631	56.658	114.798	7.2	4.0	1	42
440	0	0	78.538	4.321	1180.376	477.456	10.0	5.0	4	43
441	0	0	58.486	4.276	1888.602	433.102	14.8	6.2	4	43
455	0	0	86.751	4.217	410.278	393.651	6.8	5.5	2	45
461	0	0	42.797	1.165	270.011	304.537	19.0	6.6	1	46
470	0	0	31.792	0.718	231.040	344.670	13.0	5.5	1	47
476	0	0	55.025	0.367	416.615	729.473	14.0	4.2	2	48
477	0	0	94.213	2.265	210.710	567.833	16.8	5.3	2	48
478	0	0	44.359	1.349	278.907	210.392	13.6	5.5	2	48
479	0	0	10.829	0.323	28.852	24.206	1.2	5.9	2	48

480	0	0	80.135	2.736	163.497	495.440	14.0	5.9	2	48
500	0	0	57.368	3.342	464.530	276.190	8.0	4.1	2	49
505	0	0	56.248	1.909	119.696	290.373	9.0	4.4	1	50
506	0	0	72.759	3.027	462.270	571.429	14.8	4.4	1	50
507	0	0	55.228	2.587	173.989	291.834	15.2	3.8	1	50
526	0	0	30.783	2.117	73.466	126.984	14.0	4.0	1	52
527	0	0	34.980	2.677	77.987	148.571	26.0	3.8	1	52
533	0	0	40.352	8.125	140.109	92.305	24.0	3.8	1	53
534	0	0	25.186	3.657	23.735	49.206	22.0	4.3	1	53
535	0	0	13.296	1.052	13.115	23.754	6.4	4.7	1	53
548	0	0	12.593	1.295	57.642	33.016	2.4	5.0	1	54
561	0	0	46.174	2.808	2695.631	242.857	2.4	5.0	1	55
570	0	0	30.783	3.902	161.625	93.651	2.8	3.9	2	56
577	0	0	14.692	2.493	411.974	36.190	4.2	4.0	1	57
578	0	0	15.391	2.957	134.499	47.937	3.6	3.8	1	57
587	0	0	8.395	3.700	272.954	65.714	2.4	4.4	1	58
601	0	0	39.178	1.837	91.550	132.698	7.2	4.3	2	59
620	0	0	43.376	4.217	552.689	123.810	1.3	4.4	1	61
628	0	0	50.134	1.368	499.195	156.990	1.0	4.3	1	62
629	0	0	16.244	0.805	63.825	25.564	0.4	4.6	1	62
630	0	0	34.673	4.299	1034.343	106.104	1.6	4.3	1	62
653	0	0	31.783	3.894	1221.100	98.131	0.2	4.1	1	63
661	0	0	12.228	0.488	379.500	58.311	0.2	4.3	1	64
662	0	0	23.115	4.060	475.511	104.264	0.2	4.8	1	64
672	0	0	24.560	4.115	258.586	113.771	0.8	4.0	1	165
680	0	0	36.117	3.968	373.513	114.998	1.6	4.2	4	265
684	0	0	64.807	6.487	2143.385	153.449	1.0	4.6	1	66
685	0	0	37.562	4.721	890.684	111.624	0.2	4.3	1	66
695	0	0	30.339	3.674	876.319	93.838	0.4	3.9	1	67
724	0	0	43.341	6.429	948.148	171.730	0.2	5.1	1	68
730	0	0	13.002	2.094	238.474	51.212	0.8	4.5	1	69
741	0	0	41.896	4.886	876.319	143.517	0.4	5.7	1	70
752	0	0	23.115	3.766	511.425	117.451	0.4	5.0	1	71
768	0	0	28.124	0.501	8443.633	498.119	0.4	4.8	1	72
769	0	0	18.409	0.459	222.951	16.741	0.4	5.0	1	72
770	0	0	33.228	2.517	135.039	129.717	2.8	4.5	1	72
785	0	0	7.580	0.212	43.716	5.656	0.2	6.9	1	74
786	0	0	11.558	2.094	415.174	77.892	0.8	7.1	1	74
798	0	0	18.781	1.837	317.486	76.972	1.6	4.6	1	75

173											
174											
175											
176											
177											
178											
179											
180											
181											
182											
183	806	0	0	24.455	0.731	1660.892	181.778	0.4	5.2	1	76
184	807	0	0	6.497	0.301	23.607	8.370	0.2	4.8	1	76
185	842	0	0	52.009	0.107	21692.480	10303.777	760.0	4.9	1	77
186	852	0	0	21.670	1.727	2758.250	1272.639	8.0	7.0	1	78
187	869	0	0	52.009	3.233	861.953	254.528	2.0	6.4	1	80
188	880	0	0	25.600	3.780	12.661	102.365	0.4	4.4	1	81
189	883	0	0	21.333	3.672	115.213	86.526	6.8	4.4	1	81
190	893	0	0	44.089	2.412	554.541	2522.456	24.0	7.2	1	85
191	994	0	0	22.756	5.381	153.195	92.979	6.8	4.5	1	87
192	1011	0	0	21.333	5.201	30.386	268.378	8.0	4.5	4	88
193	1018	0	0	24.178	4.031	63.304	78.900	10.0	3.9	1	89
194	1031	0	0	14.222	1.944	16.459	41.357	11.2	3.9	1	90
195	1041	0	0	18.342	2.207	95.571	56.894	6.0	4.2	1	91
196	1042	0	0	15.644	3.258	44.313	34.317	16.0	4.3	1	91
197	1058	0	0	59.733	2.700	87.359	140.495	8.8	4.0	1	292
198	1064	0	0	103.936	1.314	294.135	1069.420	18.0	5.6	1	93
199	1085	0	0	48.356	1.818	29.120	454.629	14.0	6.0	1	94
200	1101	0	0	19.564	0.582	50.105	361.195	2.4	7.4	3	95
201	1117	0	0	41.244	3.995	179.783	109.991	1.2	4.3	1	96
202	1124	0	0	50.134	0.528	2495.977	568.941	18.0	5.4	1	97
203	1125	0	0	72.533	4.085	387.419	475.160	24.0	5.4	1	97
204	1171	0	0	36.978	1.998	81.029	193.584	8.0	4.8	1	98
205	1172	0	0	45.511	2.196	138.002	178.918	7.2	4.5	1	98
206	1173	0	0	41.244	2.610	172.186	258.112	6.8	4.8	1	98
207	1174	0	0	42.394	2.138	73.031	195.951	6.4	4.8	1	98
208	1175	0	0	45.318	2.343	155.191	173.827	4.8	4.7	1	98
209	1176	0	0	52.627	2.412	149.974	176.988	5.2	4.5	1	98
210	1177	0	0	51.165	2.206	139.542	183.309	5.6	4.7	1	98
211	1178	0	0	51.165	2.343	147.366	180.148	4.0	5.0	1	98
212	1179	0	0	51.165	2.309	163.016	167.506	3.2	4.6	1	98
213	1180	0	0	49.703	2.412	155.191	180.148	4.0	4.8	1	98

