APPENDIX 2

ARD POTENTIAL AND MANAGEMENT

NORECOL, DAMES & MOORE
1994

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FINAL REPORT

ACID ROCK DRAINAGE POTENTIAL AND MANAGEMENT TELKWA COAL PROJECT FOR PITS NORTH OF TELKWA RIVER

MANALTA COAL LIMITED

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EXECUTIVE SUMMARY

Manalta Coal Limited (MCL) is proposing to produce coal at the Telkwa Coal Project, located near Telkwa, British Columbia. Several types of solid mineral wastes will be produced during open pit mining. As part of the evaluation of mine environmental impacts, Norecol, Dames & Moore, Inc. (NDM) has been retained by MCL to predict the acid rock drainage (ARD) potential of waste materials and to develop waste management approaches to ensure that ARD can be prevented at the coal deposits north of the Telkwa River. This study follows previous studies in 1985 on the coal deposits near Goathorn Creek, and in 1990 and 1991 on the coal deposits north of the Telkwa River. This report discusses all relevant evidence on the potential for acid generation, provides a comparison with the Appalachian coal mining region and provides options for management of wastes to ensure prevention of ARD.

Methods available to evaluate ARD potential at the Telkwa Project included acid-base accounting, comparison with the Appalachian coal region, evaluation of field evidence from existing mines and excavations, interpretation of short term kinetic studies, and natural background groundwater quality. It is concluded that comparison with the Appalachian coal mining region is valid. The water quality and ABA database of 113 existing mines in West Virginia and Pennsylvania represents a diverse range of geological conditions. The Telkwa Coal Project fits into the range of conditions represented by the database. Telkwa's lower concentrations of iron carbonate and presence of calcareous glacial tills indicate that it represents a significantly better than average geological setting for prevention of ARD when compared to Appalachian mines in comparable settings. Criteria for prevention of ARD (NP>15 kg $CaCO_3$/t, NNP>10 kg $CaCO_3$/t, NPR>2.0, on a mass-weighted basis) developed for the Appalachians are proposed for Telkwa and are believed to be conservative.

Waste rock acid generation potential is defined in terms of zones between coal seams. In general, potential for acid generation increases as the proportion of mudstones and coal increases. Short term kinetic information shows that sulphate release under pH neutral conditions from sedimentary rocks is proportional to total sulphur content and alkalinity is readily available to neutralize acidity. Intrusive granodiorite and non-oxidized glacial till are predicted to be acid consuming due to the presence of calcite. Preparation plant rejects are potentially acid generating, although fine tailings may not be acid generating due to elevated NP's and the presence of sulphur in organic form. Volume balance calculations for all waste rock show that the Appalachian criteria for prevention of ARD can be met with some selective management of potentially acid generating rock for the proposed Pit 7 and minimal management for Pit 8.

Elevated alkalinity from backfill in an old bulk test pit, alkaline seepage from a former coal mine at the property, and the presence of naturally alkaline groundwater in the proposed pit area support the conclusion that ARD can be prevented at the Telkwa Coal Project. The test pit data show that seepage is more alkaline than would be expected from the Appalachian database. The presence of calcareous till and a generally calcareous sedimentary sequence between the proposed open pits and the Telkwa River indicate a strong environmental assimilative capacity to further prevent ARD impacts. All potential waste materials at Telkwa contain background heavy mineral and metal concentrations (for example, lead, zinc, cadmium, copper) and, therefore, significant leaching of these metals is not anticipated.

Mixing of potentially acid-generating and acid-consuming waste rock is recommended as the main waste rock management measure. Long range planning using operational ABA determinations and short range planning to achieve in-pit control of dump trucks are recommended to ensure optimal mixing in the waste rock dumps. During production in Pit 7, some potentially acid generating strata may need to be segregated to achieve operational criteria for prevention of ARD. If this material has a significant potential for acid generation, it is recommended that it be capped with compacted non-oxidized glacial till in a separate area of the waste rock dump such that any seepage can be directed to the tailings ponds for treatment, if necessary. Capping with compacted tills is recommended to reduce infiltration and oxygen diffusion. As soon as suitable pits become available, any segregated potentially acid generating rock could be placed underwater. If preparation plant fines are found to be acid-generating, they should be maintained under a permanent water cap, or until the bulk composition indicates that acid generation will not occur. If preparation plant coarse rejects are found to be acid generating, it is recommended that they be handled using the same measures as waste rock with similar characteristics.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

Page

LIST OF TABLES

LIST OF FIGURES

ACID ROCK DRAINAGE POTENTIAL AND MANAGEMENT
TELKWA COAL PROJECT FOR PITS
NORTH OF TELKWA RIVER

1.0 INTRODUCTION

1.1 BACKGROUND

Manalta Coal Limited (MCL) is planning to extract coal by open pit mining at the Telkwa Project, located near Telkwa, British Columbia (Figure 1). Several types of solid mineral wastes, including waste rock, fine tailings and coarse preparation plant reject, will be produced. As part of the evaluation of mine environmental impacts, the potential for release of acid rock drainage (ARD) from these wastes and open pits is being addressed. Norecol, Dames & Moore, Inc. (NDM) has been retained by MCL to develop waste management approaches to ensure that ARD can be prevented at the coal deposits north of the Telkwa River. This report discusses the assessment of acid generation potential and recommended waste management approaches.

ARD can be produced when mine wastes containing reactive sulphide minerals are exposed to moist atmospheric conditions, and do not contain sufficient quantities of naturally acid consuming minerals, such as calcium and magnesium carbonates. Un-neutralized ARD from coal mines typically has a low pH (near 3), and elevated concentrations of sulphate, iron, aluminum and manganese. Non-acidic coal mine drainage may contain elevated sulphate concentrations and alkalinity, but does not contain elevated metal concentrations. Other heavy metals, such as zinc, copper, lead, cadmium, mercury and others are not associated with coal mine drainage because the mineral components responsible for these metals are not normally present in coal mine wastes in sufficient quantities.

1.2 PREVIOUS AND ONGOING ACID GENERATION INVESTIGATIONS

Several previous investigations have specifically evaluated the potential for ARD at the Telkwa Coal Project. These investigations and the conclusions drawn are discussed below.

Sturm Environmental Services (SES)(1985) evaluated acid generation potential in the proposed Pit 3 area east of Goathorn Creek (Figure 1) for Crows Nest Resources Limited (CNRL). The study consisted of acid-base accounting of 257 samples from five cores and 11 column leach tests on composites and potentially acid generating zones. It was concluded that the quantities of acid consuming minerals were much greater than the potentially acid generating minerals, although it was recognized that careful management of potentially acid generating material types would be required to prevent acid generation. Encapsulation of potentially acid generating materials within potentially acid consuming rock was recommended to prevent ARD formation.

CNRL was granted Approval-in-Principle to mine the coal deposits in the Goathorn Creek area.

SES's conclusions were based on a core thickness weighting approach rather than the probable volume of mine wastes. In addition, the criterion used for determining potential for acid generation has been reviewed and revised in the last five years (for example, Cravotta *et al.*, 1990). Therefore, Norecol Environmental Consultants Ltd. (NECL) (1991a) were retained by CNRL to re-evaluate the Pit 3 data. The conclusions of the SES report were confirmed by NECL with reference to the more recent criterion, that is, the change in interpretation did not fundamentally affect the conclusions presented by SES. Mixing of potentially acid generating waste rock and acid consuming rock was recommended to prevent formation of ARD.

In March 1990, CNRL submitted a Stage II report to the B.C. government proposing expansion of the Telkwa Coal Project to include coal reserves in the same geological sequence to the north of the Telkwa River (Pit 7 and 8 area, Figure 1). As part of the proposal, NECL (1990, 1991b) assessed the acid generation potential of waste rock, coarse rejects, tailings and pit walls. The report concluded that waste rock mixing could be used to prevent ARD provided that the waste management plan addressed handling of certain potentially acid generating waste rock zones and other rock wastes.

In 1992 and 1993, following acquisition of the project from CNRL, MCL began collecting further data on acid generation potential at the Telkwa Coal Project, north of the Telkwa River, as part of additional delineation of coal reserves. In February 1994, MCL (1994a) issued an update on recent studies and the proposed waste management concept. The Ministry of Energy, Mines and Petroleum Resources (MEMPR) (with input from other agencies) requested additional supporting information in April 1994. This information related to support for comparison of Telkwa with other coal mining regions and specific details of the proposed waste management plan.

1.3 OBJECTIVE AND STRUCTURE OF REPORT

In support of the information requests by MEMPR and to provide a comprehensive report on acid generation potential, MCL commissioned several reports to address specific aspects of acid generation studies, as follows:

- Brian McKinstry (1994) has prepared a report on the geology and variation of acid-base accounting parameters in the mine wastes.

- Piteau Engineering Ltd. (PEL) (1994) has prepared a report on water balances in the areas of Pits 7 and 8.

- MCL's geologists and engineers (MCL, 1994b) have completed a report on the geology and detailed waste management plan.

NDM has prepared this report to discuss the chemical aspects of acid generation and to provide recommended waste management options. The objective of this report is to determine whether the chemical aspects of acid generation potential at the Telkwa Project are well-characterized and can be used to develop the recommended waste management options.

The report has been structured, as follows:

Section	Contents
2.0	Describes the approach used to predict acid generation potential at the Telkwa Project and interpretation rationale.
3.0	Describes the predicted acid generation potential of each type of mine waste and of the whole site.
4.0	Presents recommended approaches to waste management including background, concepts, operational challenges, contingencies and application examples from other mines.
5.0	Summarizes conclusions for each of the above section.

2.0 APPROACH TO PREDICTION OF ACID GENERATION POTENTIAL

2.1 OVERVIEW OF PREDICTION APPROACH

Several different methods can be used to predict acid generation potential and the risk of potential ARD impacts at a proposed mine site:

- chemical and mineralogical characterization of waste materials (for example acid-base accounting (ABA));
- comparison with other mining regions, if applicable.
- evaluation of weathering of natural outcrops and existing mines in the project area; and
- kinetic evaluation of the reactivity and availability of minerals (for example, humidity cells);

Individually, these methods can provide useful information. A more thorough approach uses information from several of the sources. For the Telkwa Project, all of the above have been used to develop a comprehensive prediction of acid generation potential in both the individual rock units and the expected waste deposits. The following sections describe the methods used to generate and interpret the data for each source. Results and the interpreted acid generation potential are presented in Section 3.0.

2.2 ACID-BASE ACCOUNTING (CHEMICAL CHARACTERIZATION)

Acid-base accounting has been used for initial characterization of all potential waste materials at Telkwa. The sources of test materials and the methods used to obtain representative samples are described in the report by Brian McKinstry. Methods of analysis and interpretation are described below.

2.2.1 Analytical Methods

Acid-base accounting (ABA) is a relatively simple test procedure involving three components (Sobek *et al.*, 1978): (1) an evaluation of the presence of reactive carbonate using hydrochloric acid (the "fizz" test); (2) determination of the sulphur content; and (3) quantification of the acid neutralization potential of the rock. Each of these procedures is described below.

Evaluation of Reactive Carbonate Content

Three main types of carbonates are typically present in coal-bearing strata, namely, calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and siderite ($FeCO_3$). It is important to distinguish between these forms since calcite and dolomite are generally regarded as useful natural acid consumers, whereas pure siderite probably does not result in net neutralization of acid. When dissolved by acid, siderite releases ferrous iron which, when oxidized and precipitated at the reaction site or subsequently along the flow path, releases acid. The amount of acid produced ($2H^+$) is the same as that consumed:

$$2H^+ + FeCO_3 \dashrightarrow Fe^{2+} + H_2CO_3^o$$

$$Fe^{2+} + O_2 + 5/2H_2O \dashrightarrow Fe(OH)_3 + 2H^+$$

This test was performed by geologists in the field to qualitatively distinguish between the various types of carbonates. The degree of reaction with cold dilute hydrochloric acid with each of these minerals is a useful diagnostic tool (Hurlbut and Klein, 1977). Calcite reacts strongly with room temperature dilute hydrochloric acid producing a rapid effervescence ("fizz") and release of carbon dioxide. Dolomite reacts slowly, and siderite does not react. If the acid is heated, all three minerals will react with acid, though this is not done in the field.

A vigorous reaction was commonly observed in 60% of rocks from several parts of the Telkwa stratigraphic section. This indicates that calcite is present but not necessarily the absence of dolomite or siderite. Further discussion of the siderite content is presented under "neutralization potential".

Determination of Sulphur Content

Total sulphur concentrations are determined as an indication of total acid generation potential (referred to as maximum potential acidity, MPA). It is generally recognized that natural acid generation occurs as a result of sulphur oxidation; however, at coal mines, pyrite (FeS_2) is the only significant contributor to acid generation. Sulphur in organic or sulphate form is not significantly acid generating. The determination of sulphur in pyrite would be more appropriate than total sulphur. Unfortunately, pyritic sulphur determinations are usually not reliable.

