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THE CHARACTERIZATION OF HYDROLOGIC PROPERTIES AND MOISTURE MIGRATION PATHWAYS OF A WASTE ROCK PILE

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ABSTRACT

A multiphase research program has been initiated on a large waste rock pile which has undergone partial excavation. The focus of the research is to define the distribution of moisture migration pathways in the waste rock and to develop a conceptual model of the heat and mass transfer processes within the pile. The first phase of the research program was conducted simultaneously with the excavation process. This phase included a field logging and sampling program of exposed waste rock from numerous test pits. The test pits were excavated along predetermined transect lines established on the benches of the waste rock pile which were exposed during the excavation process. Phase I included visually logging the exposed rock and insitu measurements of matric suction, temperature, relative humidity and water content. Samples of each waste rock unit described in phase I were obtained for further analysis. The second phase of research includes a laboratory testing program to determine saturated and unsaturated hydraulic and thermal properties of the rock. The properties being measured include grainsize, porosity, moisture retention characteristics, saturated hydraulic and thermal conductivity and specific heat capacity. In summary this paper outlines the research program to date and discusses the initial findings of the field program.

INTRODUCTION

The mining industry is working towards improved environmental technologies. Research for modelling and predicting seepage quality, especially in the long term, is an important part of these research efforts. Prediction of effluent releases from waste rock piles requires an understanding of both geochemical and hydrogeological characteristics of the sulphide bearing waste rock material found within waste rock piles.

This paper describes the first phase of a research program to determine the hydrogeologic properties and moisture migration pathways of a large waste rock pile. The first phase of the research program was conducted for a waste rock pile located at a large open pit gold mine in southwestern Montana. The removal of a portion of the waste rock pile provided a unique opportunity to observe the internal structure of a large waste rock pile which has undergone oxidation, in some locations, for more than ten years.

A field logging and sampling program, to document the waste rock pile, was initiated in the fall of 1994 and was conducted simultaneously with the waste rock excavation operations. An estimated total of 15 million tons of waste rock was removed from a pile containing approximately 100 million tons. The excavation processes provided approximately, a 100m deep cross-section through the waste pile. The excavation operations intersected material at different depths within the pile as well as material which was placed in the pile over a twelve year period. These operations provided access to waste rock material ranging from the original pile top surface to material, in some locations, situated within 3m of the original ground surface. Removal of this material allowed for insitu testing and sampling of waste rock of different ages and waste rock located at various depths within the pile.

LOCAL SETTING

Climate

The climate in the area is classified as semi-arid inter-mountain. The local area is described as characteristic of the continental climate modified by local ranges of the Rocky Mountains (Golder, 1995). Precipitation monitored at the site averages 355 mm annually. There is s seasonality to the precipitation at the site with approximately 75 percent of the precipitation occurring during the period between April and September, with the maximum precipitation occurring during the months of May, June and July (Golder, 1995). Mean monthly precipitation from November through February is less than 13 mm. The average annual temperature is approximately 7.2° C. Air temperatures can range from -40° C to +38° C. Freezing temperatures have been recorded from September to June. Pan evaporation is reported at 1118 mm annually for the period of May through September (Golder, 1995).

Mine Geology and Waste Rock Mineralogy

Economic gold mineralization at the site occurs in arid around a pipe shaped hydrothermal breccia. The breccia is approximately 215 m in diameter and plunges 35° to the south-west (Foster, 1991). The hydrothermal breccia cuts Proterozoic sedimentary rocks and Cretaceous latite porphyry sills. The

Proterozoic sedimentary rocks and Cretaceous latite porphyry rocks comprise the majority of the waste rock types.

The Proterozoic rocks are the oldest rock types at the; site and are primarily clastic sedimentary rocks consisting of sandstones and shales. These rocks are: thought to be part of a submarine fan, slope and shelf complex which prograded over basin plain deposits in the area (Foster, 1991). Proterozoic siliciclastic sandstones and shales of the basin plain and submarine fan fades (Lahood Formation) are overlain conformably by shales (Bull Mountain Group) of the marine slope and shelf fades at this site (Foster, 1991).

Exhalitive and/ or diagenetic massive sulphide horizons occur in the submarine fan complex sandstones and shales. Synsedimentary mineralization in the form of disseminated diagenetic sulphides in the matrix of silty beds occur in the shale rocks of the marine slope and shelf facies (Foster, 1991). Exhalitive and/or diagenetic massive sulphide mineralization along with the synsedimentary diagenetic sulphides comprise the major form of sulphide mineralization in the Proterozoic clastic sedimentary waste rock.