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 USER "AWKF" SIGNED ON AT  01:38:38 ON THU MAY 04/72
$LIST *SOURCE*
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APPENDIX C

RESULTS OF ATOMIC-ABSORPTION ANALYSIS OF PLANT MATERIAL

MACMILLAN PASS AREA

HNO3/HCLO4 EXTRACTABLE METAL CONTENT

EXPRESSED AS P.P.M. DRY WEIGHT

ID NO	CU	FE	MN	ZN	MO	SPP	SITE

SITE = SOIL SITE NUMBER

SPP= SPECIES ABBREVIATION

TREES
- ABL = ABIES LASIOCARPA
- PIG = PICEA GLAUCA
- POT = POPULUS TREMULOIDES

SHRUBS
- BEG = BETULA GLANDULOSA
- SAA = SALIX ALAXENSIS
- SAP = SALIX PHYLICIFOLIA
- CAT = CASSIOPE TETRAGONA
- EMN = EMPETRUM NIGRUM
- POF = POTENTILLA FABELLIFORMIS
- DYI = DRYAS INTEGRIFOLIA

FORBES
- LUA = LUPINUS ARCTICUS
- EPL = EPILOBIUM LATIFOLIUM
- EPA = EPILOBIUM ANGUSTIFOLIUM
- VAS = VALARIAN STICHENSIS
- VEV = VERATRUM VIRIDE
- SET = SENECIO TRIANGULARIS
- PCA = POLYGONUM ALASKANUM

GRASSES
- CAA = CAREX AQUATALIS
- FEA = FESTUCA ALTAICA
- CAC = CALAMAGROSTIS CANADENSIS
- CAM = CAREX MICROCHAETA
- DEC = DECHAMPSIA CAESPITOSA

LICHENS
- CLA = CLADONIA ALPESTRIS

CEN = CETRARIA NIVALIS
ALX = ALECTORIA
UMX = UMBILICARIA
STX = STEREOCAULON

3	0	0	10.805	81.344	104.559	67.057	0.6	CAA	1
4	C	0	10.805	88.824	218.674	243.435		SAA	1
7	0	0	10.084	60.774	190.567	307.654		BEG	1
10	0	0	10.805	73.864	387.879	110.516		BEG	2
11	0	0	3.602	169.233	16.864	11.500		CLA	2
17	0	0	10.805	69.189	241.160	140.386		BEG	3
18	0	0	3.602	202.893	21.924	12.993		CLA	3
24	0	0	10.805	80.409	421.607	134.412		BEG	4
25	0	0	3.602	155.208	27.545	12.694		CLA	4
32	0	0	7.923	89.759	213.052	97.075		BEG	5
33	0	0	3.602	143.053	17.426	22.253		CLA	5
37	0	0	3.602	103.784	82.635	11.201		CLA	6
38	0	0	10.084	100.044	1101.801	141.879		BEG	6
43	0	0	4.322	131.833	54.528	17.025		CLA	7
44	0	C	7.923	65.449	803.865	141.879		BEG	7
52	0	0	3.602	107.524	82.635	14.039		CLA	8
53	0	0	6.983	88.928	653.920	162.902		BEG	8
56	0	0	11.173	95.551	115.893	64.459		CAC	9
57	0	0	6.285	87.982	240.202	279.462		SAA	9
58	0	0	6.983	88.928	157.329	228.906		BEG	9
62	0	0	3.492	105.011	102.944	17.273		CLA	10
63	0	C	6.983	103.119	1754.578	167.115		BEG	10
66	0	0	9.776	74.738	219.484	237.332		BEG	11
67	0	0	6.983	65.277	159.919	164.307		SAA	11
72	0	C	6.983	69.061	77.046	136.220		SAA	12
76	0	C	2.793	87.982	156.034	17.835		CLA	13
77	0	C	7.681	62.439	1638.038	174.137		BEG	13
78	0	0	8.380	48.248	407.891	53.224		ABL	13
81	0	0	3.492	72.846	49.206	12.499		CLA	14
82	0	0	6.893	56.868	610.800	259.313		BEG	14
83	0	0	5.586	69.061	427.314	63.054		ABL	14
86	0	0	6.983	82.306	213.010	209.245		SAA	15
87	0	0	7.681	74.738	1599.191	265.418		BEG	15

88	0	0	9.776	47.302	420.840	57.437		ABL	15
92	0	0	5.586	116.364	284.229	167.115		SAA	16
93	0	0	6.983	80.414	524.431	265.418		BEG	16
108	0	0	3.446	97.888	55.186	15.532		CLA	18
109	0	0	6.893	131.449	830.473	162.071		BEG	18
111	0	0	4.825	97.888	280.218	168.824		SAA	19
112	0	0	6.893	81.107	1189.452	226.899		BEG	19
116	0	0	6.893	90.430	1393.052	202.589		BEG	20
117	0	0	5.514	103.481	407.200	110.748	0.4	SAA	20
121	0	0	8.644	86.954	494.686	235.968		SAA	21
122	0	0	7.923	69.189	1349.144	171.749		BEG	21
123	0	0	5.042	28.985	1068.073	44.057		PIG	21
267	0	0	13.786	2004.371	67.509	108.047	4.5	CAA	22
268	0	0	9.650	1165.332	35.362	45.785	3.5	VAS	22
279	0	0	4.136	90.430	68.045	14.181		CLA	23
280	0	0	6.893	58.733	1553.789	175.577		BEG	23
284	0	0	6.893	77.378	107.694	114.800	0.3	SAA	24
285	0	0	6.893	71.784	546.505	129.657		BEG	24
289	0	0	6.204	84.836	921.558	164.772		BEG	25
290	0	0	2.757	66.191	80.368	11.480		CLA	25
294	0	0	6.204	116.533	600.084	110.748		SAA	26
295	0	0	6.893	92.294	1264.463	189.083		BEG	26
298	0	0	6.893	92.294	632.231	151.266		SAA	27
299	0	0	6.893	105.346	1098.368	229.600		BEG	27
302	0	0	3.446	81.107	73.403	11.210		CLA	28
303	0	0	6.893	88.565	269.502	73.607		BEG	28
308	0	0	9.112	68.073	915.033	178.119		BEG	29
309	0	0	7.290	70.305	643.137	130.518		SAA	29
310	0	0	2.430	90.392	58.562	14.587		CLA	29
311	0	0	10.327	236.583	204.967	50.518	1.0	CAA	29
316	0	0	4.252	68.073	294.379	31.171	0.6	FEA	30
317	0	0	7.290	65.841	773.856	153.551		BEG	30
318	0	0	7.290	179.669	34.510	72.476	0.6	EPL	130
322	0	0	6.075	63.609	56.993	36.084	0.5	POF	230
325	0	0	6.682	65.841	449.673	176.583		SAA	31
326	0	0	6.682	79.233	141.699	41.766	1.2	CAA	31
329	0	0	3.645	47.986	637.908	12.438		EMN	32
330	0	0	0.607	85.929	33.987	11.516		CLA	32
331	0	0	5.467	50.218	496.732	153.551		BEG	32