For the Telkwa project, total sulphur in waste rock has been used as the indicator of acid generation. This leads to a conservative estimate of potential acidity but is also the correct basis for comparison with coal mines elsewhere. In wastes containing coal (unrecoverable seams, coal loss, coarse reject and fine reject), the pyritic sulphur content will be less than the total sulphur content due to the higher proportion of organic sulphur.

Neutralization Potential

Neutralization potential (NP) was determined as an indication of acid neutralization capacity. An initial test ("paste" pH) gives a qualitative indication of acid neutralization. If the paste pH is low (less than 5), the sample will not consume acid and may produce acid without oxidation. Paste pH's greater than 7 indicate acid neutralizing minerals are present.

Neutralization potential is expressed as kg $CaCO_3$/t since calcium carbonate is the preferred form of carbonate. In fact, neutralization potential represents the sum of all minerals which can potentially consume acid. In some rocks, silicate minerals may provide significant neutralizing capacity. However, silicate minerals present at Telkwa (Table 1) probably have approximately 0.1 to 1% the reactivity of carbonates (Kwong, 1993).

A potential concern with neutralization potential determinations is that siderite, which is probably not a natural acid consumer, may contribute to the neutralization potential (Morrison *et al.*, 1990a,b). This might over-estimate actual neutralization potential if siderite was a significant component. This is a legitimate concern since the oxidation of iron (II) to iron (III) by atmospheric oxygen is relatively slow and the laboratory procedure may not allow adequate time for the reaction to occur. Morrison (*ibid*) suggested addition of hydrogen peroxide at the end of the procedure to oxidize ferrous iron.

Metal and inorganic carbon dioxide concentration data determined by NECL (1990, see appendix of that report) for selected samples of all rock types were re-evaluated for indications of siderite content and interference of siderite in the NP determination. A note of caution is that the metal data were generated using an aqua regia digestion which also reacts with silicates, as shown by aluminum, potassium and sodium concentrations.

Calcium, magnesium, iron and carbon dioxide concentrations were calculated as calcium carbonate equivalents and compared graphically to neutralization potential (Figure 2). NP as iron carbonate was determined after estimation of iron contained in pyrite. The iron concentrations are the least reliable since iron silicates were probably the most susceptible to the strong acid digestion. The graph demonstrates that:

- all three estimates of the mineralogical form of carbonate are correlated with neutralization potential;

- total carbonate (from carbon dioxide) is probably composed of calcite, dolomite and siderite, since carbonate concentrations are mostly greater than iron, calcium and magnesium carbonates; and

- neutralization potential mostly closely correlates with estimated calcium and magnesium carbonate concentrations.

The last point is significant as, although siderite is probably present (although concentrations cannot be reliably estimated), it does not appear to be interfering with the neutralization potential determination. This suggests that the laboratory allowed enough time for the iron oxidation and precipitation steps to occur before completing the procedure. Neutralization potential is therefore a reliable indication of calcite and dolomite content.

2.2.2 Interpretation of Acid-Base Accounting

The acid-base accounts were calculated using two relationships. Net neutralization potential (NNP) was calculated from the conventional formula:

$$NNP = NP - MPA$$

Neutralization potential ratio (NPR) was calculated from:

$$NPR = NP/MPA$$

Maximum potential acidity (MPA) was calculated using the conventional 1 %S = 31.25 kg $CaCO_3$/t factor. Although higher factors have been suggested to account for re-evaluations of the acid neutralization reaction, the conventional factor is a basis for comparison with other datasets.

Evaluation of acid generation potential based on NNP and NPR requires an understanding of critical levels (or criteria) for which acid generation will not occur. It is important to distinguish between interpretation of the acid generation characteristics of discrete samples as opposed to large rock masses. The former depends on the concentration, reactivity and availability of the acid generating and acid consuming minerals. The latter is also dependant on the bulk heterogeneity and physical characteristics (for example, physical breakdown and resulting composition of rock fines) of the waste mass in addition to the other factors. The potential for acid generation in the large scale rock mass is relevant to waste management planning. Therefore, the approach used to acid generation interpretation for the Telkwa project has been to determine criteria for classification of acid generation and neutralization potential in large scale rock masses. The source and validity of these criteria are described in Section 2.3.

2.3 DEVELOPMENT OF CRITERIA FOR PREVENTION OF ARD

2.3.1 Appalachian Coal Mine Databases

Two possible approaches could be used to develop ARD prevention criteria for waste rock management. The first approach would rely on an extensive program of kinetic testing involving large scale rock piles and long term monitoring. The second approach would draw on existing operational experience with comparable coal deposits. Kinetic tests appear to offer the advantage of obtaining site-specific data and development of criteria directly applicable to the proposed mine. In practice, residual concerns always remain on extrapolation of small-scale laboratory and field tests to full-scale operating conditions. The time required to complete adequate test programs is often greater than a reasonable time frame for development. Therefore, waste rock management criteria developed from databases of coal mine water quality accumulated since 1977 for the Appalachian coal fields of Pennsylvania and West Virginia were examined. The Appalachian region was selected because coal deposits in this region were thought to resemble those at Telkwa and an extensive database is available. Comparison with other coal mines in western Canada would not be representative since these were deposited in a different paleoenvironment.

A reasonable concern with this type of geological comparison is that the geological and environmental conditions in the Appalachian coal fields are significantly different from those anticipated at Telkwa. To address this concern, appropriate comparative data relevant to acid generation data were gathered. The potential for acid generation and impact from acid rock drainage are controlled by several factors, including:

- types, abundance and occurrence of sulphide minerals - affects rate of oxidation, duration of acid release;

- types, abundance and occurrence of potential acid neutralizers - affects rate of acid consumption and characterization of the rock mass;

- coal paleoenvironment - affects the bulk sulphur content, for example, the sulphate in marine environments increases the sulphur content of coals and the host rock;

- physical characteristics of the rock - affects the exposure of the reactive minerals as a result of blasting and weathering;

- types of mines - primarily affects the size of the mines and limits the size of waste rock piles;

- types of mining methods - affects waste placement methods; and

- the buffering capacity of the receiving environment - affected by the carbonate content of surficial materials and bedrock downgradient of the minesite and the alkalinity of the receiving waters;

These factors are listed in Table 1. Two separate databases of information are available for Pennsylvania and West Virginia. The coals mined in these two states are comparable, therefore the data are essentially interchangeable. Although certain factors are fairly constant (sulphide mineral type, silicate mineral type), it is readily apparent that the databases represent a wide variety of geological and environmental conditions. This is particularly true for paleoenvironment, occurrence of calcareous tills, proportion of interburden rock type, occurrence of pyrite, occurrence of carbonates, sulphur content and neutralization potential. Brady (1994) noted that each mine site has its own unique characteristics. The coal mines in the databases do not represent sites with a narrow band of characteristics.

In terms of general geological and environmental comparisons, the characteristics of the Telkwa Coalfield fit within the range of conditions relevant to acid generation. The Appalachian region receives more precipitation and is milder than the Bulkley Valley (Telkwa) region. Significant snow accumulation is common at Telkwa but rare in the Appalachians. Climatic conditions in the Appalachians are probably more conducive to acid generation and leaching than in northern British Columbia, but the difference is probably not significant.

The relative proportions of carbonates are significantly different. Siderite is commonly referred to as the main carbonate at Appalachian coal mines (SES, 1985; Morrison et al., 1990b). At Telkwa, siderite is present but calcite and dolomite are more abundant (Palsgrove and Bustin, 1990). This represents a more desirable condition since it means that the measured neutralization potential is due to environmentally beneficial carbonates rather than siderite. In addition, calcareous tills are present at Telkwa. This represents a stronger assimilative capacity than is available for most mines in the Appalachian region.

The only characteristic that has not been reliably documented is the ratio of pyritic sulphur to total sulphur in the interburden rocks. This ratio is largely controlled by the presence of carbonaceous matter since organic sulphur is associated with vegetation, which is controlled by paleoenvironment. Since the Appalachian database covers a wide range of paleoenvironments, it is probable that the ratio is also highly variable in the interburden rocks and therefore this is not a significant datagap.

The above comparison shows that the Telkwa Coalfield does not possess any characteristics which would make it more susceptible to acid generation and ARD impacts, compared to the Appalachian coalfields. The presence of calcium and magnesium carbonates and calcareous tills indicate that the Telkwa Project would represent a better than average site for prevention of ARD if located in the Appalachians.

2.3.2 Acid Generation Prevention Criteria

Researchers in both Pennsylvania and West Virginia have investigated relationships between mass-weighted acid-base accounts and observed seepage water quality. This comparison is possible because after 1977, coal mining companies have been required to provide acid-base accounts for the complete mine sequence prior to receiving a mine permit. Since the permits were issued based on an acid generation prevention criterion of NNP>-5 kg $CaCO_3$/t, several sites have generated acid, thereby allowing a comparison of water quality and mass-weighted ABA's for a range of conditions spanning either side of equal MPA and NP.

diPretoro and Rauch (1988) evaluated data for 75 mines in West Virginia covering a wide range of conditions from NP:MPA = 0.1 to 4.3 (see Table 1). Drainage quality was described in terms of net alkalinity, where

$$\text{Net Alkalinity} = \text{Alkalinity} - \text{Acidity}$$

A positive net alkalinity is non-acidic drainage, and a negative value is acidic drainage. diPretoro and Rauch (*ibid*) found significant correlations between the ABA parameters and net alkalinity although the data showed considerable scatter. Table 1 summarizes the derived criteria for prevention of acid generation.

Brady *et al.* (1994) recently completed a similar evaluation of comparable data for 38 mines in Pennsylvania. Their approach to waste rock volume calculations was more rigorous than that used by diPretoro and Rauch (1988). As a result they were able to present better defined acid generation prevention criteria (Table 1). These are:

- NP>15 kg $CaCO_3$/t
- NNP>10 kg $CaCO_3$/t
- NPR>2.0

MPA is not used as a criterion since it does not appear to be related to drainage quality except for rock containing no neutralization potential.

In addition to the criteria defined by NP, NNP and NPR, the positive benefit of having calcium and magnesium carbonates (carbonates "fizzing" with dilute hydrochloric acid) is noted. Mines generally lacking carbonate would be considered a higher risk for ARD. Brady (1994) also noted that the presence of groundwater with alkalinity exceeding 70 mg $CaCO_3$/L was a positive factor.

Based on the comparison of information from the Appalachian coal mine databases, the criteria developed by Brady *et al.* (1994) are appropriate for Telkwa. Given the presence of reactive carbonates and calcareous till in the project site, the Appalachian criteria should provide a conservative margin of safety for the Telkwa Coal project.

2.4 CORRELATION OF FIELD CONDITIONS AND KINETICS

2.4.1 Telkwa Project Area

Several features of the Telkwa Project area have been evaluated to support the waste rock ABA study, as follows:

- coal has been mined historically at Telkwa;

- a large scale bulk sample (200 t of coal, approximately 2000 to of waste rock) was collected by CNRL from the proposed Pit 3 and the excavation backfilled with waste rock; and

- groundwater quality has been monitored in the Pit 7 and 8 area.

Natural outcrops of the stratigraphic sequence for proposed mining are rare. Exposures of the coal measures are limited to Seam 1. An older open pit (the Forestburg Mine, Figure 1) extracted coal from Seams 2 to 6. This is the same sequence as the proposed Pit 7. In September 1993, the pit area was visited. Underground workings (Figure 1) appeared to have extracted Seam 1. This seam will not be mined under the current proposal and the associated stratigraphy has not been characterized.

Seepage from the bulk sample backfill provides an opportunity to compare observed water quality predictions of water quality based on ABA. This seepage was sampled in September 1993 (PEL, Baseline Data Surface Water and Groundwater Quality Telkwa Coal Project - report in preparation).

Groundwater quality from the pit areas provides evidence of natural in situ neutralization.

The results and interpretation of these studies are described subsequently in Section 3.3.2.

2.4.2 Kinetic Testing

Eleven column leach experiments were conducted by SES (1985). The test materials were composites of whole core previously used for acid-base accounting representative of the stratigraphic section in the Pit 3 area. Three different configurations were used (Table 2):

- whole core composites (thoroughly mixed);
- the same bulk composition as above but potentially acid generating zones segregated and surrounded ("buried") by acid consuming rock; and
- potentially acid generating rock.

The tests were conducted in 1 L or 2 L polyethylene bottles using 500 or 1000 g of rock screened to 2 mm. Size fraction analyses, petrographics and post-test analyses were not completed by SES. The material was humidified from the base and leached weekly. The volume of water introduced and leachate recovered were recorded. Each week, the leachate was analyzed for pH, total hot and mineral acidity, total alkalinity, conductivity, dissolved solids, sulphate, total iron and manganese, and dissolved sodium. Composite unfiltered leachates from eight weeks of leaching were analyzed for a variety of metals.