The Proterozoic sedimentary rocks were intruded by at least three plutonic phases. Cretaceous age porphyries (latites) commonly form sill like bodies intruding the sedimentary rocks (Foster, 1991). The latite intrusions are thought to be contemporaneous \vith breccia formation. Latite rocks comprise the major igneous waste rock type found in the waste rock pile. Latite porphyry rocks contain both disseminated sulphide mineralization and mineralization in the form of sulphide filled veins and joints (Foster, 1991). Irregular hypabyssal mafic intrusions (potassic trachybasalts and basaltic andesites) are also present. Lampophyre dikes, sills and irregular bodies cut other intrusive rocks (Foster, 1991). Although present, these rock types represent a very minor percentage of rock found in the waste rock pile.

In summary, massive and disseminated sulphide mineralization is found in both the sedimentary (shale) and igneous (latite) rock types. These two rock types comprise the bulk of waste rock material found in the pile. Unoxidized waste rock generally contains 2% to 5% pyritic S and has no significant neutralizing capadty (Schafer et al. 1994).

RESEARCH PROGRAM

A multiphased research program was undertaken by the University of Saskatchewan which focuses on defining the distribution of moisture migration pathways in the waste rock pile and the development of a conceptual model for the heat and mass transport processes within the pile. The objectives of the research program are as follows:

1. To define the hydrologic characteristics of pile materials and identify water and oxygen migration pathways.
2. To physically describe the waste rock material. This will provide the basis to evaluate the extent of chemical weathering and the corresponding age of the materials.
3. To collect samples and perform laboratory analysis.
4. To establish the occurrence and extent of water in the waste rock pile and to establish a water balance.
5. To establish liquid water and water vapor fluxes within the waste pile associated with temperature gradients due to internal heat generation.
6. To provide a conceptual and predictive hydrologic model which includes the heat and mass transport processes within the pile.

The first phase of the program involved a field logging and sampling program conducted during the excavation of the waste rock pile. The second phase includes a laboratory program which will focus on the hydrogeologic properties relevant to moisture and oxygen migration pathways within the pile.

FIELD PROGRAM

Excavation of the waste rock was performed using electric shovels removing the waste rock in approximately 20m lifts with a bench left along the excavated highwall for stability. Upon completion of a bench, the shovel was moved approximately 20m below to begin the next excavation surface. Attempts were made to conduct the field research on the level 20m above the operating shovel. This would allow for the maximum surface area to excavate test pits along established transect lines before the surface was removed by the shovels.

One east-west transect line and two north-south transect lines were established. The transect lines were located in a position to maximize the excavated area in the waste rock pile and to encounter rock material ranging from the oldest to the most recently placed material within the waste rock pile. Test pits were excavated using a tracked backhoe or D8 cat along the transect lines at spacings between 30 and 90 m depending on accessibility on the excavated surface. As the next 20m lift was removed by the excavation operations, the transect lines were re-established and pits were again excavated on the new level. In this way, sample points were obtained at various depths and locations within the pile as the removal of waste rock provided access to deeper portions within the waste rock pile.

A standard logging and sampling procedure was used in each pit. Layering of the waste rock material was observed in the waste rock pile and was defined either by changes in grainsize distribution and/or color. All layers encountered within the pit were visually logged with respect to general mineralogic components (i.e. intrusive varieties vs. shale varieties), general grainsize range, texture, structure, general comments on the condition of interparticle spaces (i.e. either open voids or interparticle spaces infilled with fine matrix), state of oxidation and weathering, color (i.e. Munsell soil colors), strike, dip and any other special features were noted. All layers were photographed.

Attempts were made to obtain measurements of temperature, relative humidity and matric suction. Matric suction measurements were taken using either a tensiometer or the filter paper method. The tensiometer uses a transducer to measure the water tension in the soil around a porous cup in mbar. Measurements of matric suction using a tensiometer was found to be sioitable only for use on the finest layers found within the waste rock pile. The presence of coarse particles often resulted in poor contact between the ceramic cup and the surrounding material. In addition, many of the layers encountered were very dry with water contents of less than 1%. Tensiometers are limited to negative pore water pressures of 90 kPa due to the cavitation of the water in the tensiometer. At very low water contents, it is possible that the negative pore water pressure exceeded the measuring range of the tensiometer in some of the layers. The filter paper method was used in an attempt to measure both matric and total suction. This procedure uses filter papers as passive sensors to evaluate the soil matric and/or total potential. Temperatures and relative humidity values were determined using a portable relative humidity and temperature indicator.

Samples were obtained to determine moisture content and other analysis. Two samples were taken to determine gravimetric moisture contents for each layer. One of the samples was used to obtain gravimetric water content data on the bulk material taken from the layer. The second sample was used to obtain gravimetric moisture content on the material smaller than -3/8" from the same layer. All layers described throughout the field program have these corresponding gravimetric moisture contents. Two bulk samples were also taken from each layer for laboratory analysis to be performed during phase n of the research program. Finally, a third bulk sample of each layer was taken by Montana State University for geochemical analysis.