335	0	0	7.290	61.378	784.314	168.906		BEG	33
336	0	0	0.607	85.929	43.399	15.048		CLA	33
1337	0	0	3.645	43.522	250.458	33.628	0.4	FEA	33
2337	0	0	7.897	70.305	136.471	65.873	1.4	CAA	33
338	0	0	8.505	1450.742	690.196	191.939		SAA	33
340	0	0	4.900	66.657	435.020	30.369	0.6	FEA	3
342	0	0	7.290	248.858	286.536	43.762	2.8	CAA	33
347	0	0	12.150	113.465	102.901	69.333		CAC	10
348	0	0	6.682	49.700	100.179	63.852	1.4	CAC	12
349	0	0	11.542	42.198	21.234	49.185		SET	12
350	0	0	9.720	53.451	50.634	53.481	0.6	EPA	12
351	0	0	3.645	27.194	1143.344	47.852		PIG	13
352	0	0	3.037	25.319	936.453	36.889		PIG	14
353	0	0	6.075	70.330	301.081	207.407		SAA	14
354	0	0	4.860	34.696	256.436	72.741		PIG	15
355	0	0	7.290	137.846	103.990	100.741		EPA	15
356	0	0	9.720	152.850	451.893	53.481	2.8	CAA	16
357	0	0	7.962	76.317	248.245	39.652	0.4	CAC	16
360	0	0	9.112	75.956	150.812	59.556	2.6	POA	34
361	0	0	5.467	162.227	173.679	17.630	0.8	CAT	34
362	0	0	6.075	68.454	157.346	12.741	1.2	EMN	34
363	0	0	7.349	74.385	261.485	58.483	2.0	FEA	34
370	0	0	4.860	797.070	8.711	23.556	0.8	UMX	35
371	0	0	1.822	209.114	31.034	14.074		CLA	35
372	0	0	6.682	59.077	306.525	214.815		BEG	35
373	0	0	5.467	77.831	256.436	28.000		CAT	35
379	0	0	3.645	468.865	7.078	20.593	1.0	UMX	36
380	0	0	2.574	148.027	40.233	14.243		CLA	36
381	0	0	7.722	57.082	275.669	194.343		BEG	36
382	0	0	6.435	70.627	256.795	26.489		CAT	36
383	0	0	7.722	64.822	299.511	67.221	0.7	POA	36
389	0	0	2.574	117.067	110.765	13.710		CLA	37
390	0	0	6.435	59.017	794.723	15.042	0.6	EMN	37
391	0	0	3.861	41.602	521.537	36.339	1.4	ABL	37
392	0	0	5.792	51.277	71.028	36.073	0.6	CAC	37
393	0	0	6.435	62.887	208.118	130.449	0.6	SAP	37
394	0	0	9.010	63.855	620.877	215.641		BEG	37
395	0	0	5.792	49.342	86.923	62.695	2.6	POA	37
402	0	0	2.574	109.327	44.206	11.181		CLA	38

403	0	0	5.792	47.407	720.217	158.403		BEG	38
404	0	0	6.435	51.277	417.229	18.502	0.8	EMN	38
405	0	0	3.861	66.757	745.052	42.463		ABL	38
409	0	0	5.148	57.082	461.933	127.787		BEG	39
1410	0	0	2.574	97.717	44.206	14.509		CLA	39
2410	0	0	10.297	1596.373	30.299	24.093	0.8	UMX	39
415	0	0	7.079	52.245	69.042	295.507		BEG	40
416	0	0	5.148	73.530	224.013	266.223		SAP	40
417	0	0	5.102	99.065	28.104	225.216	0.3	SAA	40
425	0	0	2.551	118.682	72.048	8.705		CLA	41
426	0	0	8.291	59.831	268.264	172.712		BEG	41
427	0	0	7.015	1275.096	7.665	20.311	0.3	UMX	41
428	0	0	5.740	89.257	194.683	19.482		CAT	41
434	0	0	3.827	124.567	277.461	103.627		SAA	42
435	0	0	3.827	79.448	602.954	16.995		EMN	42
436	0	0	5.740	67.678	510.978	168.566		BEG	42
437	0	0	3.827	104.950	367.904	22.798		CAT	42
438	0	0	1.913	165.763	50.587	8.428		CLA	42
443	0	0	3.189	25.502	613.174	56.788		ABL	43
444	0	0	3.189	25.502	65.916	72.262		PIG	43
445	0	0	6.378	48.061	80.224	165.803		SAA	43
446	0	0	3.827	61.793	36.279	24.594	0.6	CAT	43
450	0	0	2.551	53.946	210.012	172.712	0.3	BEG	44
451	0	0	1.913	83.372	174.244	96.718		SAA	44
452	0	0	2.551	57.870	163.002	25.838		CAA	44
458	0	0	3.189	104.950	203.880	165.803	0.5	SAA	45
459	0	0	1.913	81.410	73.070	15.889		CLA	45
460	0	0	4.464	44.138	510.978	149.223		BEG	45
464	0	0	6.175	97.270	72.759	27.527	14.0	EPL	46
465	0	0	4.322	42.179	27.342	42.743	52.0	FEA	46
466	0	0	9.262	63.699	38.465	331.988	12.0	SAA	46
467	0	0	5.557	49.065	55.148	24.207	14.0	LUA	46
468	0	0	6.175	62.838	19.928	25.314	12.0	CAT	46
474	0	0	6.175	55.091	12.513	26.697	17.0	EPL	47
475	0	0	4.322	50.787	19.928	29.464	1.8	DYI	47
486	0	0	9.262	62.838	57.466	307.089	1.0	SAA	48
487	0	0	19.141	63.699	38.465	75.112	2.8	VEV	48
488	0	0	6.792	42.179	28.269	43.020	9.0	EPA	48
489	0	0	10.497	56.812	25.952	75.666	5.0	SET	48