Since the tests were only run for eight weeks. They provide indications of the early oxidation rate under non-acidic conditions. To provide a basis for comparison of the tests, sulphate concentrations were converted to mg SO_4/kg/week. The formula used is:

$$R_{sulphate} = \frac{\text{Sulphate Concentration (mg/L) x Volume of Leachate (L)}}{\text{Mass of Sample (kg)}}$$

Based on this estimated short term rate, the time to consume all sulphur in the samples was estimated from:

$$t_{consume} = 3000S_T/R_{sulphate}$$

Finally an estimate was made of the time to produce acid based on the assumptions given in Table 2. Results of the calculations are provided in Table 2.

3.0 ARD CLASSIFICATION OF WASTE MATERIALS

3.1 OVERVIEW OF GEOLOGICAL FEATURES

The coal-bearing sequence in the Telkwa Project area consists of a series of coal seams separated by waste siltstone, sandstone and mudstone. A series of zones (designated I to VIII, where I is stratigraphically lowest and oldest) have been recognized between these layers for the purpose of classification. The report by Brian McKinstry (1994) demonstrates that these zones are the most appropriate bases for correlating acid generation potential with geological sequence in the various parts of the property. The Brian McKinstry (*ibid*) report describes in detail the levels of the various significant parameters in each zone. The following sections describe how these relate to the acid generation potential.

3.2 ACID GENERATION AND NEUTRALIZATION CHARACTERISTICS OF EACH WASTE MATERIAL

The following sections summarise lithological and acid-base accounting information reported by Brian McKinstry (1994). All characteristics were determined on fresh materials. Since the Telkwa Coal is not exposed in the area to be mined, no naturally oxidized rock (gossan) will be removed.

3.2.1 Sedimentary Waste Rock

In general, variation in acid generation potential is caused by variations in pyrite content, which is controlled by the presence of carbonaceous matter, that is, higher sulphur concentrations are associated with reducing conditions at the time of deposition of mudstone and coal layers. Neutralization potentials vary to a much lesser degree since carbonate in these rocks originates as a diagenetic (post-depositional) product in the form of cementation, veinlets and fracturing fillings.

Exposure of reactive minerals should be comparable in waste rock. Siltstones and mudstones at Telkwa tend to slake readily leading to equal exposure of pyrite and carbonates. In more resistant rocks such as sandstone, slaking will be less rapid but breakage of rock will probably occur along fractures and veinlets resulting in preferential exposure of carbonate minerals. These factors cannot be readily quantified but qualitatively it is not expected that the availability of either pyrite or carbonate minerals will limit the potential for acid generation or consumption.

Metal concentrations in selected samples of waste rock were previously described by NECL (1990). Metal concentrations were typical of this type of sedimentary sequence.

Zone I

Zone I comprises siltstones and sandstones underlying Seam 2. In the Pit 8 area, volume-weighted sulphur concentrations for drillholes vary little (0.3% to 0.5%) and neutralization potential is greater than maximum potential acidity. NNP is never less than zero in any part of the zone in Pit 8 and the NPR exceeds 3.0. In Pit 7, overall NNP's are greater than zero and NPR exceeds 2.2, although sulphur content is more variable than in Pit 8. A 3-m thick sandstone unit has 1.7% sulphur.

Zone I is predicted to be acid consuming on balance. An isolated sandstone layer containing elevated sulphur concentrations in Pit 7 could be selectively segregated. However, since sandstones tend to be more competent than the associated siltstones (PEL, 1994), the layer represents a lesser source of acid generation potential and could be handled with the balance of acid consuming rock.

Zone II

This zone comprises finer sedimentary rock (mudstone and siltstone) between Seams 2 and 3. In Pit 8, this zone is a consistently acid consuming with low average total sulphur content (0.2% to 0.4%). However, in Pit 7, the proportion of mudstones in the section increases and is correlated with increased pyrite content near Seam 3. The lower part of Zone II in Pit 7 may or may not be acid generating (NPR = 1.3). The upper part is potentially acid generating (NPR = 0.33).

Zone III

Zone III comprises mudstones and coal with minor siltstone between Seams 3 and 5. Total sulphur concentrations are elevated (0.6% to 2.0%). These may be higher than the reactive sulphur content since part of the sulphur is expected to be present in organic form. Nonetheless, the zone is consistently classified as potentially acid generating.

Zone IV

The lithology of this zone is comparable to Zone III and represents rocks between Seams 5 and 6. However, average total sulphur concentrations are lower in Pit 8 (0.2% to 0.9%) with comparable neutralization potentials. In Pit 7, part of the zone is expected to be acid consuming in the northern part and potentially acid generating in the southern part.

Zone V

Zone V is a coarser sequence of sandstones and siltstones between seams 6 and 8. Total sulphur concentrations are variable in this zone (0.3% to 1.1%) but the zone is consistently acid-consuming on average.

Zone VI

Zone VI comprises a mixed sequence of mudstone, coal and sandstone between Seam 8 and the base of a distinctive green sandstone. Average total sulphur content is elevated (1.2% to 2.5%) and therefore the zone is consistently predicted to be acid generating (NPR<0.8).

Zone VII

Zone VII is the green sandstone. Most of this unit contains elevated total sulphur concentrations (1.7% to 3.1%) and is potentially acid generating (NPR<0.6). To the west, however, sulphur content decreases to 0.8% and neutralization potential increases from typical average values of about 30 kg $CaCO_3$/t elsewhere in the sequence to 74 kg $CaCO_3$/t. Brian McKinstry (1994) infers that this could represent an increased freshwater influence.

Zone VIII

Lithologies in this zone above the green sandstone are siltstone and mudstone with minor sandstone. Coal is absent. Sulphur content is lower than elsewhere (0.3% to 0.6%) and neutralization potentials are higher (35 to 59 kg $CaCO_3$/t). As a result, this zone is predicted to be acid consuming.

Oxidation Rates

Information is available on short term oxidation rates (indicated by sulphate release) at neutral pH by the 8-week kinetic tests conducted by SES (1985) (Table 2). No information in oxidation rates under acidic conditions was obtained, although experience on other projects suggests that the rates would be two or three orders-of-magnitude higher. The following features were observed:

- A very strong correlation exists between total sulphur concentration and sulphate release rate at approximately neutral pH (Figure 3) showing in general that the reactivity of the pyrite is not highly variable. The derived relationship is:

$$\text{Rate (mg } SO_4\text{/kg/week)} = 112 \ln(S_T) + 111.$$

- The sulphate production rates are relatively high, probably due to the typical rapid slaking nature of the sedimentary rock.

- As a result of the rapid sulphate release rates it is predicted that all pyrite would be consumed in less than a decade if initial rates were maintained and all sulphur were to be available for oxidation (Table 2). This would certainly hold true for potentially acid generating materials since sulphate release rates would be much greater under acidic conditions. The assumption is less likely to be true for non-acid generating materials.

- Alkalinity in all rock types is readily available as acid-consuming calcium and magnesium carbonates. This will provide short-term buffering capacity in potentially acid generating rocks. A moderately well-correlated relationship between NPR and time when acid could conceivably be released (see Table 2, footnote 5 for calculation assumptions) (Figure 4) is:

  $$t(\text{months}) = 9.924\text{NPR}^{0.6745}$$

  The relationship is similar to one derived from Ferguson and Morin (1991) for laboratory kinetic tests for numerous metal mine sites:

  $$t(\text{months}) = 13.75\text{NPR}^{0.5}.$$

  This relationship is shown in Figure 4 and shows, as expected, that release of ARD would be expected sooner from coal mine wastes.

3.2.2 Coal

Coal is predicted to be potentially acid generating based on an average total sulphur concentration of 1.5% and neutralization potential of 21 kg $CaCO_3$/t. Although over 35% of the sulphur is present in non-pyritic form.

3.2.3 Granodiorite Intrusive Waste Rock

The granodiorite intrusive contains negligible total sulphur but, based on four samples, fairly uniform neutralization potential (32 to 41 kg $CaCO_3$/t). Inorganic carbon dioxide determinations yielded comparable equivalent calcium carbonate concentrations. However, site geologists have not observed calcite or a strong reaction with hydrochloric acid. This probably indicates that the calcium carbonate is an alteration product of calcic plagioclase or other silicates. In addition, the rock does not break down as readily as the sedimentary rock when blasted. This rock is likely to be acid consuming, but the neutralizing potential may not be completely available or, alternately, it may be released slowly.

3.2.4 Glacial Till

Glacial till consists of clay and crushed rock originating from outside the Telkwa Project area and contains negligible total sulphur concentrations. Determinations of neutralization potential may not be reliable due to the effect of fine silicates. Unoxidized till has been observed to react rapidly with hydrochloric acid and is therefore inferred to contain free calcite. Therefore, inorganic carbon dioxide concentrations appear to be a reliable indicator of carbonate content in the glacial till. These are lower than the equivalent neutralization potentials. Occurrences of detectable carbonate (>0.2% CO_2) are patchy in the till but indicate that it can be used as an acid neutralizing material, and that in contact with water it will yield dissolved alkalinity.

3.2.5 Preparation Plant Rejects

Coarse Rejects

Acid-base accounts for four coarse reject samples representing Seams 2, 3, 5 and 6 in the Pit 7 area indicate variable total sulphur concentrations (1.2 to 3.9%) and neutralization potential (25 to 58 kg $CaCO_3$/t). Due to the presence of coal and other organic matter in carbonaceous rejects, total sulphur content probably over-estimates the acid generation potential of this material. Neutralization potential is also a more reliable indicator of acid consuming minerals than inorganic carbon dioxide since other iron carbonates may be present.

The coarse rejects are expected to be potentially acid generating (NPR<1, NNP<0) on average either based on total sulphur (NPR 0.6) or sulphur in pyritic form (NPR 0.8). Neutralization potentials (25 to 58 kg $CaCO_3$/t) are comparable to rock from elsewhere and indicate the presence of significant buffering capacity. Coarse rejects should be assumed to be potentially acid generating for the purpose of waste management.

Based on observed oxidation rates in kinetic tests on silty rock with similar total sulphur content (potential acid generators in Table 2), carbonate in the rock could naturally buffer oxidation products for up to a year. This assumes that the average total sulphur content is 2.7%, average neutralization potential is 39 kg $CaCO_3$/t, and about 40% of the neutralization potential would be available to buffer acid generation under pH neutral conditions. At the relatively elevated oxidation rates observed, sulphur consumption is potentially very rapid, although it is expected that low sulphate production in the absence of neutralizing minerals after peak acid production would lead to a longer duration of acidic drainage.

Preparation Plant Fine Tailings

A limited ABA testing program of coal seam fines reported by Norecol Environmental Consultants (1991) indicated that neutralization potentials ranged from 19 to 36 kg $CaCO_3$/t for four samples from the main seams. The samples were obtained from pilot scale testing and are comparable to tailings. Although total sulphur concentrations varied from 1.5 to 2.8% (MPA 47 to 88 kg $CaCO_3$/t), an estimate of pyritic sulphur concentrations indicated that the reactive sulphur content varies from 10 to 50% of total sulphur. Unlike rock and coarse rejects, carbonate content was lower than or equal to the neutralization potential.

Ferguson and Morin (1991) indicated that if NPR>1, tailings are unlikely to be acid generating, although this conclusion was made for metal mine tailings. However, metal mine tailings tend to be more permeable and less carbonaceous than coal mine wastes. The low permeability of the coal tailings would be expected to enhance saturation thereby limiting the depth of oxidation if the tailings are not saturated. The Telkwa project tailings may or may not be acid generating. For the purpose of mine planning, it is assumed that the tailings are potentially acid generating, although the composition of the tailings should be monitored during operation.

3.3 SITE ACID GENERATION POTENTIAL

3.3.1 Volume Balance and Comparison with Appalachian Coal Mining Region

Volume-based materials balance sheets were determined and reported by Brian McKinstry (1994) for management of all waste materials (sedimentary and igneous waste rock, till, coal losses). The assumptions used to generate the balances are provided in his report.

The balance for Pit 7 has the following weighted ABA values:

- MPA = 31 kg $CaCO_3$/t
- NP = 34 kg $CaCO_3$/t
- NNP = 3 kg $CaCO_3$/t
- NPR = 1.1

Comparison of these values with the criteria presented in Table 1 indicates that specific waste measures will be required to ensure that the wastes do not generate acid. The criteria could be reached specifically by not including Zone II and a problematic portion of Zone IV.

The balance for Pit 8 has the following weighted ABA values:

- MPA = 19 kg $CaCO_3$/t
- NP = 37 kg $CaCO_3$/t
- NNP = 18 kg $CaCO_3$/t
- NPR = 1.9

These values indicate that all but NPR significantly exceed the criteria presented in Table 1. NPR is close to 2.0 and the variability of the estimate will cover 2.0. It is expected that some management will be required to ensure that NPR exceeds 2.0 throughout the operation, although the volumes of waste which must be segregated will be relatively small.

In summary, the volume balances indicate that the proposed criteria levels developed by Brady *et al.* (1994) and diPretoro and Rauch (1988) are attainable for both Pits 7 and 8 with some specific waste management measures. Since NP is much greater than the criterion, waste management in terms of NPR is recommended.