Dry density values for the waste rock were obtained using the sand replacement method or by Troxler nuclear density equipment. Density values for a variety of material types found in the waste rock pile were determined.

All test pits were surveyed and tied into the mine grid. The x,y,z coordinates from the survey allow the position of the test pit to be determined with respect to their depth below the original surface of the pile and the depth to the original ground topography (i.e. the base of the pile). This information, in conjunction with waste rock pile as-built drawings allowed the determination of the year in which the material encountered in each test pit was placed in the pile. This data will allow for comparisons to be made between hydraulic characteristics of the pile material encountered at different depths within the pile as well as the hydraulic characteristics of material with different ages.

DISCUSSION OF FIELD OBSERVATIONS

The waste rock pile being investigated was built by end-dumping from several platform elevations. Waste rock is dumped down the dump slope from a compacted bench or dump top surface. Waste rock has been dumped into this pile from different portions of the mine beginning in late 1982 and continuing until 1994.

The method of construction of these piles has controlled the strong structural orientation observed within the pile. The structure or dipping layers of waste rock material in the waste rock pile is defined by color and/or grainsize differences. The layers are dipping at approximately the angle of repose of the material and strike at an angle consistent with the edge of the dump top surface from which the material was end dumped. Figure 1 shows a view of the exposed waste rock. The layers within the pile range from thin lenses (10-20 cm) to wide layers with a thickness of several meters. Waste rock material in the layers may consist of only one rock type (i.e. shale or latite) or may be composed of a combination of rock types.

Figure 1. Dipping, layered structure visible on an excavated section of the waste rock dump.

Grainsize differences from coarse "rubble layers" with large open interparticle voids to fine layers with a significant percentage of silt and sand matrix infilling interparticle voids were observed. Extreme changes in grainsize distribution from coarse to fine material can occur over adjacent layers marked by sharp contacts dipping at angles consistent with the overall structure within the pile. Figure 2 shows a coarse layer within the pile surrounded by finer waste rock material. Often, these coarse layers were composed of a high percentage of latite. It is possible that this rock type, in general, tends to be more coarse than shale waste rock when originally placed in the waste rock pile. The coarse grainsize along with a higher resistance to weathering in the pile may explain the existence of these coarse layers with open interparticle void spaces. Although this rock type appears to show a different weathering behavior when compared to the shale waste rock, weathering and breakdown of latite rock particles has also been observed. In addition to coarse, dipping waste rock layers situated within the pile, a coarse rubble zone occurring at the base of the pile was also observed. Evidence from a test pit excavated near the original ground/waste rock pile contact as well as evidence from the existing toe of the slope appears to confirm the presence of a coarse rubble zone at the base of the pile. The basal coarse layer is produced as a result of material segregation which occurs along the angle of repose dump slope.

Figure 2. Coarse latite rock layer with open interparticle voids surrounded by finer waste rock

Coarse dipping layers within the waste rock pile appear to be important pathways for the venting of warm, moist air. Test pits dug at sites where active venting was observed, found that coarse layers can provide preferential pathways for the movement of warm, moist air. Temperatures in one coarse, dipping layer with visible venting were measured at 65°C and relative humidity measurements were approximately 100%.

In general, the upper 15m - 20m of the waste rock pile has higher moisture contents than the drier material deeper within the pile. A wetting front developing in the upper portions of the pile is consistent with data obtained from other piles at the site where monitoring equipment has been installed. Test pit observations made during the excavation process have provided evidence for the presence of a wetting front in the upper portion of this pile, however, there is no acid drainage from the base of the waste rock pile. Gravimetric moisture contents taken from layers sampled in the upper 8m of the waste rock range from 4% to 13%. Average temperatures in the upper portion of the pile also appear to be higher overall. Temperatures recorded in the upper layer averaged approximately 30°C. It appears that an increase in heating is associated with the upper wetting front. Gravimetric water contents for the material below the wetting front, in general, range from 0.5% to 4%. Average temperatures taken in test pits below the wetting front averaged approximately 20°C. Air temperatures may have influenced these readings where excavated surfaces were exposed for some time before test pits were dug through these surfaces. In summary, elevated temperatures detected within the test pits were either associated with increased moisture content and/or the presence of warm, moist venting air.

Layering is often defined by color differences with or without grainsize changes. Color differences with very sharp contacts between layers are common in this pile. Colors ranging from dusky red to reddish yellow may change to yellow and olive colors across a very sharp contact. The color differences highlight the structure within the pile. In some instances, color changes occur where no change in grainsize is visible. Early indications are that the color differences are associated with geochemical changes in the different layers possibly associated with differences in the pH between the layers. Further testing will be performed in the laboratory as part of the classification procedure to confirm this.