490	0	0	6.792	59.395	19.928	36.104	1.6	VAS	48
491	0	0	5.557	52.508	71.832	73.729	12.0	FEA	48
492	0	0	6.792	54.230	43.099	89.914	2.4	CAA	48
494	0	0	12.349	49.065	285.938	196.426	2.4	CAC	48
503	0	0	2.470	93.827	64.417	21.164		CLA	49
504	0	0	5.557	76.611	260.912	131.412		SAA	49
509	0	0	3.705	37.014	625.634	64.876		ABL	50
510	0	0	1.235	71.446	88.516	23.654		CLA	50
511	0	0	6.792	54.230	194.178	74.006	4.5	EPL	50
521	0	0	5.929	41.167	39.399	42.728	0.3	CAA	51
522	0	0	6.522	81.376	55.815	181.050	0.5	SAA	51
529	0	0	7.114	54.570	600.366	13.470	0.8	EMN	52
530	0	0	5.336	64.144	483.107	18.974	0.6	CAT	52
531	0	0	6.522	46.911	544.082	112.975		BEG	52
1532	0	0	1.186	96.694	34.709	9.704		LUA	46
2532	0	0	8.893	60.314	89.586	32.299	2.4	CLA	52
542	0	0	6.522	75.632	183.393	48.232	0.3	FEA	53
543	0	0	2.371	175.198	23.921	20.422		CLA	53
544	0	0	11.857	50.740	375.229	47.942	0.7	CAC	53
545	0	0	15.415	73.717	95.214	54.894	0.5	SET	53
546	0	0	5.929	113.927	61.444	20.133		CAT	53
552	0	0	2.371	123.500	52.063	16.657		CLA	54
553	0	0	5.929	1072.251	8.912	17.815		ALX	54
554	0	0	15.415	299.656	205.907	27.375	0.3	CAT	54
555	0	0	6.522	89.035	254.687	56.343		FEA	54
564	0	0	7.114	56.485	187.146	105.733		FEA	55
565	0	0	14.822	69.888	154.313	115.872		SET	55
572	0	0	1.186	108.182	22.045	13.180		CLA	56
574	0	0	5.032	60.952	178.801	32.275		FEA	56
581	0	0	5.920	62.828	223.168	33.499		CAT	57
582	0	0	3.848	27.194	532.409	33.499		ABL	57
583	0	0	5.032	42.198	479.168	16.367		EMN	57
584	0	0	2.664	96.586	81.192	20.650		CLA	57
589	0	0	8.585	62.828	137.095	22.792	0.4	SET	58
590	0	0	5.920	60.952	268.423	31.969	1.2	FEA	58
591	0	0	6.809	92.835	976.083	120.841		SAP	58
592	0	0	10.657	62.828	105.151	28.910	1.2	LUA	58
593	0	0	4.736	32.821	319.445	28.910	0.4	ABL	58
594	0	0	7.993	70.330	228.492	32.581	0.4	CAC	58

604	0	0	7.105	68.454	621.144	229.445		BEG	59
605	0	0	2.368	83.458	31.501	8.719		CLA	59
606	0	0	2.664	81.582	101.601	14.532		CEN	59
607	0	0	3.256	218.491	32.388	19.732		STX	59
608	0	0	2.960	79.707	31.501	6.577		ALX	59
612	0	0	7.697	70.330	213.407	73.576		CAM	160
613	0	0	3.848	74.081	255.113	46.042		ERA	160
614	0	0	9.177	87.209	240.915	62.868	0.8	CAC	160
615	0	0	4.736	135.971	319.445	160.612		SAP	160
616	0	0	6.203	59.831	231.868	179.426		BEG	160
618	0	0	5.075	138.299	294.900	114.833		SAA	260
622	0	0	14.661	2550.193	231.868	27.416		CAT	61
623	0	0	8.458	63.755	495.251	132.057		BEG	61
624	0	0	8.458	83.372	652.832	186.603		SAA	61
625	0	0	2.819	392.337	64.833	25.694		CLA	61
626	0	0	5.639	75.525	459.233	29.426		FEA	61
627	0	0	14.097	1667.433	22.061	22.823		ALX	61
633	0	0	5.639	59.831	432.219	13.062		EMN	62
634	0	0	8.458	83.372	115.709	28.565		VAS	62
635	0	0	5.639	50.023	1305.663	57.847		ABL	62
636	0	0	4.642	42.825	0.0	37.053		FEA	62
637	0	0	16.916	87.295	180.542	117.703		SET	62
638	0	0	5.075	46.100	281.393	20.813		CAT	62
639	0	0	11.841	61.793	105.804	79.665		VEV	62
640	0	0	1.692	150.069	42.772	21.675		CLA	62
641	0	0	6.767	67.678	432.219	106.220		SAA	62
642	0	0	12.969	1618.391	27.014	30.287		ALX	62
656	0	0	6.203	95.142	585.297	60.431		LUA	63
657	0	0	5.639	128.490	675.343	79.378		SAP	63
658	0	0	5.998	48.209	974.378	149.523		BEG	63
659	0	0	2.399	132.821	58.463	10.070		CLA	63
660	0	0	4.199	32.467	1283.327	36.771		ABL	63
665	0	0	1.799	73.789	77.475	7.781		CLA	64
666	0	0	3.599	30.500	1663.573	36.465		ABL	64
667	0	0	5.998	54.112	1359.376	175.461		BEG	64
668	0	0	5.998	38.371	903.082	14.800		EMN	64
675	0	0	2.399	103.305	57.037	13.579		CLA	165
676	0	0	2.999	105.273	27.092	22.734		STX	165
677	0	0	2.399	34.435	46.105	9.002		ALX	165

678	0	0	4.642	0.0	0.0	21.371		CAT	165
679	0	0	7.198	52.145	408.763	170.884		BEG	165
681	0	0	11.996	229.239	437.281	50.502	0.8	CAA	265
682	0	0	6.598	256.787	166.833	34.940	0.4	DEA	265
683	0	0	8.397	63.951	208.660	22.734	0.3	CAC	265
688	0	0	5.998	63.951	627.404	190.718		SAA	66
689	0	0	4.799	122.982	380.245	21.208		CAT	66
690	0	0	2.399	292.206	74.623	17.851		CLA	66
691	0	0	6.124	72.453	780.199	39.652		FEA	66
692	0	0	8.397	71.822	380.245	45.620		LUA	66
698	0	0	5.802	59.955	937.289	141.448		BEG	67
699	0	0	4.642	103.732	1528.502	36.746		ABL	67
700	0	0	5.222	61.859	276.380	15.836		CAT	67
701	0	0	1.741	92.312	92.768	8.149		CLA	67
702	0	0	5.222	39.019	696.958	12.454		EMN	67
703	0	0	6.383	151.316	215.817	21.832		EPL	67
704	0	0	6.383	157.026	480.661	35.977		LUA	67
726	0	0	5.802	111.346	1393.917	25.522		LUA	68
727	0	0	5.802	56.149	865.190	146.060		SAA	68
728	0	0	6.383	265.517	471.047	12.146		EMN	68
732	0	0	4.062	58.052	576.793	17.988		CAT	69
733	0	0	4.642	324.521	35.088	13.684		CLA	69
734	0	0	2.321	46.632	75.464	11.685		ALX	69
735	0	0	4.642	51.390	672.926	12.761		EMN	69
736	0	0	5.802	58.052	605.633	196.797		BEG	69
737	0	0	5.222	1808.179	20.668	19.833		ALX	69
744	0	0	6.383	69.472	384.529	115.311	0.3	SAP	70
745	0	0	6.383	111.346	221.585	45.971		CAM	70
746	0	0	5.512	56.996	286.073	38.591		FEA	70
747	0	0	8.704	200.803	50.950	37.668		DEC	70
748	0	0	3.913	221.893	268.007	21.655		CAT	70
755	0	0	5.590	47.479	321.608	248.276		SAA	71
756	0	0	5.031	57.169	66.037	34.621		CAT	71
757	0	0	2.236	86.238	33.018	16.414		CLA	71
758	0	0	3.354	31.976	268.007	45.379		ABL	71
759	0	0	6.148	39.727	237.990	27.724		EMN	71
773	0	0	3.913	72.672	135.933	129.655		POT	72
774	0	0	5.031	39.727	814.740	19.172	0.3	EMN	72
775	0	0	4.472	55.231	110.204	28.000	0.8	EPL	72

