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Pit backfilling on two continents: Comparison of recent experiences in the Wismut and Flambeau projects

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ABSTRACT. Commitments to backfill acid generating waste rock are becoming a common part of mine closure plans. However, the difficulties associated with translating such commitments into practice are not commonly recognized. This paper compares recent experiences with full-scale backfilling operations at two mines, one in the U.S. and one in Germany.

At Wismuts' uranium mining operations in the former East Germany Ronneburg mining district, waste rock was placed in fourteen piles. Acid generating rock was mixed with neutral rock, resulting in various combinations of acid generation, heavy metal release, and radon exhalation. The need to control further acid generation and prevent formation of a contaminated pit lake led to the decision to relocate waste rock to fill the Lichtenberg open pit. The relocation program is designed to place the waste rock with the highest potential for acid generation below the future water table, and to cover the remaining acid generating rock with a layer of net acid consuming sulfidic rock, which will act as an oxygen consuming layer. The relocation program therefore requires in-field identification of different classes of waste rock and an iterative planning and control program.

In contrast, at Flambeau Mining Co.'s copper/gold/silver operation near Ladysmith, Wisconsin, waste rock was separated into non-acid generating (Type I) and potentially acid generating (Type II) waste rock during operations. The objective of the reclamation plan was to backfill the waste rock in reverse order in which it was mined. After reflooding, all of the potentially acid generating rock would be below the water table. The key problem was to quantify the acidity stored in the waste rock, and to add appropriate amounts of alkali.

The paper highlights the similarities and differences between the two programs with respect to the testing undertaken to support the backfill design, methods used for material identification, classification, control of alkali addition rates, and long and short term planning.

1. INTRODUCTION

As a result of increasingly stringent requirements for the reclamation of mine sites, backfilling of waste rock into open pits has become a viable option for consideration. Some of the objectives and advantages of backfilling include:

- Consolidating diffuse sources (multiple rockpiles) into a single location;
- Providing a secure, maintenance free repository for potentially acid generating waste rock;
- Reducing the area impacted and increasing the area of land returned to its original use; and,
- Preventing the development of an exposed acidic pit lake.

Within an open pit, three potential deposition zones can be identified in terms of the potential for continued oxidation of the waste rock, as shown in Figure 1. First, a very secure zone exists below the reflooded water table. Oxygen ingress is severely restricted and thus the saturated anoxic zone represents the zone most suited for placement of waste rock with a high potential for acid generation.

Above the water table two additional zones exist. An oxygenated zone (oxidation zone) exists from the surface down. The depth to which oxygenation occurs depends on several factors, including diffusive transport and barometric pumping. Each of these mechanisms depends on such factors such as the physical properties of the backfill and the degree saturation. Generally, advective transport is limited due to physical constraints imposed by the subsurface deposition of the waste rock. Clearly, waste rock with potential for net acid generation should not be placed in this zone. There is however some advantages in placing reactive sulfidic rock in this zone, provided it does not generate unacceptable pore water quality. The more reactive the waste rock, the more rapid oxygen will be consumed and the shallower the resulting depth of oxygen entry. The third zone, (unsaturated anoxic) is delineated by the lower boundary of the oxygenated zone and the water table. This zone is anoxic and the potential for further oxidation is limited. But, unlike the saturated zone, water flow through this zone generally is unsaturated so that only a small proportion of the waste rock is actually contacted by infiltrating water.