3.3.2 Existing Water Quality

Seepage from backfill in the CNRL test pit in the vicinity of Pit 3 provides a useful opportunity to test the validity of the relationships observed in the Appalachians with reference to Telkwa. Measured net alkalinity for this seepage is estimated at 367 mg $CaCO_3$/L, although active sulphide oxidation is probably occurring (as shown by dissolved sulphate concentrations of 284 mg/L). The ABA characteristics of the backfill are not accurately known but probably fall in the following range (SES, 1985; NECL, 1991b):

NNP = 20 to 40 kg $CaCO_3$/t
NPR = 2.5 to 4

Figure 5 illustrates how these data compare with similar data from the Appalachians. It is apparent that the Telkwa data lie within the range of conditions observed in the Appalachian although the net alkalinity is higher at Telkwa than might be expected. This may be a result of the greater proportion of reactive calcium and magnesium carbonates at Telkwa. The data indicate that Telkwa is not a "worst case" when compared to the Appalachian database and support the conclusion that alkalinity would be more available at Telkwa than at an average Appalachian mine.

Existing mines and natural seeps in the project area also show no evidence of acid generation and are pH neutral. At the backfilled Forestburg Mine, which mined seams 2 to 6, emergent seepage at one location has formed iron hydroxide precipitates but was non-acidic (pH>7) in September 1993. The precipitate originated from oxidation of iron in solution by contact with the atmosphere. White coatings on boulders downslope of seepage in other areas reacted strongly with hydrochloric acid indicating that the coatings were calcium carbonate formed from alkaline waters. The waste rock dumps in general did not appear strongly oxidized. Since this mine extracted the same seams as the proposed Pit 7, the findings support the conclusion that the stratigraphic sequence contains sufficient neutralization potential to consume acidity produced by pyrite oxidation.

3.3.3 Site Assimilative Capacity

The closest water body potentially affected by the open pits (7 and 8) and the associated waste rock dumps is the Telkwa River. Since the pits are on a bench 200 m or more above the river, water originating in the pit area would likely enter the river via the groundwater rather than runoff and surface seepage. Surface runoff will be collected in ditches running over glacial till to the tailings pond. Groundwater would flow in glacial till or bedrock. Both till and bedrock are generally calcareous (as shown by strongly alkaline groundwater). It is estimated from the expected groundwater pathways and average NP of glacial till and bedrock that there is sufficient neutralization potential in geological materials along groundwater pathways to effectively neutralize all potential acidity generated by oxidation of sulphur in the waste rock without any *in situ* neutralization. Although it is not intended to use the natural downgradient buffering capacity to neutralize ARD, the assimilative capacity provides an additional safety factor to mitigate potential impacts.

4.0 OPTIONS FOR MANAGEMENT OF WASTE MATERIALS TO PREVENT ARD

4.1 UNDERSTANDING OF GOVERNMENT EXPECTATIONS FOR PREVENTION OF ARD

The British Columbia Ministry of Energy, Mines and Petroleum Resources (EMPR) (British Columbia Reclamation Advisory Committee, 1993) recently released a draft policy document describing its preferred approach for management of acid rock drainage at mine sites. The document was largely developed based on recent experience at metal mines and generally does not address coal mining. It is understood that the document is intended to guide rather than regulate preparation of waste management plans, and that evidence may be provided by mine proponents to support less conservative approaches for waste management, such as waste rock blending.

The draft policy indicates, in general, that long term water treatment is an unacceptable ARD management approach. The preferred approach is to control acid generation *in situ* thereby substantially reducing the risk of ARD release. The management plan for Telkwa therefore focuses on ARD prevention measures. Although it is recognized that the risk of ARD can not be completely eliminated, the preferred approach employs the most suitable measures and contingencies to waste management. Potential measures described in the policy are sub-aqueous disposal, blending of potentially acid generating and acid-consuming rock to form an acid-consuming mixture, and segregation/encapsulation of acid generating rock. Recent Mineral Development Certificate (MDC) application decisions indicate the acceptability of:

- sub-aqueous tailings and waste rock disposal in man-made impoundments or natural lakes (Eskay Creek, Mt. Milligan),
- segregation of potentially acid-generating material in waste rock dumps designed to be capped with glacial till if required, and in controlled catchment areas (Mt. Milligan);
- deposition of waste rock in sub-aerial dumps for acid consuming rock (Eskay Creek, Mt. Milligan); and
- mixing of potentially acid generating and acid consuming rock in dumps (Quesnel River Gold).

4.2 FRAMEWORK FOR WASTE MANAGEMENT AT TELKWA

Rock wastes at Telkwa can be broadly classified into three categories, namely:

1. discrete acid consuming wastes (glacial till, granodiorite);

2. acid consuming wastes in general (NPR>2) but containing potentially acid generating and acid consuming components (most pit waste rock); and

3. potentially acid generating wastes (nominally NPR<2) (some pit waste rock, coarse and fine preparation plant rejects).

Approximate volumes of these different types of wastes are summarized in Table 3. Chemical volume balance calculations indicate that the largest volume of waste falls into Category 2. It is expected during operation that Category 3 waste rock will need to be selectively segregated from Category 2 rock to maintain the desired Category 2 NPR of greater than 2 in the waste rock dumps. That is, a relatively small volume of potentially acid generating rock (see Table 3) may not be suitable for disposal in the dump(s) active at that time. This rock should be managed with other Category 3 wastes. Within the proposed mine plan, several options are available for handling Category 3 wastes, including disposal in the fine tailings impoundment, disposal in decommissioned pits and stockpiling.

Proposed waste management options are discussed in the following sections.

4.3 DESCRIPTION OF WASTE MANAGEMENT OPTIONS

4.3.1 Rock Used for Construction

MEMPR's draft ARD policy indicates that construction materials should have total sulphur concentrations less than 0.5%, NPR greater than 4:1, paste pH greater than 5.0 and no significant potential for losses of residual weathering products. In terms of preventing ARD, any of the Category 1 wastes are suitable for construction purposes. Since these materials are not mineralized or originating from a gossan, losses of residual weathering products are unlikely.

4.3.2 Waste Rock Blending

Description

Waste rock blending implies operational mixing of potentially acid-generating and acid-consuming rock to form a net acid consuming rock mass. The ability of blending to prevent ARD will depend on two main factors. The first factor relates to the chemistry of the acid generation and neutralization reactions and the availability of the minerals in the reactions. That is, a certain quantity of acid neutralizing materials is required to consume acid produced by the potentially acid generating materials. The second factor relates to the heterogeneity ("degree of mixing") of the waste rock mass as a whole. Since potentially acid generating and acid consuming rocks occur in different sections, mining without management of wastes could result in spatial segregation of wastes. Acid produced would not necessarily be neutralized by contact with the acid consuming rocks and ARD could be released. Operational waste rock management is therefore required to ensure prevention of ARD.

In a mineable deposit type for which little information on chemistry is available, site-specific operational blending criteria would be needed to control both the chemical and heterogeneity factors. For Telkwa, however, geological and field evidence demonstrates that the geological and environmental conditions are comparable to coal mines in the Appalachian region. Therefore, Appalachian criteria developed for operational blending allow for the chemistry of acid generation and neutralization, operational mixing of potentially acid generating and consuming rocks, and the availability of the various minerals in different size fractions. In Section 2.3.2, it was noted that waste rock dumps should not generate acid if certain criteria were exceeded, based on the Appalachian experience. The recommendation therefore is to control waste rock dump bulk chemistry such that the criteria are satisfied on a lift-by-lift basis.

Details of Management Concept

During operation, waste rock composition will need to be monitored in the pits and at the active waste rock dump. The suggested sequence of operations is described in the following sections.

The pits will be mined in benches. At any time during mining, several coal seams may be exposed as well as several of the interburden zones (designated I to VIII in Brian McKinstry's report). These zones have been characterized as part of acid generation studies and have variable acid generation and consumption characteristics. The ABA characterization to date has been used to determine whether the general waste management concept is applicable; however, additional characterization will be needed during mining to confirm the ABA's for each zone. Initially, operational sampling for ABA will be fairly intensive but as the ABA database expands, sampling intensity can be reduced. Rock samples for ABA could be obtained from blast hole samples.

A pit geological engineer should be responsible for developing the dumping plan for the current waste rock dump lift which accommodates the waste rock zones exposed at that time in the pit floor. The engineer should determine a schedule for dump trucks leaving the pits. Individual dump trucks should be designated as containing either potentially acid generating or acid consuming rock. To facilitate monitoring, decals on the trucks or truck colour could indicate the type of rock being removed. The engineer should determine the appropriate average frequency of trucks of each type in order to achieve the NPR of 2.0 (or better) in the current lift. For example, an appropriate ratio could be four acid consuming rock trucks for every acid generating rock truck. To facilitate mining, the truck ratio will need to vary. It is suggested that the ratio should generally not fall below a level such that the NPR would be less than 1.0 at any given time. If more acid generating rock is produced than can be handled, this rock will need to be directed for other means of disposal or stockpiling (see Sections 4.3.3 and 4.3.4). The destination of trucks could be controlled by radio communication.

At the waste rock dump, individual truck loads should be deposited in sequence to maintain the truck ratio in the current dumping area. Therefore, trucks should unload such that every "n"th load will be potentially acid generating rock where n is the truck ratio. In areas where the dumping method is less likely to result in mixing (for example, piles are dumped side-by-side and do not mix under the influence of gravity), a bulldozer could be used to grade the piles, thereby resulting in a greater degree of mixing. To avoid inception of localized acid generation, this procedure should probably be performed less than 2 months after dumping.

In the event that it is preferable to stockpile waste rock before including it in the mixed waste rock dumps, measures needed to prevent acid generation during stockpiling will depend on the NP and sulphur content. This is discussed in Section 4.3.5.

Operational Challenges

Key factors relate to the management of acid generating and acid consuming rock in the pit and the degree of mixing achieved in the waste rock dumps.

The successful management of rock within the pits is dependant on the ability to visually recognize the different types of rocks. However, it is proposed that the rock be managed on a zone-by-zone basis rather than a rock layer basis. In some instances, the zones may split into two or three sub-zones based on substantial lithologic variation. This eliminates the problems associated with correlating a specific rock layer and reduces the problem to correlation of coal seams. Since the coal seams are reliable marker units and must be thoroughly correlated for cost-effective mining, the interburden layers will also be well-correlated and should be readily manageable even during difficult operating conditions such as snowstorms or fog.

A second in-pit management issue relates to the control and movement of trucks. A strict definition of dumping sequences should be established to manage material movement to the waste dumps.

The second issue relates to the degree to which the different waste rock types will be mixed in the waste rock dump. Mixing will effectively be achieved by controlling the frequency of relatively small dumps trucks of potentially acid generating rock reaching the waste rock dumps since it is not practical to mix rock by combining two streams. On a small scale, the two types of materials will be deposited as discrete loads; however, at full scale (for example a 2 million m^3 dump is composed of 45,000 75-t dump truck loads), each dump truck load becomes a small component.

In the vertical direction, it will not be possible to avoid occasionally depositing two acid generating loads on top of each other. It is not practical to survey the position of individual loads in the dump. Assuming random orientation of lifts, the probability of stacking two loads will be 1/(n+1) where n is the number of potentially acid consuming rock loads for every acid generating rock load. The probability of stacking three loads will be $1/(n+1)^2$. For example, if n=5 (a probable typical value), the following probabilities would apply:

Stacked Loads	Probability
2	17%
3	3%
4	0.5%
5	0.002%

Contingencies and Monitoring

The following contingencies are suggested, in the event that any acidic seepage is produced:

- the dumps should be sited such that any surface seepage could be collected and routed to the tailings pond area for treatment;
- compacted till could be placed on selected dumps, if necessary, to reduce infiltration and oxygen diffusion; and
- the dumps will be placed on calcareous glacial till overlying a predominantly calcareous sedimentary sequence.

The latter point is particularly significant and considerably reduces the potential for impacts on groundwater in the unlikely event that acid is produced (see also Section 3.3.3).

In the event that drainage treatment were to be required, treatment would not be a long term requirement. Estimated times to consume all sulphur are less than a decade. Pyrite tends to oxidize rapidly in coal mine wastes (as shown by kinetic tests, Table 2).

Monitoring is recommended to evaluate internal conditions in the waste rock dumps and water quality downgradient. Internal monitoring would consist of temperature and gas concentrations. Downgradient of the dumps, monitoring boreholes and seepage collection should be used to evaluate water quality. A reliable advance monitoring indicator would be the ratio of sulphate to calcium + magnesium (expressed in molar terms).

Operational Examples

Two data sources permit thorough evaluation of the viability of waste rock mixing as a management approach:

- the extensive Pennsylvanian and West Virginian databases provide a spectrum of mines for which waste rock acid-base accounts and drainage quality are known; and
- documented examples of waste rock mixing or limestone addition.

The Appalachian databases do not on the whole represent mines that intentionally mixed waste rock to prevent acid drainage. Instead, the mines were issued permits based on earlier less conservative ARD prevention criteria. These mines would have minimized the potential for ARD release using commonsense measures (such as not segregating potentially acid generating rock), but would not have managed waste rock to the degree proposed for Telkwa Coal. Therefore, the use of this database to justify waste rock mixing at Telkwa Coal is valid because the mixing criterion proposed (NPR>2) was developed for mines which did not specifically mix their waste rock dumps but released non-acidic drainage.