776	0	0	3.354	53.293	132.503	165.517		SAA	72
777	0	0	2.795	66.858	643.216	168.276		BEP	72
778	0	0	4.472	59.107	66.894	23.034		LUA	72
779	0	0	5.031	62.983	1166.365	213.793		BEG	72
780	0	0	4.900	45.404	170.698	22.147		FEA	72
782	0	0	5.590	148.251	272.295	204.138		SAP	73
783	0	0	5.590	119.182	224.268	44.000	0.6	CAA	73
789	0	0	6.148	76.548	80.188	18.759	0.4	POF	74
790	0	0	1.677	109.493	21.012	10.069		CLA	74
791	0	0	3.354	51.355	196.824	50.897		PIG	74
792	0	0	5.031	72.672	55.317	53.655		SAA	74
793	0	0	3.302	166.017	27.121	9.838	0.4	SHC	74
794	0	0	6.053	92.341	115.747	14.273		EMN	74
800	0	0	4.953	83.500	136.088	80.785		SAA	75
801	0	0	3.302	46.170	799.092	40.878		PIG	75
803	0	0	2.201	64.835	107.030	12.887		CLA	75
802	0	0	4.953	77.606	34.385	17.598	0.5	LUA	75
811			4.953		93.470	138.568		POT	76
812			4.953		64.412	21.478		LUA	76
813			3.302		513.356	56.951		PIG	76
814			6.053		308.982	187.067	0.4	SAA	76
815	0	0	4.953	57.959	484.298	117.783		BEG	76
816			2.752		184.518	30.624	1.2	EPA	76
984	0	0	8.564	127.906	48.128	34.527		CAA	86
997	0	0	2.284	158.942	38.405	10.186		CLA	87
998	0	0	4.567	50.786	213.414	22.885		CAT	87
999	0	0	9.135	46.084	340.296	178.586		BEG	87
1014	0	0	7.349	45.404	243.517	32.491		CAC	88
1015	0	0	10.602	89.202	72.426	56.564		VEV	88
1016	0	0	17.297	69.857	175.621	102.843		SET	88
1021	0	0	5.022	119.295	208.757	18.591		CAT	89
1022	0	0	2.232	142.939	39.290	11.998		CLA	89
1023	0	0	6.696	78.455	539.645	145.035		BEG	89
1034	0	0	3.906	33.317	247.574	36.786		ABL	90
1035	0	0	5.022	50.512	212.544	20.173		CAT	90
1036	0	0	6.696	52.662	305.325	57.882		BEG	90
1037	0	0	1.116	89.202	21.775	9.361		CLA	90
1045	0	0	4.464	72.007	254.201	17.272		CAT	91
1046	0	0	2.790	127.893	20.828	10.680		CLA	91

1047	0	0	6.696	44.064	243.787	98.888		BEG	91
1061	0	0	6.696	47.288	591.716	121.302		BEG	292
1062	0	0	2.790	155.836	24.142	6.724		CLA	292
1063	0	0	3.906	25.793	497.041	32.567		ABL	292
1069	0	0	8.370	114.996	48.757	243.923	8.0	SAA	93
1070	0	0	6.138	58.035	54.911	200.412	5.0	SAP	93
1071	0	0	6.124	41.540	66.672	79.967	50.0	FEA	93
1072	0	0	10.602	61.259	33.609	73.572	18.0	SET	93
1073	0	0	6.214	37.816	89.745	37.793	44.0	EPL	93
1088	0	0	2.824	67.610	101.778	136.003	1.2	SAP	94
1089	0	0	3.389	85.945	74.704	125.541	2.0	SAA	94
1090	0	0	4.519	175.327	37.101	30.208	1.6	SET	94
1091	0	0	4.519	49.275	196.036	32.562	1.0	CAA	94
1104	0	0	5.084	324.297	20.556	21.054	12.0	EPL	95
1105	0	0	1.130	49.275	83.228	130.772	1.2	SAA	95
1106	0	0	3.389	46.983	101.778	23.931	0.4	CAA	95
1107	0	0	7.908	40.107	14.540	41.978	12.0	SET	95
1121	0	0	5.084	572.963	200.047	91.541		SAP	96
1122	0	0	4.519	30.940	551.508	38.316		ABL	96
1123	0	0	1.695	81.361	83.729	14.777		CLA	96
1129	0	0	6.214	44.691	269.738	228.852	1.4	SAP	97
1130	0	0	7.343	56.150	104.787	228.852	1.2	SAA	97
1131	0	0	6.214	184.494	752.057	222.313	0.4	BEG	97
1132	0	0	3.389	40.107	115.817	43.547	3.6	FEA	97
1133	0	0	6.778	46.983	150.913	56.624	3.0	EPA	97
1134	0	0	8.473	56.150	75.707	78.202	1.2	SET	97
1135	0	0	6.778	41.253	99.773	85.002	3.6	CAC	97

* BLANK = <0.2 P.P.M.