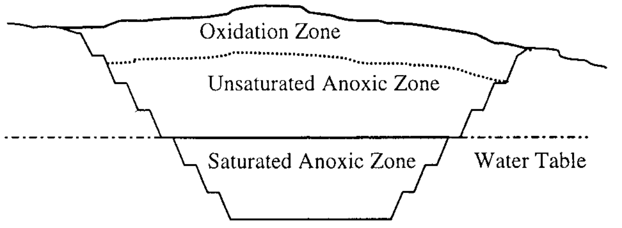

Figure 1. Conceptual zonation of backfilled open pit

It is clear from this zonation of the open pit that there is a preferred placement of the backfill. Selective relocation of the waste rock is key to achieving this preference. The first step in achieving selective relocation is characterizing the waste rock. In particular, the potential for acid generation and the quantity and type of secondary mineralization is important. Field and laboratory studies are undertaken to characterize the waste rock. Second, the spatial distribution of the waste rock within the dump is required. This is necessary to complete the third step, which is scheduling of the relocation program. Scheduling, akin to mining, may be undertaken in two or three levels. Long term planning would address the overall schedule to ensure that placement locations for different types of materials are available when required. Short term planning is required to provide a daily or weekly plan of action when, for example, material with characteristics different to the original projection is encountered. Short term planning is based on field sampling and testing immediately ahead of the relocation face to provide a lead time of 1 day to 3 months, depending on the planning requirements of the relocation activity. Finally, a control program is required to ensure that the material is placed correctly within its designated zone. The control program represents a quality assurance program in which sampling and testing of the placed material is undertaken. The results are used in a feedback control loop to identify and correct any errors in material classification ahead of relocation or actual relocation errors.

Two case studies are presented below. While the basic principals are common to both case studies, some differences exist in the project objectives and circumstances. It is interesting to see how these slight differences in objectives and circumstances have lead to significant differences in the planning and control programs.

2. WISMUT

2.1 Project Background

Uranium was mined from WISMUT mining districts located in the former East Germany during the period 1946 to 1990 (Hockley *et al.*, 1997). Uranium production totaled approximately 200,000 tonnes, 65% of which was produced in the Ronneburg district. The Ronneburg mining complex is spread over an area of about 35 km^2 and comprises extensive underground workings, some 14 waste rock piles (originally totaling 125 million m^3 of waste rock), and a large open pit, the Lichtenberg open pit. The waste rock piles covered a planimetric area of about 460 ha (1,110 acres) the largest of which are located in close proximity to the open pit. The open pit represents an area of about 200 ha (481 acres). One of the rock piles (containing approximately 6 million m^3 of rock) was a partially spent low grade ore heap leach operation called the Gessenhalde. Monitoring identified the Gessenhalde as a significant radon source.

Mining operations ceased in 1990 after German re-unification, at which time reclamation of the site was initiated. Since the Gessenhalde represented a significant radon source, relocation work on this heap was initiated before a clearly defined reclamation plan was developed. This work however provided some lead-time to allow optimization of the reclamation plan for the remainder of the waste rock dumps. Initial investigations were undertaken on the basis of existing records, as described below, and a backfill concept was developed.

2.2 *Backfill Objectives*

The primary objective for the backfilling of the open pit was to prevent the formation of an acidic lake in the open pit. A large proportion of the waste rock was net acid generating and the need for controlled placement in the pit was recognized. Consequently, the Lichtenberg open pit was divided into zones as illustrated in Figure 1. For practical reasons, the anoxic saturated zone was identified as the A-Zone, the anoxic saturated zone as the B-Zone, and the oxygenated zone as the C-Zone. A fourth zone, the D-Zone, was also defined and represents a composite soil cover that will be placed over the waste rock after backfilling has been completed.

The rock piles were not homogeneous but contained portions of rock with similar geochemical characteristics. The need to selectively place material in each of the backfill zones required that a control program be developed to identify material with specific geochemical characteristics. In addition, the control program was required to establish the alkali amendment rate required to neutralize stored acidity contained in some of the rock piles that have already become net acid generating.

2.3 *Investigations*

Desk Study

During exploration and operations at Wismut, extensive records were kept of the various rock types mined. Detailed analyses were completed on each rock type to provide a statistical log of the average composition of each. Although acid base account determinations were not completed, sulfur speciation and carbonate analyses were available so that the acid generation potential of each rock type could be estimated. While records referencing where the rock was placed relative to its origin in the pit were limited, the study did identify large cells of material with similar characteristics within the rock piles.

As a result of the findings of the desk study, a two stage program of drilling was undertaken to characterize each of the rockpiles. Table 1 summarizes the number of drill holes and approximate volumes of each of the rock piles. The initial stage was undertaken to assess material variability in each of the rock piles. The second stage primarily provided infill data in areas of uncertainty, especially in the larger piles.