Examples of limestone addition are presented in Section 4.3.5.

4.3.3 In-pit Sub-aqueous Disposal/Pit Water Quality

Description

As noted in Section 4.3.2, it is expected that a small volume of potentially acid generating waste rock (estimate provided in Table 3) may not be incorporated in the mixed waste rock dumps due to the need to maintain NPR>2. Sub-aqueous disposal in non-active pits is the best option for this waste rock. As noted in Table 3, flooding of the pits could allow sub-aqueous disposal of approximately three times the anticipated volume of acid generating rock which might not be included in the mixed waste rock dumps. This allows a wide margin for uncertainty in the predicted volumes.

Sub-aqueous disposal has several advantages. Firstly, the water cover significantly reduces the rate of pyrite oxidation, as has been documented by numerous studies. Secondly, the neutralizing minerals in the potentially acid generating wastes continue to be available to create an alkaline environment in the saturated backfill (Patterson, 1989). Therefore, if the rock is slightly oxidized when disposed, or is not fully submerged, leached acidity will be neutralized by contact with reactive carbonates. Since coal wastes, in general, do not release deleterious substances (primarily zinc, stable in solution at neutral pH), pit water quality produced by leaching of oxidized rock is expected to contain elevated sulphate concentrations but generally low concentrations of iron.

A potential concern relating to sub-aqueous disposal is the net alkalinity of the pit water. If the pit water were to be acidic, leaching of the backfilled waste rock might be a concern. It is likely that some strata in the pit walls will produce acidic seepage. However, the overall acid-base account for all pit walls will be acid-consuming and therefore the pit water will be alkaline with elevated sulphate concentrations.

In Pit 7, this is a result of:

- glacial till in the top 10 to 20 m of the pit walls is calcareous;
- the north wall is composed of acid consuming granodiorite;
- the floor of the pit will be in acid consuming Seam 2 footwall rock; and

- the highwall east of the fault is composed of predominantly acid consuming rock beneath Seam 2.

In Pit 8, similar factors apply. In addition, the strata are expected to be less pyritic than Pit 7 and the overall NPR of the coal-bearing strata is near 2.0.

In-pit sub-aqueous disposal is therefore a suitable approach for perpetual disposal of potentially acid generating rock which cannot be accommodated in the mixed waste rock dumps.

Details of Management Concept

The concept of sub-aqueous disposal is relatively simple. Dump trucks containing potentially acid generating rock unsuitable for disposal in the mixed waste rock dumps could be re-directed to a suitable open pit. The waste rock should be dumped so as to ensure that it is underwater. The dumping procedure will need to avoid leaving a portion of the waste rock on pit benches. This could be achieved by accessing the pits down the Seam 2 footwall.

In the event that potentially acid generating wastes must be deposited above the current water level, temporary in-pit encapsulation with glacial till or limestone addition could be used (see Sections 4.3.4 and 4.3.5). This should not be attempted until the predicted rate of flooding (Piteau, 1994) has been confirmed.

Operational Challenges

The main challenge relates to the steps taken to ensure that the rock is flooded within a few weeks to prevent significant oxidation. As noted previously, the presence of neutralizing minerals in the pits' walls and potentially acid generating rock should mitigate acidity potentially released prior to flooding.

Contingencies

The need for contingencies relates to the extremely unlikely event of pit water becoming acidic. The pit could then be backfilled with acid consuming waste rock and till and finally capped with till.

Operational Examples

The nearby Equity Silver mine represents an example of backfilling an acid generating pit with potentially acid generating rock resulted in non-acidic pit water. Zinc concentrations remained elevated since the buffering pH natural carbonate minerals was not high enough to precipitate zinc carbonates and hydroxides (Patterson, 1989). This situation will not occur at Telkwa due to the absence of abundant zinc-bearing minerals in the host rocks.

4.3.4 Disposal of Segregated Waste Materials - Glacial Till Capping

Description

During development of Pit 7, it is expected that some potentially acid generating waste rock (refer to Table 3) may be produced that will not be suitable for inclusion in the mixed waste rock dumps. Also, a suitable pit for sub-aqueous disposal will not be available until later. This waste rock management approach proposes use of stripped glacial till at the site to cap piles of this waste rock. The capped piles should be placed in a location suitable for perpetual disposal should monitoring indicate that acid generation is not occurring. If the piles show evidence of significant acid generation, the material is accessible for re-location to a completed pit.

Glacial till capping will prevent acid generation in situ by reducing oxygen diffusion into the unsaturated waste rock pore spaces. Oxygen in the pore spaces is consumed initially at the same rate as if the rock was not covered, but the oxidation rate then rapidly decreases to a rate in equilibrium with the reduced oxygen supply. At metal mines, oxygen movement in waste rock piles is by temperature driven advection ("wind") (Gélinas *et al.*, 1994) in the pile. The presence of a fine-grained cover practically eliminates advection as an oxygen transport mechanism.

A low permeability cover also reduces infiltration, thereby reducing the volume of water available for contaminant transport, and, the volume of contaminated seepage, if any.

The thickness of a cover required to achieve the desired reduction in oxygen diffusion and infiltration rate is probably, about 30 cm. A thicker cover reduces the potential for significant breaches due to settlement and penetration by roots and animals.

Use of till covers on wastes at Telkwa is attractive, for several reasons:

- the volume of till available is such that thick covers (greater than 1 m) could be placed on the waste rock;
- the deeper less weathered tills are calcareous and contain visibly reactive carbonate, therefore, infiltrating water will initially be alkaline and inhibit oxidation in the rock closest to the nearest source of oxygen; and
- the potentially acid generating sedimentary rocks are mostly fine-grained and will tend to slake (physically breakdown) soon after blasting thereby further reducing permeability in the rock mass.

It should be noted that most other recent examples of glacial till covers have generally involved a limited supply of suitable till, non-calcareous till and intrusive or volcanic metal-mining waste rock with limited slaking tendency (see operational examples, below).

Details of Management Concept

A suitable capped waste rock pile location should be selected such that seepage can be readily collected and groundwater monitored. The site should be separate from the main mixed waste rock dumps and should be readily amenable to re-excavation, if required. Based on the sulphate production rates in kinetic tests (Table 2, Figure 4), internal evidence of acid generation might be detected within four months to one year of placement of the waste rock depending on the average NPR of the pile.

The piles would contain potentially acid generating rock which cannot be incorporated into the mixed waste rock dump. It is anticipated that the disposal area would be used periodically rather than continually, and will be required during the early years of mining until suitable in-pit disposal locations become available. The amount of rock potentially capped is shown in Table 2 (Category 2 wastes). During active dumping, till caps need not be placed since the alkalinity released from newly deposited rock should be sufficient to maintain mostly alkaline conditions in the rock beneath and prevent surface oxidation. However, during periods of inactivity (more than a few months), a compacted till layer should be placed to limit oxidation of the surface layer. Based on column leach tests on several potentially acid generating rock types from the Pit 3 area, a cover should be placed after three months to allow for the lowest neutralization potentials expected in the waste (Figure 4).

Finally, once a particular pile has been completed it should be capped with a till layer at least 1 m thick. Based on experience elsewhere (see operational examples), about two-thirds of the cover needs to be mechanically compacted with the balance as an uncompacted layer suitable for vegetative growth. Each pile and its cover should be instrumented to monitor internal conditions (water infiltration, temperature, oxygen concentrations).

Operational Challenges

Constructing a physically stable low permeability cap will be the required. The cap could potentially be subject to failure (ie, significant increase of permeability) due to inadequate compaction and presence of gravelly material, biological factors (root penetration, animal burrowing), freeze-thaw, wetting-drying and differential settlement of the pile. The physical properties of the till will control its suitability as a capping material and will need to be determined. The thickness of the till and compaction may be used to control biological factors. Likewise, the thickness should limit the effects of freeze-thaw and wetting-drying cycles. Considerable engineering experience is available, both from the mining and landfill construction industry, to allow these factors to be thoroughly addressed.

Contingencies

Contingency measures can include construction of the piles in a controlled catchment area to ensure that any contaminated drainage could be collected, diverted to the tailings pond and, as a final contingency, treated, if required. Based on 10% infiltration into the piles, seepage from the piles would represent much less than 0.5% of the input to the fine tailings impoundment (PEL, 1994) and would probably be completely neutralized by mixing with the alkaline pond water. This would be a temporary measure prior to flooding the wastes in the pits.

Operational Examples

Examples of till caps to control waste rock dump leachate quality are available for existing mines with acid generating dumps.

Bell *et al.* (1994) described a pilot scale project at the Heath Steele Mine in New Brunswick. The 10,000-tonne pile was capped with a 60 cm compacted till layer ($k=1.0\times10^{-6}$ cm/s) on 3:1 slopes. Granular layers above and below the till act to maintain saturation in the till layer. Two years of monitoring data demonstrated the substantial reduction in internal oxygen concentrations (20% decreased to 1%), reduction in variability of oxygen concentrations, and reduction in infiltration (1 to 2% of precipitation during two 55-day periods).

Bennett *et al.* (1988) described capping of waste rock dumps with 30 cm of compacted clay (properties not available). Infiltration was reduced from 50% of incident precipitation to 5%. Internal oxygen concentrations were also reduced.

Lindahl (1990) reported on capping of large waste rock dumps at the Bersbo Mine in Sweden. The cap consisted of 2 m of moraine (glacial till). Early results indicated that oxygen concentrations had decreased to 0.2% in pore spaces and infiltration had also been substantially reduced.

The nearby Equity Silver Mine operation began applying till covers to its waste rock dumps in 1990 (M. Aziz, Equity Silver, personal communication). A 0.5 m compacted till cover overlain by a 0.3 m uncompacted cover has resulted in infiltration of less than 5% (based on lysimeter studies) and decreasing oxygen concentrations. The till contains approximately 10% stones. Oxygen concentrations are expected to continue decreasing until encapsulation is completed in 1994.

These studies and operational examples confirm that low permeability covers reduce infiltration substantially, and reduce oxidation rates by limiting oxygen flux due to diffusion and advection. As these examples represent a diverse range of conditions, and one (Equity Silver) that is in the same region as Telkwa, the above examples are relevant to Telkwa. The main difference is that fine grained sedimentary waste rock at Telkwa would be expected to further reduce the permeability of the piles.

4.3.5 Temporary or Perpetual Disposal of Acid Generating Wastes - Limestone Addition

Description

Limestone addition is an option for temporary or perpetual disposal of potentially acid generating waste rock. This is comparable to waste mixing in that the neutralizing potential is increased by adding imported limestone. The amount of limestone required to neutralize acidic drainage from potentially acid generating stockpiles in situ was the subject of a recent study for the Mine Environment Neutral Drainage Program (MEND) and British Columbia Acid Mine Drainage Task Force (Norecol, Dames & Moore, 1994; Day, 1994) for a gold mine. It was concluded that a delay in the release of acid drainage (and metals such as iron) could be achieved using crushed limestone. The delay was related to neutralization potential (NP) according to an exponential relationship:

$$t_{delay} = 11.2e^{0.079NP} \quad (1)$$

This equation should be regarded as site specific since it depends on the particular rock characteristics and the configuration of the columns. However, the relationship is also partly a result of the chemical relationship between acid generation and neutralization. It can be made more general by expressing t_{delay} and NP in more general terms. The approach taken was to replace these variables by t_{delay}/t_o and NP/NP_o, respectively, where

- t_o is the time required to consume all sulphur at the observed sulphide oxidation rate at neutral pH; and
- NP_o is the theoretical maximum NP required to neutralize acidity produced if all the sulphur were to oxidise.

By using these factors, the equation is scaled according to site specific conditions (ie, sulphate production rate and sulphur content). Therefore, based on the MEND study the general equation becomes:

$$t_{delay} = \left(\frac{t_o}{317}\right)e^{9.875\left(\frac{NP}{NP_o}\right)} \quad (2)$$

since t_o = 3500 weeks and NP_o = 125 kg $CaCO_3$/t for the MEND project. This equation can be re-organized to estimate the NP required (NP_{add} for a required time delay if a given NP is present ($NP_{present}$):

$$NP_{add} = \frac{NP_o}{9.875} \ln(\frac{t_{delay}}{t_o} 317) - NP_{present} \quad (3)$$

t_o is simply estimated from total sulphur (S_T, in %) and the observed sulphate release rate at neutral pH ($R_{sulphate}$ in mg SO_4/kg/week):

$$t_o = 30000 S_T / R_{sulphate} \quad (4).$$

Based on data for the Pit 3 area (Table 2), there is a strong correlation between sulphate production rate and total sulphur concentration, described by the relationship (Figure 3):

$$R_{sulphate, Telkwa} = 112 \ln(S_T) + 111 \quad (5).$$

Therefore,

$$t_o = \frac{30000.S_T}{112.\ln(S_T) + 111} \quad (6)$$

The following example illustrates the operational calculation of limestone addition:

> A requirement to maintain a stockpile of potentially acid generating waste rock containing on average 2% sulphur and NP of 30 kg $CaCO_3$/t for two years is determined by ongoing waste rock management.
>
> Using equation (6), t_o is estimated at 318 weeks. NP_o is estimated conservatively as 2 times MPA (ie, 125 kg $CaCO_3$/t, as suggested by Cravotta *et al.*, 1990; Brady *et al.*, 1990).
>
> Using equation (3), the total NP required to be added is is 30 kg $CaCO_3$/t. This translates into approximately 3% pure limestone to achieve the required delay.
>
> A 75-t truckload would receive approximately 2.3 t of crushed limestone from a hopper.