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$SIGNOFF

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$SIGNON AWKF PRIO=L COPIES=2
**LAST SIGNON WAS: 01:37:22   THU MAY 04/72
 USER "AWKF" SIGNED ON AT  01:38:02 ON THU MAY 04/72
$LIST *SOURCE*
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APPENDIX D

PART I

RESULTS OF EMISSION SPECTROGRAPHIC ANALYSIS (METHOD 1) OF STREAM SEDIMENTS
MACMILLAN PASS AREA
PPM

LOC = U.T.M. CO-ORDINATES

ID NO	LOC	SR	BA	CR	CO	NI	AG	TI	CU	IN	V	MO	BI	GA	SN	PB	MN
6		80	1000	150	80	250		8000	500	25	500	30		15		15	500
700019	4477013	80		150	15	40			90	20	500	20		15		10	40
700026	4477011	100		150	40	60			200	20	500	25		15		20	300
700027	4477010	70		150	400	700			300	60	500	30		15		20	5000
700028	4467010	100		200	60	200	3		400	30	700	20		20		20	4000
700034	4447007	100		200	30	500			200	25	800	40		18		20	300
700039	4417006	80		180	100	350			500	40	700	30		20		20	1000
700045	4397005	60		120	10				80	20	2000	60		15		100	30
700046	4387004	60		180	5	20			50	20	2000	60		15		30	20
700059	4387002	100		100	18	30			80	30	400	20		20		20	200
700068	4386997	400		40	10	20			18	30	60	2		20		20	400
700073	4396995	80		100	15	60			70	20	300	10		15		20	300
700079	4396993	100		180	30	80			70	30	500	10		20		20	400
700084	4346991	80		200	60	200			80	30	500	10		20		20	1000
700089	4316989	80		100	50	80			70	30	500	15		20		15	500
700094	4276985	120		100	30	70			60	25	500	10		20		15	500
700095	4276986	100		100	40	100			60	35	200	5		20		15	1000
700102	4246979	100		180	20	200			100	30	500	20		20	5	15	1000
700103	4236978	80		100	40	50			60	40	200	15		18		25	2000
700113	4166974	100		80	20	80			60	30	200	20		18		15	700
700118	4076971	100		150	30	100			100	20	500	20		15		10	700
700146	4427004	60		80		30			50	20	800	20		20	25	40	100
700151	4417005	80		180		15			30	25	2000	40		20		50	50
700153	4407005	80		180		20			50	30	1500	50		20		50	50
700262	4437008	150		200	30	500			150	30	1500	40		15		20	400

700263	4437009	200		300	50	600		100	30	2000	60	20		20	200
700264	4447009	200		400	50	500		80	40	1000	30	15	10	10	400
700275	4406998			30				12	30	40		20		20	200
304		500	5000	150	30	60	8000	20	30	100		20		20	500
319		200	9998	200	100	500	9998	200	30	500	15	25		20	1000
320		300	5000	180	70	100	8000	70	40	100	5	30		40	5000
321		150	5000	150	60	100	9998	50	30	400	10	25		20	500
323		100	5000	150	60	200	8000	70	25	400	10	20		15	500
332		100	9998	200	70	400	9000	100	30	800	20	20		30	500
700341	4477011	200		200	60	300		150	30	600	20	25		30	500
700343	4457008	70		300	30	50		100	15	1500	50	15		15	100
700483	4427010	100		200	30	200		90	30	800	20	20		20	200
700495	4427009	200		200	50	400		200	30	1000	30	15		20	500
700496	4427008	700		500	30	300		200	30	1000	30	20		20	200
700512	4417008	200		400	40	300		100	40	800	20	20		20	200
700514	4417009	100		200	30	200		150	30	600	20	20		20	200
700523	4407008	1000		400	60	600		200	50	1000	200	15		20	5000
700539	4427003	80		180	10	60		80	25	1000	60	15		30	80
700556	4417002	100		180	15	50		50	30	200	10	20		30	500
700562	4427002	200		100	1000	1000		100	100	80	10	15	5	15	
700563	4427001	80		180	50	70		70	20	400	15	15		15	100
700576	4417001	500		60	40	150		60	30	60	5	25	5	20	500
700578	4407002	60		180	30	80		100	25	400	20	20		30	500
700581	4407000	300		15	10	20			25	20		15		15	200
700594	4407001	100		100	40	60		70	25	500	20	20		20	400
700595	4397000	60		200	15	50		150	20	1000	50	20		30	200
700643	4447023	300		180	70	90		100	40	60		30		50	3000
700645	4447022	200		200	60	70		100	25	80	2	30		30	500
700647	4427022	300		200	70	50		60	25	80		30		20	800
700649	4437023	300		180	80	60		60	25	70		30		30	1000
700651	4427023	400		200	80	60		100	30	60		25		30	1000
700708	4417024	200		200	80	70		60	30	80	2	25		30	1000
700762	4407023	200		200	100	90		100	30	60		30		40	1000
700764	4397024	200		200	70	70		60	25	60		25		20	1000
700766	4407025	200		150	60	70		60	30	50		30		30	1000
819		100	5000	180	30	90	9998	80	25	100	5	15		100	1000
820		200	4000	180	50	90	9998	90	25	100	2	15		10	600
821		200	1800	80	20	40	5000	30	25	150	2	15		15	500
822		200	2000	100	20	50	7000	30	25	100		15		15	500

823		2002000	120	20 50	9998	20	25 100	2	15		15 200
824		1002000	100	20 40	8000	20	25 90		15		10 500
825		5009998	200	30 80	9998	70	40 300	5	20		20 500
826		2009998	150	20 60	8000	60	30 100	5	20		20 500
827		3006000	100	20 50	8000	30	30 70	2	20		15 600
828		5009999	200	50 150	9998	120	40 100	5	25		251000
829		5009998	200	40 80	9998	80	30 100	5	25		20 500
830		3009998	200	40 70	8000	30	30 80	2	20		101000
700831	3786933	400	200	40 70		30	30 80	2	25		151000
700832	3836945	200	200	60 80		80	30 100	2	20		151000
700833	3846946	200	200	50 100		100	30 200	5	20		151000
700834	3906951	400	200	40 80		90	30 200	5	20		151000
700835	3956955	600	200	30 80		80	30 300	5	20	5	401000
700836	3966956	600	200	40 80		70	40 500	2	25		20 700
700837	3976958	400	200	40 100		60	30 500	5	25		151000
700838	3986966	400	400	50 300		300	301500	30	25		152000
700839	4006967	500	500	60 400		200	401000	20	30		202000
859		4001500	300	20 100	8000	80	301000	15	25		15 500
700934	4447004	100	200	20 70		300	25 500	15	25		30 200
700937	4457004	100	200	50 100		200	20 500	15	20		30 500
700939	4447005	80	200	50 80		200	25 500	15	20		40 700
700940	4447006	80	200	50 100		300	25 500	15	20		30 700
700975	4437004	500	180	15		20	20 500	25	15		30 15
700977	4437003	100	200	15 10	3	100	202000	90	15		400 30
700985	4497006	500	150	20 60		100	30 400	30	25		40 200
700987	4497007	600	300	15 70	4	200	25 700	60	20		40 200
701002	4487007	300	200	15 50		100	301000	50	25		20 200
701006	4487006	200	400	40 50		200	301500	100	20		50 400
701025	4477006	50	200	20 10		80	252000	60	15		15 100
701027	4477007	80	200	30		80	301000	80	25		40 40
701038	4477008	100	200	15 40		100	251000	20	20		20 200
701048	4467008	100	200	20 40		100	251000	40	20		20 200
701074	4367011	500	300	30 400		80	251000	400	15		8 150
701076	4377011	200	400	60 500		100	251500	80	15		15 500
701080	4377010	400	400	70 500		300	301000	20	20	5	100 500
701095	4377009	500	300	100 600		150	40 700	20	20	5	502000
701098	4377008	100	200	80 400		200	40 700	40	30	5	401500
701109	4397008	100	700	801000		100	40 700	20	25	5	301500
701111	4387008	500	400	70 500		100	301000	50	20	5	20 500