Significant changes in the waste rock material are apparent when fresh waste rock is compared to waste rock which has been in place within the pile over several years. Initially the waste rock has a fresh appearance to it. The percentage of fine silt and sand sized particles is low. The material is loose with the particles orientated with an edge to face particle framework. The color of the layer was the same as the color of the fresh rock surfaces (i.e. light to dark grey). Figure 3 shows some fresh shale waste rock placed in the pile within the last year. Over time, there is an increase in the percentage of silt and sand sized particles associated with the weathering and breakdown of the waste rock particles. The material in some layers appears to have undergone some compaction. Infilling of interparticle void spaces with fine silt and sand is common in many layers. Figure 4 shows a fine waste rock layer composed of material which has been in the pile for several years. Staining of the particle surfaces, coating of reaction products on the surface of the particles and the precipitation of salts is also common. In some layers weak cementing of fine matrix and rock particles is apparent. A high degree of cementing has been observed but is rare overall. Weathering and breakdown of waste rock particles has been observed, in places, in all rock types commonly found in the pile.

Figure No. 3   Unweathered waste rock material recently placed in the waste rock pile.

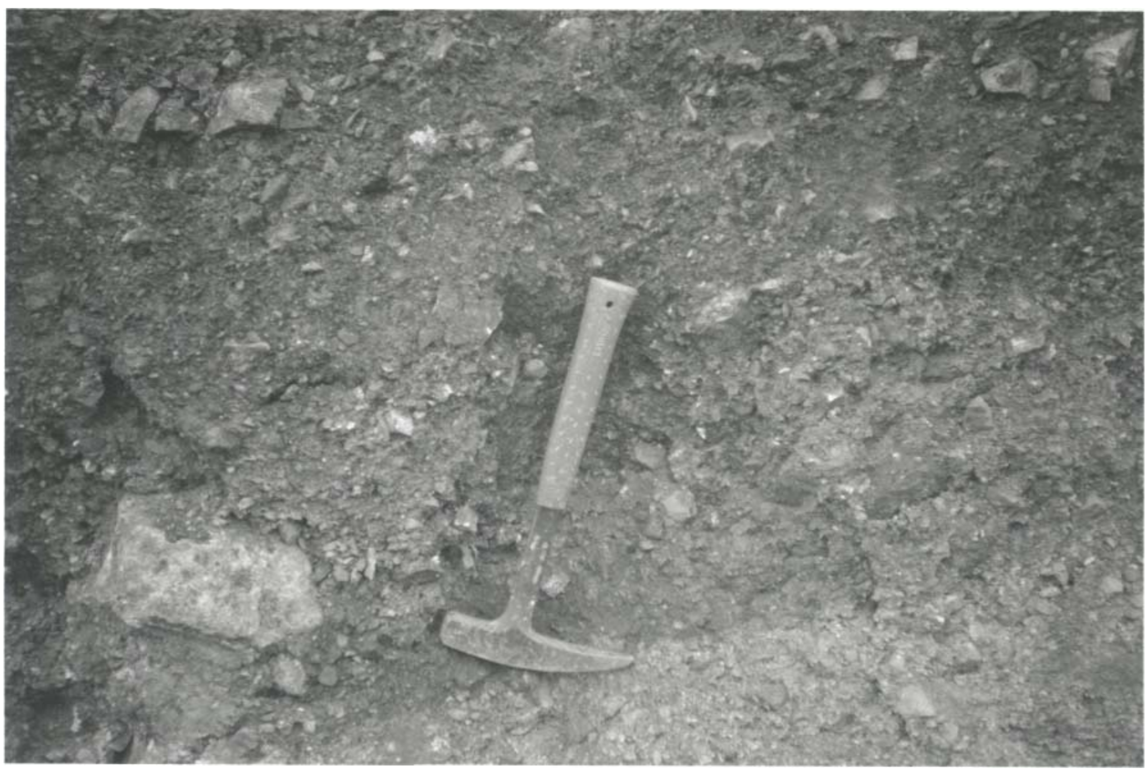

Figure No. 4   Weathered waste rock material which has been in the waste rock dump for several years.

CONCLUSION

The excavation of 15 million tons of waste rock from a large waste rock pile has provided a unique opportunity to study the structure and processes which occur in a large waste rock pile. The first phase of the research program has been completed. The field program has documented and sampled waste rock materials with different physical characteristics throughout the pile. Dipping beds or layers of waste rock material containing different physical characteristic, including hydraulic properties, will influence the distribution of moisture and pathways within this pile. The field investigation and sampling has set the structural framework for analyzing the distribution of moisture and the pathways for moisture (both liquid and vapor) and oxygen migration in the waste rock pile. Further research at the University of Saskatchewan will focus on determining the hydraulic characteristics of the waste rock material sampled and defining the heat and mass transport processes. Results from this research will be used to develop a conceptual hydrologic model which includes the heat and mass transport processes within the pile.

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