These values represent an ideal situation. To provide a conservative margin of safety for operational conditions, it is recommended that the desired stockpiling time should be doubled to calculate the limestone requirement until operating information is available on the consumption of limestone in stockpiles.

Details of Management Concept

Limestone addition could be used early on in the operation to address management of highly reactive wastes (such as coarse rejects). It could be used as an interim measure to manage small piles of other potentially acid generating rock prior to disposal in the mixed waste rock dumps if the neutralization potential present is not adequate for the anticipated stockpiling period (Figure 4).

The following approaches are recommended to optimize distribution of limestone within waste rock stockpiles:

1. The limestone should be crushed probably to approximately 1 cm.

2. For wastes originating in-pit, crushed limestone could be added from a hopper directly into dump trucks en route to the stockpiling area.

3. For wastes originating at the preparation plant (for example, coarse rejects), crushed limestone could be added directly to the waste stream.

No special measures will be needed for the area used to store limestone with waste rock added, except to allow for drainage collection and seepage monitored.

Operational Challenges

Operational challenges will relate to mixing the waste rock and limestone. The measures proposed above should provide an optimal degree of mixing under operational conditions. For in-pit wastes, the limestone added to dump trucks would become well-mixed when dumped. For preparation plant wastes, the addition of limestone to the waste stream would provide optimal conditions for mixing.

Day (1994) noted that large-scale limestone layering (ie. batch limestone addition) is not desirable and that the delay in acid generation is likely to be related to the neutralization potential in the larger volume of rock between the layers. The above approaches to limestone addition are suggested to avoid layering.

Contingencies

The requirement for contingencies primarily relates to release of acidic drainage sooner than predicted by the time delay equation. This could be handled initially by calculating limestone requirements by doubling the desired time delay. The stockpiles should be constructed in the catchment area of the tailings ponds to allow any drainage to be collected and treated if necessary. If suitable sub-aqueous disposal sites are available, the waste could be removed to these areas.

Operational Examples

In the Appalachian Coal Region, limestone addition has been attempted as a means to perpetually prevent ARD release. Brady *et al.* (1990) studied 10 coal mines sites at which limestone was added to mine backfill. The limestone was generally added to address an existing ARD problem. The study demonstrated the need for thorough mixing before an ARD problem occurs. They concluded with the recommendation that for perpetual prevention of ARD the amount of limestone required was twice the MPA.

Skousen and Larew (1994) presented an example of recently permitted alkaline addition in northern West Virginia. After two years of operation, no acid production had been noted.

4.3.6 Sub-Aqueous Disposal of Fine Rejects

Description

Fine rejects (tailings) from the preparation plant are assumed to be potentially acid generating (see Section 3.2.3), although it is possible that the tailings may not be acid generating on balance due to the presence of organic carbon in coal and the presence of carbonate.

Previous options for disposal were discussed by Norecol Environmental Consultants Ltd. (1991). These were perpetual sub-aqueous disposal, addition of an alkaline material (lime or limestone), till covering, and dewatering for disposal as cake. The present recommendation is for sub-aqueous disposal in a constructed tailings impoundment. The impoundment water balance will need to be designed to ensure that the water cover is maintained during extreme drought periods. The depth of the water cover will depend on the water balance for these drought conditions.

Details of Management Concept

The management concept consists of discharge of the tailings slurry to the impoundment. In general, the tailings should be discharged underwater without beaching. Since the tailings will contain significant neutralization potential (possibly 30 kg $CaCO_3$/t) and lime will be added in the mill process, short term (several months) exposure of tailings should not result in degradation of water quality. PEL (1994) determined that a 1-m water cover can be maintained.

Operational Challenges

The primary operational challenge will be maintenance of the water cover during dry periods. The cover will also need to be maintained at closure.

Contingencies

Contingencies will be needed to address maintenance of the water cover. In the event that the water cover cannot be maintained during operation, lime may be added to the tailings to raise the neutralization potential. This scenario should be addressed for the early stages of operation before the base of the tailings is sealed by tailings deposition. As indicated above, the presence of significant neutralization potential in the tailings should ensure that exposure during dry conditions in late summer will not result in significant degradation of water quality.

Operational Examples

Sub-aqueous disposal has been demonstrated as an acceptable means for long term management of potentially acid generating tailings (Fraser and Robertson, 1994). The approach is both theoretically and practically proven (St-Arnaud, 1994).

Locally, Equity Silver maintains a perpetual 1.5 m water cover over its sulphide tailings area (Aziz, 1994).

4.3.7 Final Pit Closure

At final closure, the pits will flood and are predicted to eventually discharge once filled. The quality of this discharge will depend primarily on the acid generation characteristics of the pit walls. As discussed previously in Section 4.3.3, most of the pit walls and exposed floors will be acid consuming due to the intrusive and footwall of Seam 2. Some acidic seepage will be expected in parts of the exposed walls, but this will be neutralized by reaction with calcareous layers and the alkaline pit water.

5.0 SUMMARY AND CONCLUSIONS

The following summary of conclusions is organized according to the foregoing sections of the report.

Approach to Prediction

- Chemical and mineralogical characterization, kinetic testing, evaluation of natural site conditions, and geological comparisons have been applied to understand the potential for acid generation at the Telkwa Coal Project.

- Based on a consideration of the major element geochemistry of the sedimentary rocks, acid-base accounting is a reliable method for quantifying acid neutralization potential. Iron carbonate is the least abundant carbonate and the static neutralization potential was not significantly affected by iron carbonates or silicates.

- Comparison of coal mine ARD experience in the Appalachian coal mining region with the Telkwa Coal Project is a good means of assessing the acid generation of the Telkwa Coal Project. The Telkwa Coal project fits into the range of geological and environmental conditions represented by Appalachian experiences. The Telkwa Coal Project would probably represent a lower risk for ARD than in the Appalachians due to the lower proportion of iron carbonates and the presence of calcareous tills at the Telkwa Project.

- Small-scale kinetic testing was not expected to provide reliable data since questions will remain on the extrapolation of small-scale tests to full-scale mining. Appalachian operational experience and the ABA-water quality database provide a reliable operational basis for development of waste management criteria for prevention of ARD at Telkwa.

- Based on the Appalachian experiences, the derived acid generation prevention criteria for assessment of overall acid generation potential in large rock masses are:

    - Neutralization Potential > 15 kg $CaCO_3$/t
    - Net Neutralization Potential > 10 kg $CaCO_3$/t
    - Neutralization Potential Ratio ≥ 2.0
    - Reactive carbonates shown by fizz reaction with hydrochloric acid.
    - Background groundwater alkalinity greater than 70 mg $CaCO_3$/L.

ARD Classification of Waste Materials

- Sedimentary rock acid generation potential is based on zones defined by correlatable coal units. Generally, acid generation potential increases as the proportion of mudstones and coals increases in the section.

- Coal is potentially acid generating though probably lower than predicted by total sulphur.

- Granodiorite waste rock is expected to be mildly acid consuming although not all neutralization potential is readily available due to limited physical breakdown.

- Non-oxidized deeper glacial till is acid consuming due to the presence of reactive carbonates.

- On average, coarse rejects are potentially acid generating.

- Fine preparation plant rejects may or may not be acid generating based on ABA. The fine and carbonaceous nature of the tailings should also limit the diffusion of oxygen into the tailings mass.

- Volume balance calculations demonstrate that the Telkwa Project rocks contain more neutralization potential and have greater net neutralization potential than comparable mines in the Appalachian region. Waste management should focus on the NPR which is close to the target criteria based on Appalachian experiences.

- The volume ABA balance for Pit 7 indicates that specific waste management measures will be needed to ensure that ARD is prevented. These measures could include segregation and special handling of selected potentially acid generating waste rock zones.

- The volume ABA balance for Pit 8 indicates that ARD should be preventable with minimal special handling of waste rock.

- Backfill in the large bulk sample test pit in the Pit 3 area is producing alkaline seepage. The alkalinity of the water is greater than would be predicted by water quality-ABA relationships developed in the Appalachians. This lends support to the assertion that the Telkwa Coal Project presents much better than average conditions for prevention of ARD.

- A former open pit coal mine in the project area mined the same seams as the proposed Pit 7 and has alkaline seepage from backfill and waste rock.

- The presence of abundant thick calcareous tills, calcareous bedrock and alkaline groundwater along the migration pathways to the nearest receiving water body demonstrate that the site has a strong natural acid assimilation capacity thereby reducing the risk of ARD impacts.

Options for Management of Waste Materials to Prevent ARD

- Some special waste rock management measures may be needed to ensure prevention of ARD.

- Glacial till and granodiorite are suitable for use as construction materials.

- Waste rock blending is recommended as the main management approach for waste rock. Management of potentially acid generating and acid consuming wastes could be accomplished by long range planning using ABA results from blast hole cuttings, in-pit control of colour-coded trucks and controlled dumping to ensure that potentially acid generating materials are surrounded by acid consuming materials. The management approach should be based on defined zones between coal seams rather than individual rock units.

- In-pit sub-aqueous disposal is recommended for disposal of potentially acid generating materials (such as coarse rejects) which cannot be incorporated in the waste rock dumps. The pit water is predicted to be acid-consuming.

- Glacial till encapsulation is recommended for piles of potentially acid generating wastes produced during mining of Pit 7. The dumps should be sited to allow collection of drainage in the event that acid generation occurs.

- Limestone addition is a potential option for stockpiles.

- Sub-aqueous disposal of preparation plant fine rejects is recommended.

- No particular measures are anticipated for closure of the pits. The pits will eventually flood with alkaline water.

16/6/94

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TABLES

TABLE 1
ACID GENERATION COMPARISON OF APPALACHIAN COAL REGION AND TELKWA COALFIELD

FACTOR	PENNSYLVANIA DATABASE	Ref	WEST VIRGINIA DATABASE	Ref	TELKWA COAL	COMMENTS
Coal grade	Bituminous	2	Bituminous	1	Bituminous	
Type of Mining	Open pit		Open pit		Open pit	
Paleoenvironment	Freshwater, brackish, marine	2	Freshwater, brackish, marine		Freshwater, brackish, marine	
Climate	Data not obtained		1050 to 1150 mm	1	513 mm (Smithers) -9 to 15 deg C (daily)	Appalachian region warmer, little snow accumulation
Types of interburden	Same strata as West Virginia		Shale=Sandstone>Mudstone	1	Siltstone>Sandstone> Mudstone	
Glacial till	Strongly calcareous till in north	5	Absent		Moderately calcareous till.	
Iron sulphides	Pyrite, marcasite	4	Pyrite		Pyrite	
Occurence of iron sulphide	Data not obtained - probably comparable to West Virginia		Framboidal, isolated euhedral, aggregates of euhedral, irregular massive sulphide masses, fracture filling.	1	Fracture fillng, irregular masses, subhedral crystals, isolated crystals.	
Carbonates	Siderite>calcite, dolomite.	2,3	Data not obtained		Calcite=dolomite>>siderite	
Occurence of carbonates	Data not obtained		Data not obtained		Fracture filling, veinlets, matrix cement.	
Silicates	Quartz, potassium feldspar, albite, muscovite, kaolinite, illite, chlorite	3	Data not obtained		Quartz, plagioclase, potassium feldspar, muscovite, chlorite	Silicate reactivity not generally expected to be significant
Occurence of silicates	Mineral particles	-	Mineral particles	-	Mineral particles	Occur as clastic grains in sedimentary rocks
Volume Proportion of Acid Generating Rock	No data		2 to 99%		15 to 20%	Data for West Virginia assumes sandstones are main acid generators.
Rock Strengths	14,700 to 23,000 psi	6	Data not obtained		500 to 31,800 psi	
Volume weighted total S (range)	0.1 to 0.9%		0.1 to 0.8%		0.5 to 0.8%	
Volume weighted NP's (range)	0 to 55 kg CaCO3/t	2	0 to 110 kg CaCO3/t	1	26 to 34 kg CaCO3/t	
Volume wighted NPR's (range)	None given		0.1 to 4.3	1	Proposed > 2.0	
Criteria for non-acid-generating	NP>15 kg CaCO3/t NNP>10 kg CaCO3/t NPR>2.0 Carbonates "fizz" Groundwater alkalinity>70 mg/L	2	NP>20 to 40 kg CaCO3/t NNP>10 to 30 kg CaCO3/t NPR>2.0 to 2.4	1		West Virginia database subject to scatter due to use of approximate volume-weighting method.