1151		2009999	300	20	100		8000	80	301000	15	25	15	500
701181	4417004	100	150	5	15	3		60	302000	100	20	100	50
1183		4009999	300	20	70		9998	100	252000	60	15	30	800

* BLANK = >2,000 P.P.M.
9998 = 10,000 P.P.M.
9999 = >10,000 P.P.M.
** BLANK = NOT DETECTED

PART II

HNO3/HCLO4 EXTRACTABLE ZN CONTENT OF SELECTED SAMPLES DETERMINED BY ATOMIC-ABSORPTION SPECTROPHOTOMETRY

ID NO			ZN(PPM)
19	0	0	77.233
28	0	0	222.043
34	0	0	260.660
46	0	0	30.314
146	0	0	45.374
151	0	0	24.174
153	0	0	27.611
262	0	0	289.622
263	0	0	299.276
264	0	0	662.269
341	0	0	276.106
343	0	0	47.305
483	0	0	235.559
495	0	0	220.113
496	0	0	191.150
512	0	0	218.182
514	0	0	764.602
523	0	0	608.206
539	0	0	47.305
595	0	0	29.735
934	0	0	71.440

233				
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235				
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243				
244				
245				
246				
247				
248				
249	937	0	0	166.050
250	939	0	0	80.322
251	975	0	0	2.702
252	1002	0	0	202.735
253	1006	0	0	90.748
254	1025	0	0	57.924
255	1027	0	0	14.481
256	1048	0	0	84.956
257	1074	0	0	225.905
258	1095	0	0	530.937
259	1111	0	0	482.703

END OF FILE

$SIGNOFF

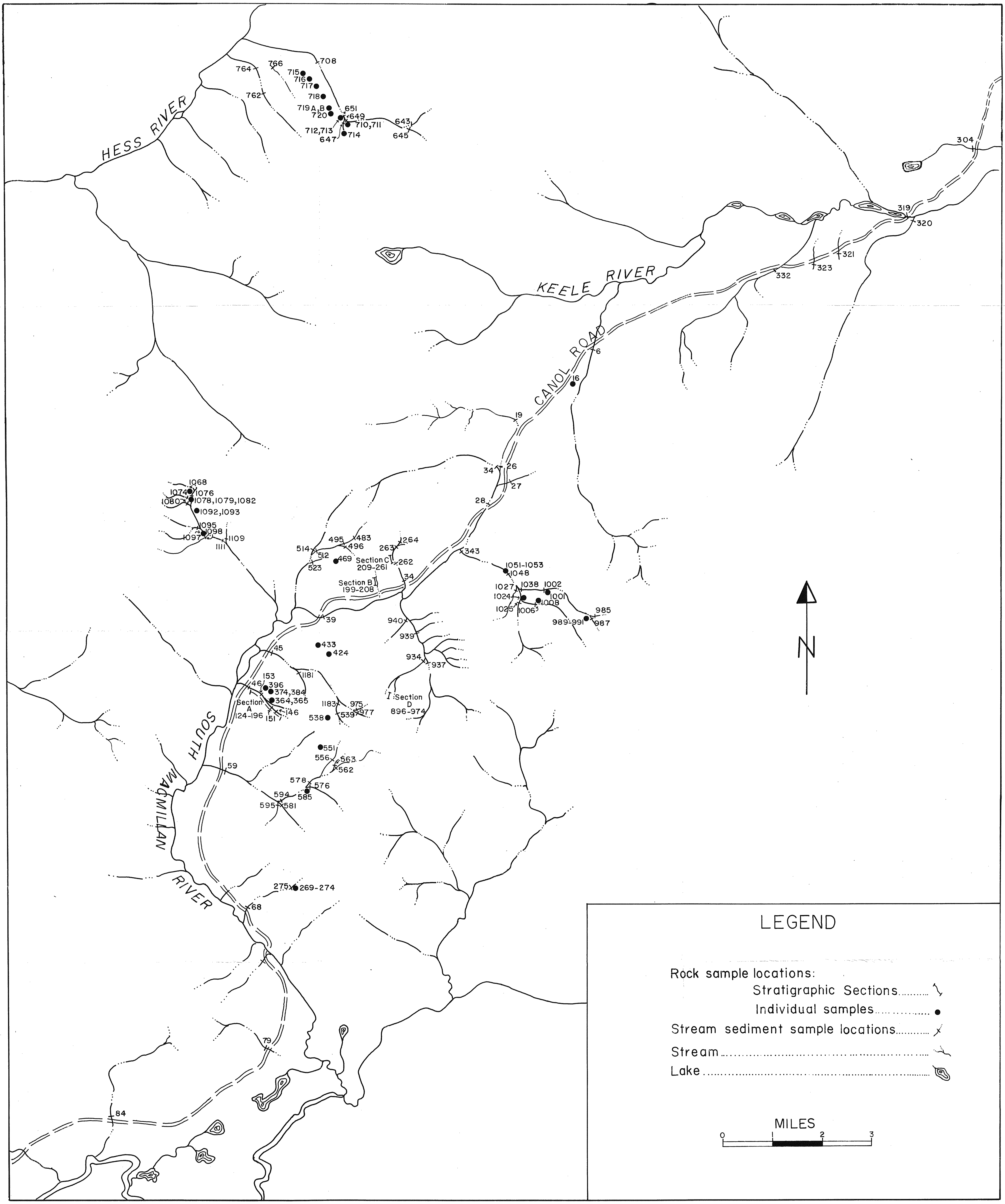

Figure 16. Stream sediment and rock sample locations within the detailed study area.