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1. diPretoro and Rauch (1988)
2. Brady et al. (1994)
3. Cravotta et al. (1994)
4. Brady (1994)
5. Brady and Hornberger (undated)
6. Geyer and Wilshusen (1984)

TABLE 2
SUMMARY OF KINETIC DATA - PIT 3 AREA
(DATA FROM SES, 1985)

Column Description (1)	Predominant Lithology	Total S	NP	NNP	NPR	Sample Mass	Interval (2)	Leach Volume (3)	Average Sulphate (3)	Average Alkalinity (3)	Lowest pH	Sulphate Production (3)	Time to Consume S (4)	Time for Acid to be Produced (5,6)
		%	kg CaCO3/t			g	weeks	mL/week	mg/L	mg CaCO3/L		mg/kg/week	Years	Months
411 COMPOSITE	Whole core - Seams 2 to 7+	0.556	52	35	2.99	1000	5	954	39	46	7.1	37	9	NPR>2
411 COMPOSITE+AG	As above, AG zones "buried"	0.556	52	35	2.99	1000	7	969	43	46	6.5	42	8	NPR>2
418 COMPOSITE	Whole core - Seams 2 to 9+	0.639	79	59	3.96	1000	8	943	82	44	7.2	77	5	NPR>2
418 COMPOSITE+AG	As above, AG zones "buried"	0.639	79	59	3.96	1000	7	953	64	86	7.8	61	6	NPR>2
438 COMPOSITE	Whole core - Seams 8 to 10+	0.717	45	23	2.01	1000	7	939	81	52	7.6	76	5	NPR>2
438 COMPOSITE+AG	As above, AG zones "buried"	0.717	45	23	2.01	1000	5	960	54	109	8.5	52	8	NPR>2
418 POTENTIAL AG	Siltstone and Seams 8 and 9	1.31	25	-16	0.61	500	7	440	315	12	6.5	277	3	4
418 POTENTIAL AG	Siltstone and Seams 6 and 7	1.13	37	2	1.05	500	6	453	142	14	6.7	129	5	14
418 POTENTIAL AG	Siltstone and Seams 4 and 5	1.03	22	-10	0.68	500	7	332	203	32	7.1	135	4	8
418 POTENTIAL AG	Siltstone above Seam 3	2.51	18	-60	0.23	500	7	247	418	8	6.0	207	7	4
418 POTENTIAL AG	Siltstone between Seams 2 and 3	1.76	17	-38	0.31	500	7	423	204	6	6.1	172	6	5
Blank							9		1	2	5.3			

Notes:

1. Composite+AG = acid generating zones segregated and surrounded by layers of acid consuming rock.
2. Interval = period over which leachate chemistry was stable following initial flushing of products accumulated during sampe storage.
3. Average values were calculated over the period the indicated "interval".
4. Total S consumptions assumes current sulphate production rate maintained and S is available.
5. Time for acid to be produced assumes current sulphate production maintained, 40% NP is consumed under neutral pH and four moles of CaCO3 are needed for each mole of pyrite oxidized.
6. A month is defined as four weeks for the sake of calculation.

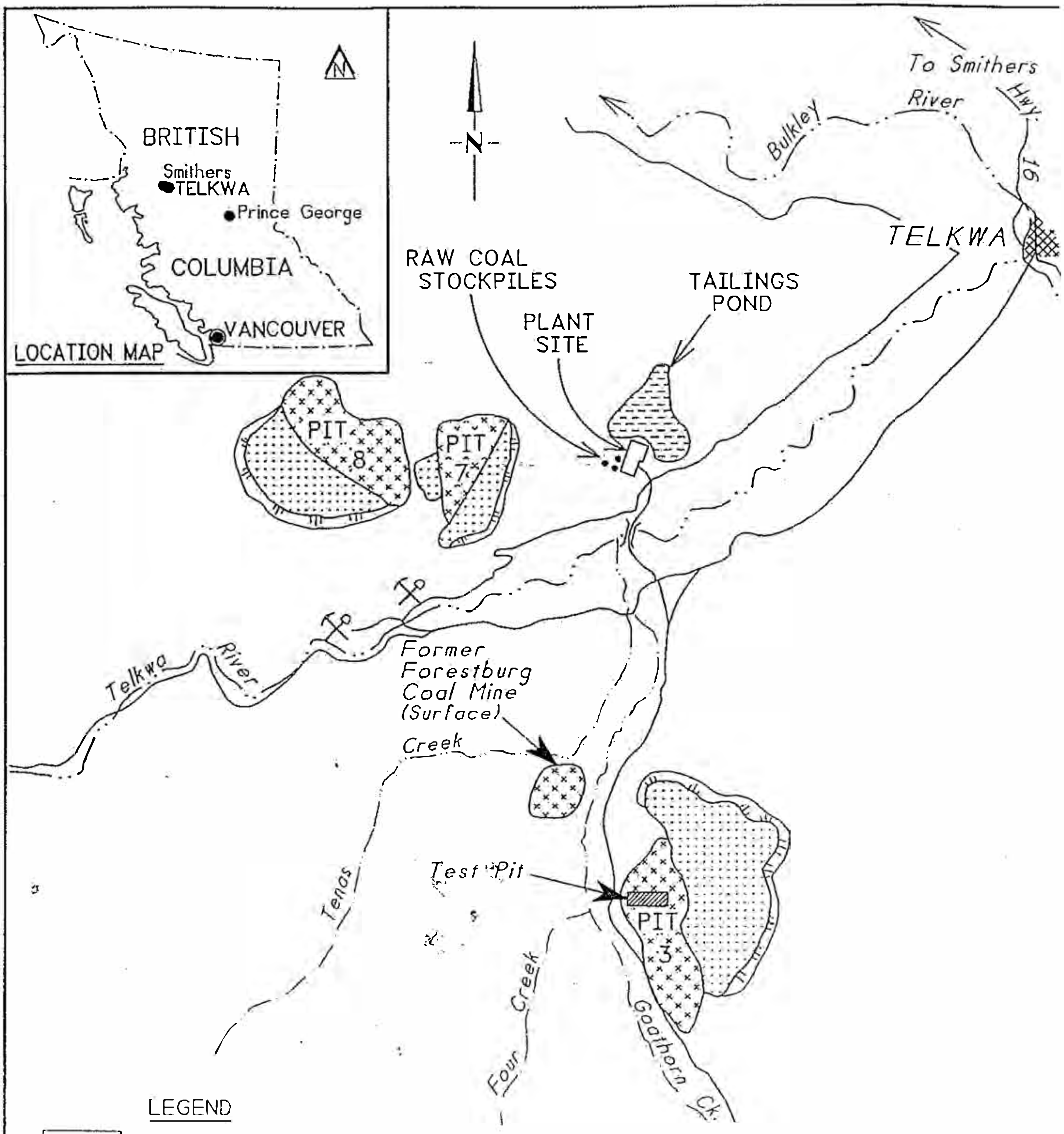
TABLE 3
SUMMARY OF VOLUMES (cu. m) OF WASTES ACCORDING TO ACID GENERATION POTENTIAL

CATEGORIES (1)	TOTAL (2)	CATEGORY 1		CATEGORY 2		CATEGORY 3		PIT VOLUME AVAILABLE FOR SUB-AQUEOUS DISPOSAL (4)
		TILL (3)	INTRUSIVE	ACID CONSUMERS	ACID GENERATORS	SEGREGATED TO GIVE NPR>2	COARSE REJECT	
PIT 7 (average)	14,830,461	1,483,046	3,134,980	6,129,373	1,304,894	2,778,169	711,216	Rapid Filling: 1,749,000 Final Volume: 7,809,000
PIT 8 (average)	28,973,220	2,897,322	1,453,964	19,927,497	3,915,011	779,426	1,006,372	Rapid Filling: 1,862,000 Final Volume: 5,653,000

Notes:

1. The categories are described in the text.
2. The total volume includes all Category 1 and 2, and Category 3 segregated to give NPR>2. Coarse rejects are not included.
3. Till volumes shown are 10% of the dump volumes. Additional till is available for construction, capping, etc.
4. Pit volumes for sub-aqueous disposal are shown for rapid filling (first 5 years) and the final volume.

FIGURES



LEGEND

⠿	Waste Rock Dump
×	Open Pit
⚒	Former Underground Coal mines

SCALE 1:70,000 (Approximate)

0 1 2 3 kilometres

0 1 2 miles

TELKWA COAL PROJECT

LOCATION MAP

TELKWA, BRITISH COLUMBIA

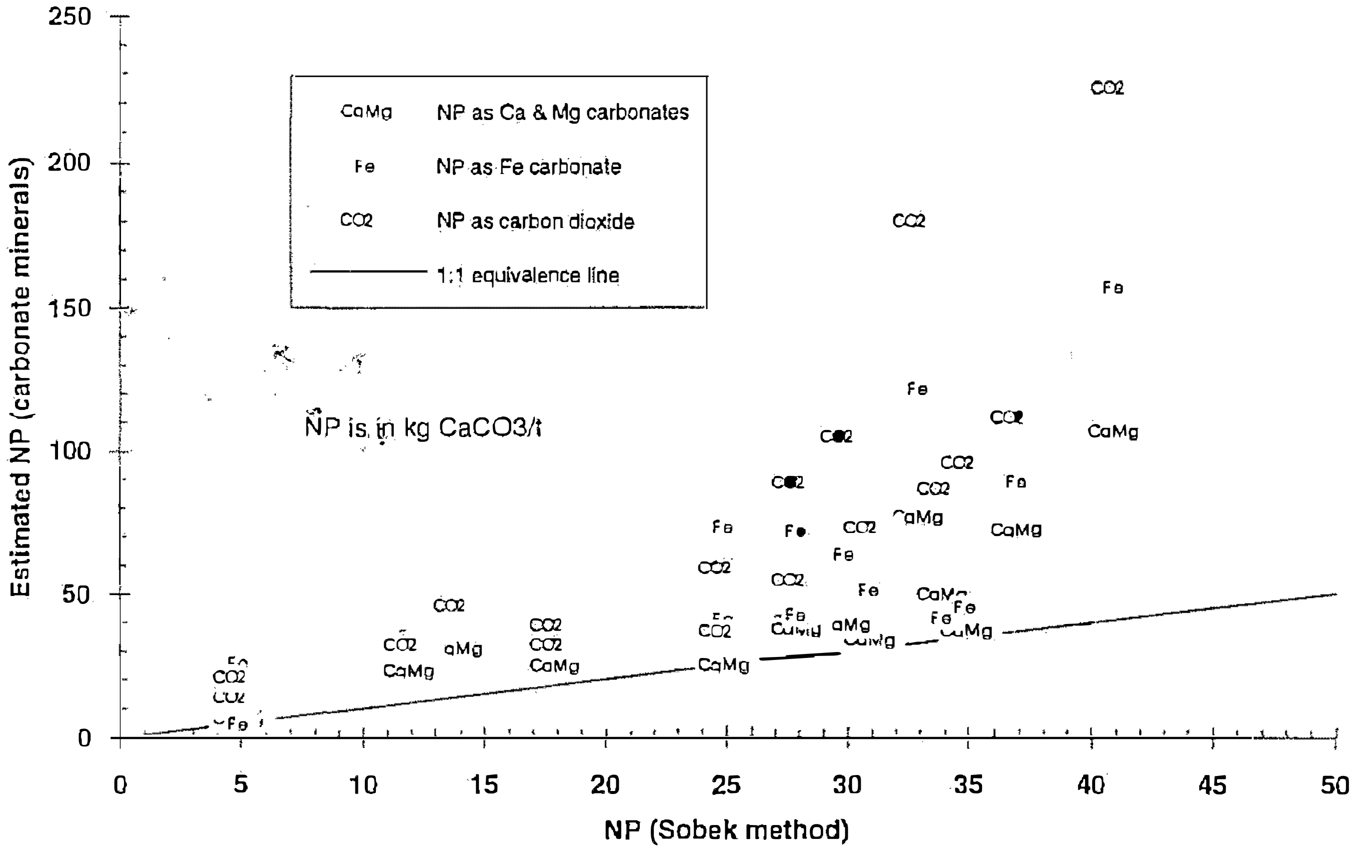
MANALTA COAL LTD.