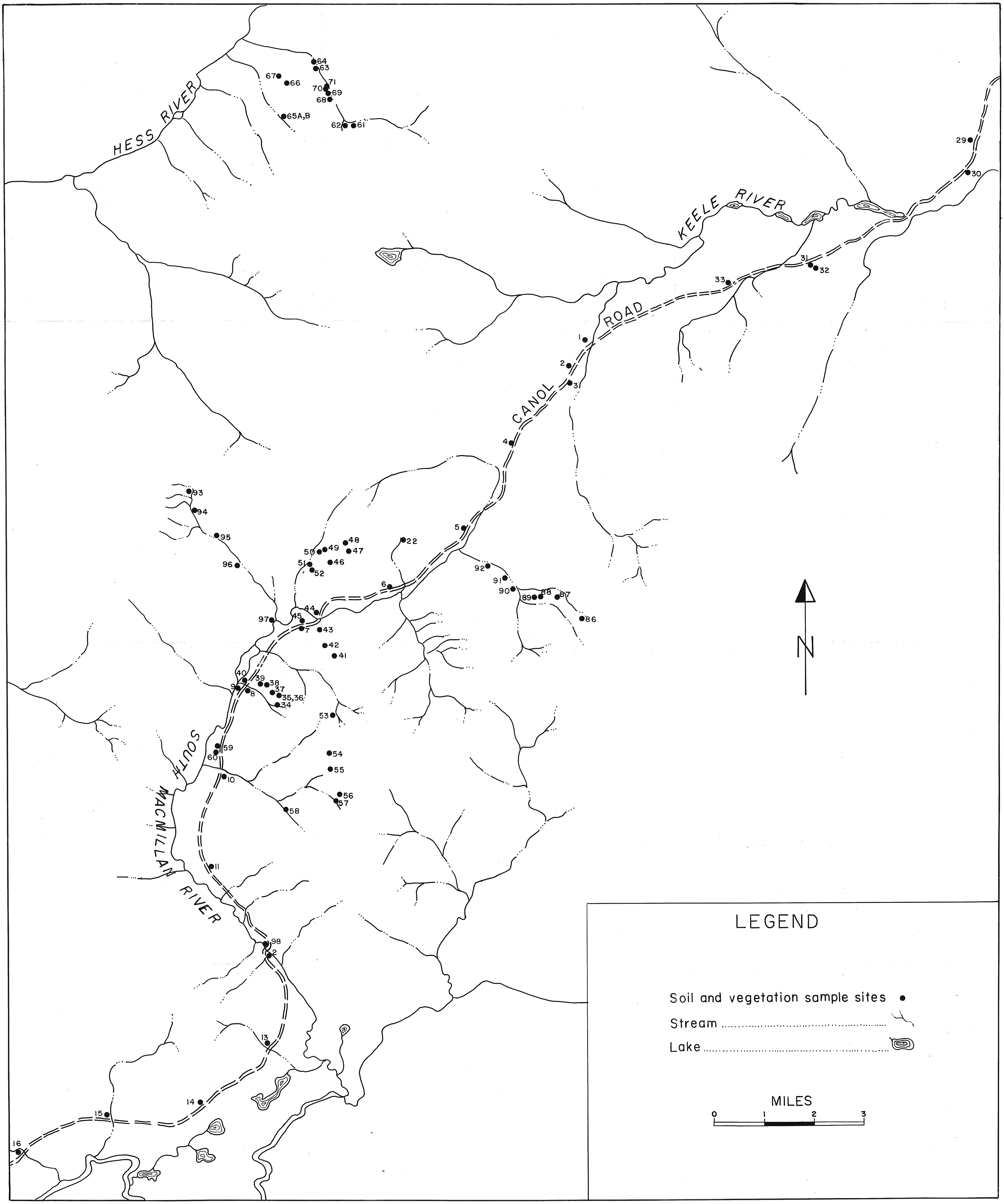

Figure 17. Soil and vegetation sample site locations within the detailed study area.

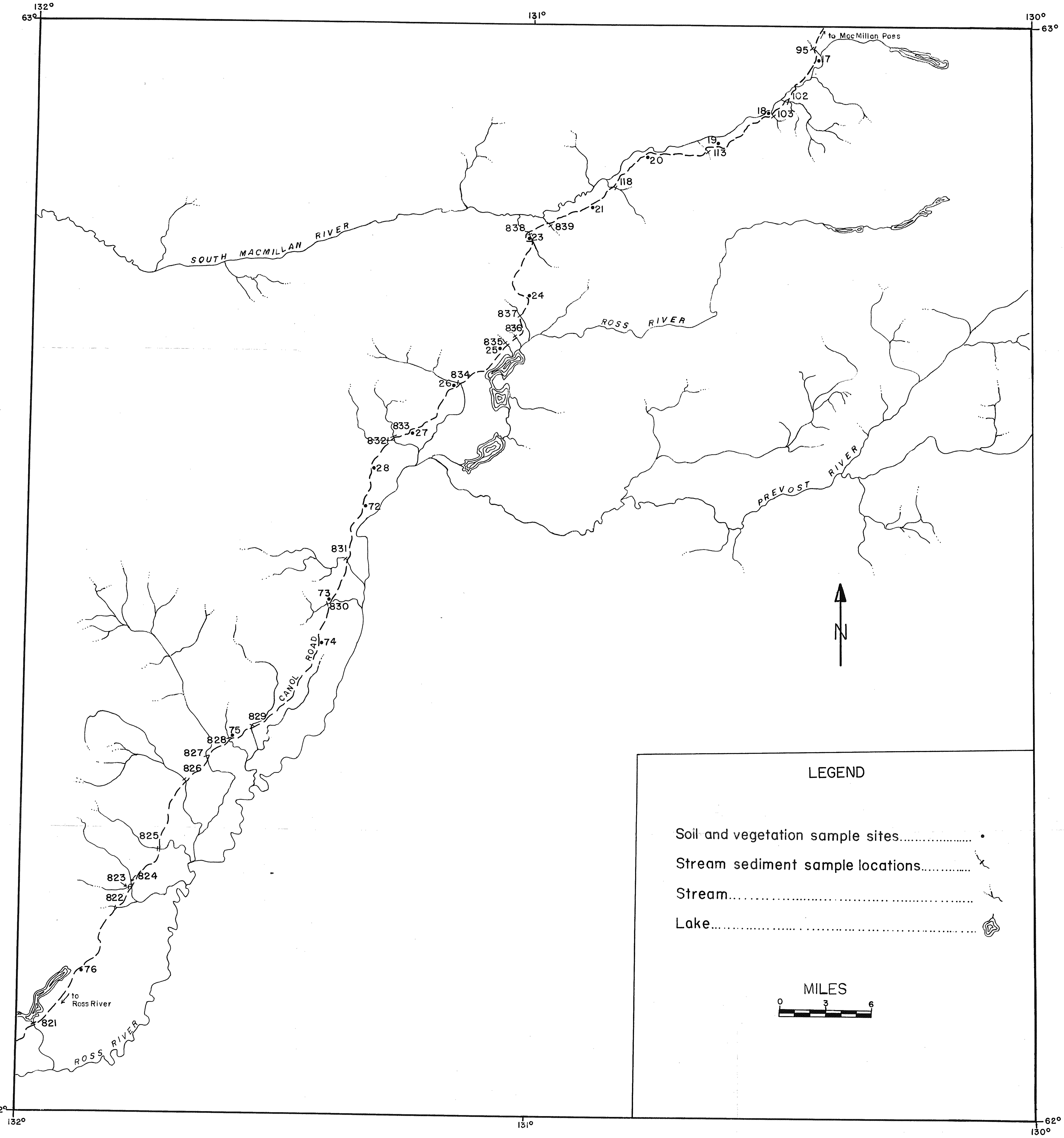

Figure 18. Soil and vegetation site and stream sediment sample locations along the Canol Road between Ross River and MacMillan Pass.