JUNE 1994

FIGURE 1

312\25373-3\FIG-1

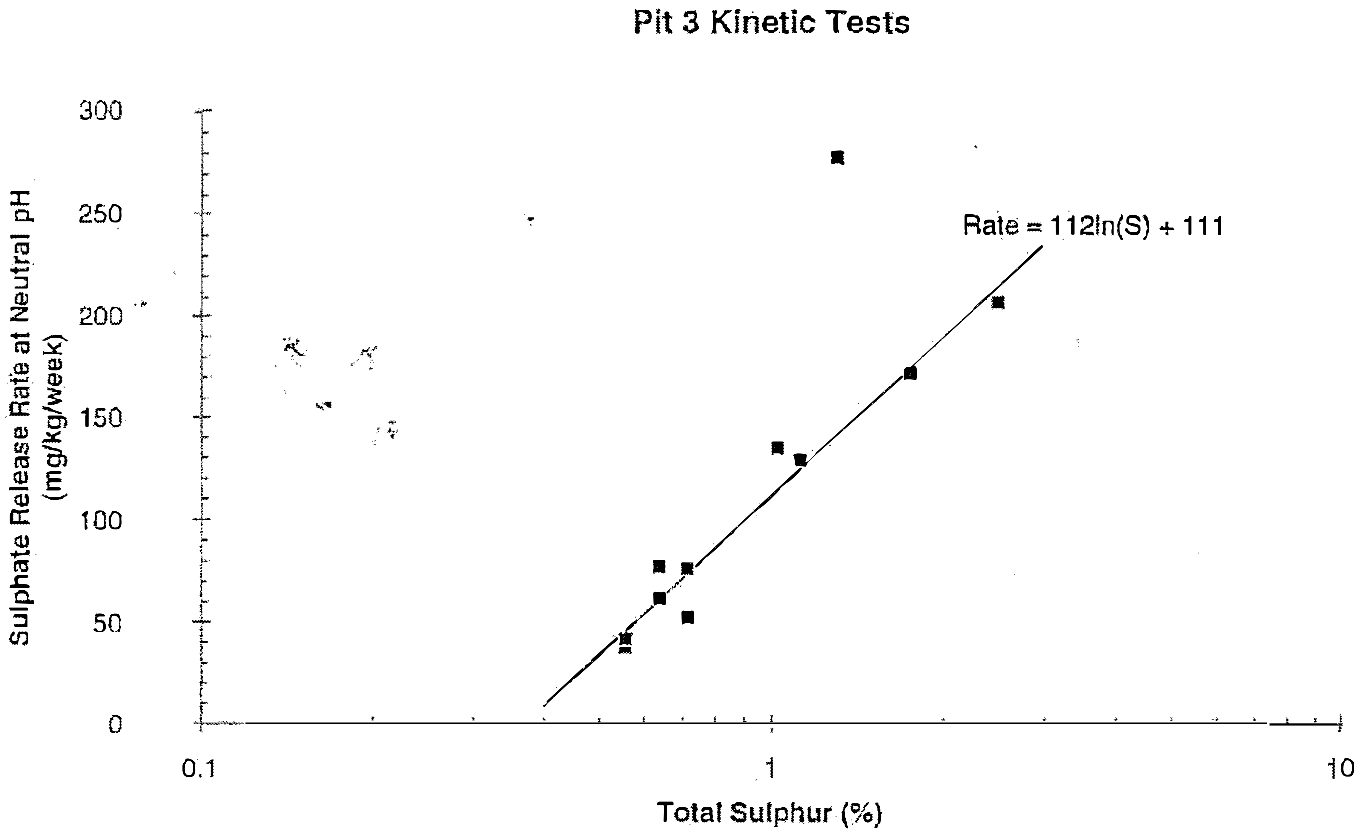
NORECOL, DAMES & MOORE, IN



TELKWA COAL PROJECT
CONVENTIONAL NP
COMPARED TO ESTIMATED
MINERALOGICAL NP

MANALTA COAL LIMITED

JUNE 1994	FIGURE 2



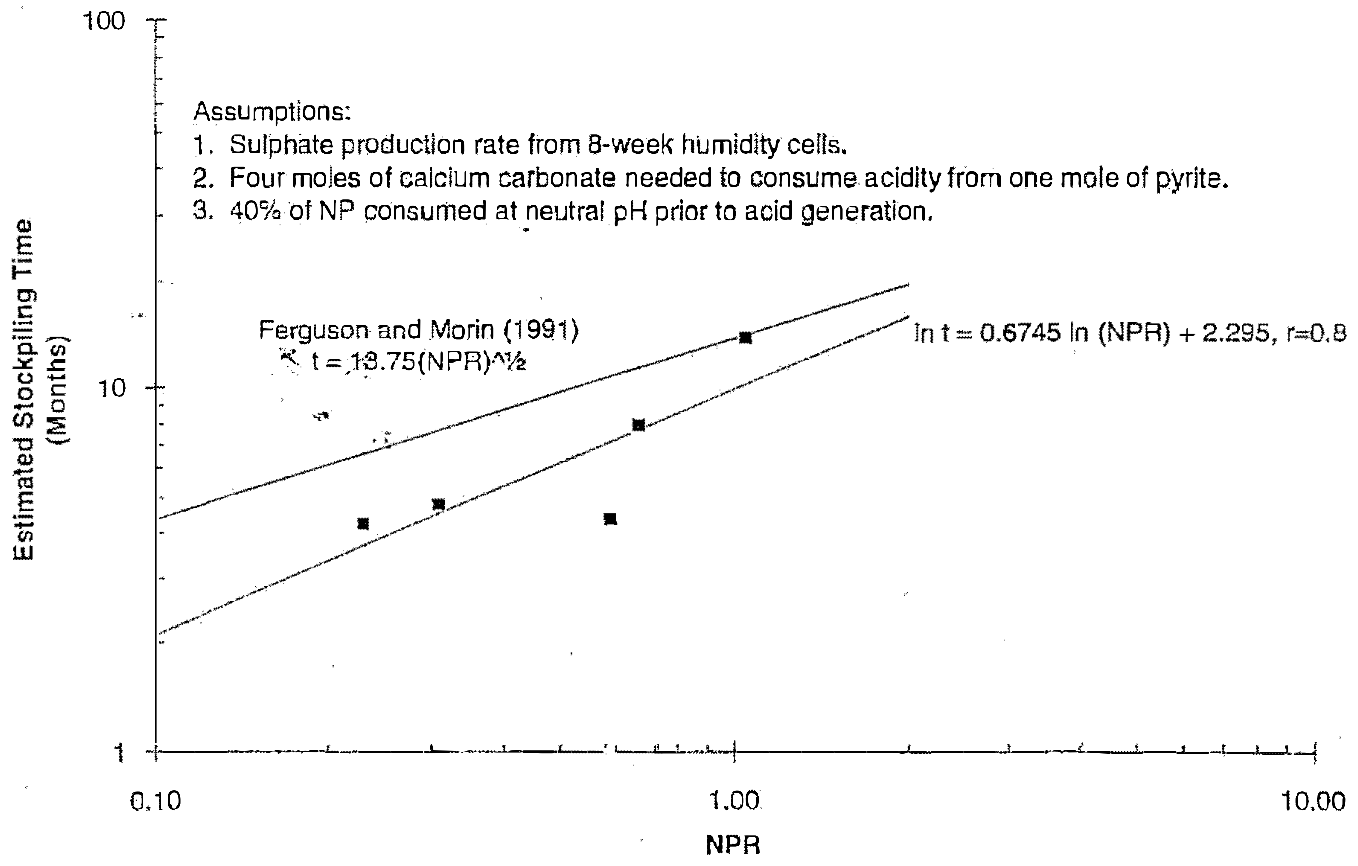
TELKWA COAL PROJECT
TOTAL SULPHUR VS.
SULPHATE PRODUCTION
RATE AT NEUTRAL PH

MANALTA COAL LIMITED

JUNE 1994 | FIGURE 3

Job No. 25373-003-312

Norecol, Dames & Moore



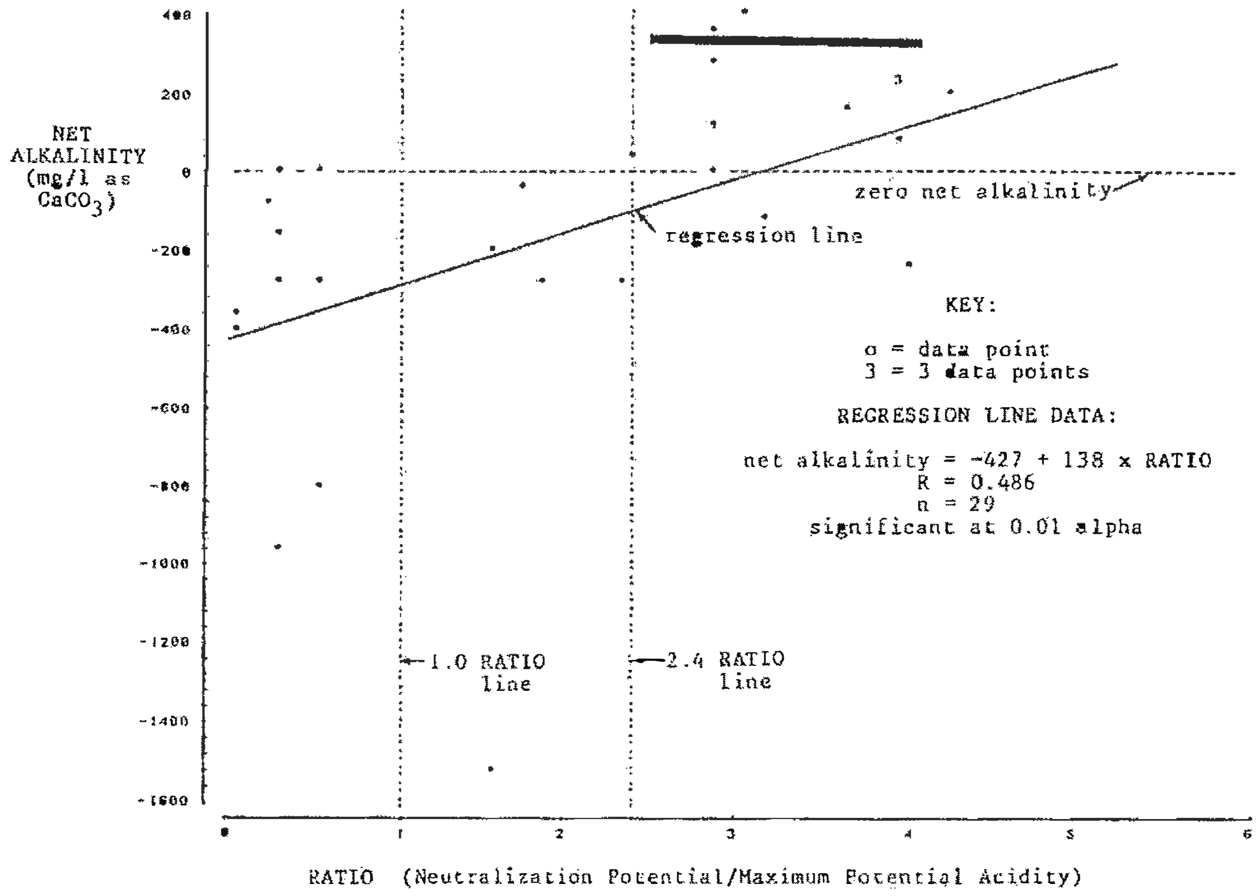
Assumptions:

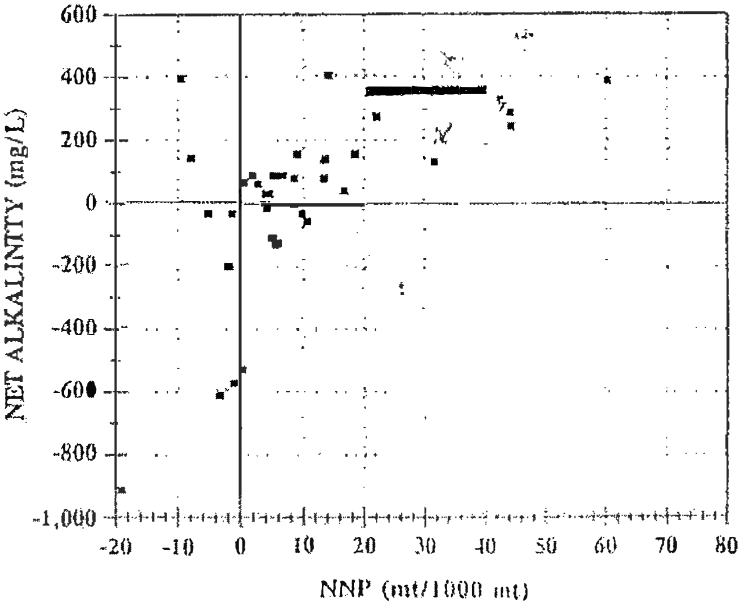
1. Sulphate production rate from 8-week humidity cells.
2. Four moles of calcium carbonate needed to consume acidity from one mole of pyrite.
3. 40% of NP consumed at neutral pH prior to acid generation.

TELKWA COAL PROJECT
ESTIMATION OF STOCKPILING TIME AS A FUNCTION OF NPR

MANALTA COAL LIMITED

JUNE 1994	FIGURE 4





diPretoro and Rauch (1988)

Brady et al. (1994)

Bars indicate estimated range of ABA characteristics for backfill.

TELKWA COAL PROJECT
ALKALINITY OF TEST PIT BACKFILL
COMPARED TO RELATIONSHIPS
FOR APPALACHIANS

MANALTA COAL LTD.

JUNE 1994	FIGURE 5