Composite samples of the drill core were taken over 2 m intervals and analyzed. The results from the more detailed drill hole investigation were interpreted in several ways. Conventional hand interpretation techniques as well as different Kriging techniques were used to estimate overall volumes of material with specific geochemical characteristics. Historical construction information (such as placement schedules) was used in the block model to provided 'physical' boundaries to refine the Kriging estimates. The blocks were Kriged on the basis of neutralization potential (carbonate analysis) and acid generation potential (sulfide analysis) to estimate the net acid generation potential. The block model provided a spatial record of the location of potentially acid generating and acid consuming material which was used in the long-term planning and scheduling of the relocation operation.

TABLE 1. Phase I and Phase II Drilling Programs

Mine Rock Pile	Volume ($x10^6$ m^3)	Drill Holes Phase I	Phase II	Total	Ratio ($x10^6 m^3$ per hole)
Absetzerhalde	63.7	22	25	47	1.35
Halde 4	1.0	38*	-	38*	0.03
T. Reust	8.0	8	8	16	0.5
T. Paitzdorf	6.5	10	-	10	0.65
Halde S.381	0.8	7	-	7	0.11
Nordhalde	14.5	16	7	23	0.63
Halde 377	0.4	8	-	8	0.05
Innenkippe	66.9	-	17	17	3.93
Schmirchau	12.0	-	10	10	1.2
Schutzdamm	0.07	-	-	-	-
Halde S.370	0.8	50*	3	53*	0.015
Halde Drosen	3.5	10	-	10	0.35
Halde Beerwalde	5.0	9	-	9	0.57
Halde Korbussen	0.4	4	-	4	0.1

* shallow ram-core holes

Field and Laboratory Investigations

In parallel to the aforementioned, detailed field and laboratory investigations were undertaken. The objective of the field investigation was to identify and develop the field testing methods needed to rapidly and accurately determine the geochemical characteristics of waste rock during the relocation. The objectives of the laboratory investigation included assessment of alkali addition rates, determination of alkali availability, and developing "cut-off" criteria that would allow selective placement in the pit. For the field and laboratory investigations, samples were obtained from 5 m deep test pits. Table 2 summarizes some of the test procedures used and the number of tests undertaken in the field and laboratory investigations.

TABLE 2. Laboratory and Field Investigation Program for Test Pit Samples

Test Method	Number of Tests: Whole sample	< 20 mm fraction	< 2 mm fraction
Field Classification Tests			
Paste pH and conductivity	112	-	-
NP reactivity	112	-	-
Lithology	112	-	-
Size Distribution	112	-	-
Mod. NAP/NAG	-	112	224
Standard Extraction	-	56	56
Ammonium Oxalate Extraction	-	56	56
Paste pH and conductivity		56	56
Laboratory Classification Tests			
Moisture Content	112	-	-
Chemical analyses	112	56	56
Acid Soluble Al, As, Pb, Ni, Cu, Zn	112	56	56
Mineralogy	Select	-	-
ABA (modified Sobek and CO_3-NP)	112	56	56
NAP	112	-	-
Behaviour Tests			
Saturated Columns	112	-	-
Infiltrative Columns	55	-	-
Large Scale Oedometer	30	-	-
Falling Head Permeability	15	-	-
Proctor Compaction	15	-	-
Wet-Dry Slaking	15	-	-
Unsaturated Conductivity/Capillary	5	-	-

Results

Some of the more significant conclusions from the field and laboratory programs are summarized below. In general, the neutralization potential (NP) in the rock was present as carbonates (calcite and dolomite). Sulfide mineralization was predominantly pyrite.

Particle size. Results from the field and laboratory investigations showed that conservative estimates of the contained acidity are obtained when testing is completed on the less than 2 mm size fraction. The results also showed that in the fines fraction (for weathered material) both sulfides and carbonates were depleted relative to the whole sample, but that that the depletion was proportionate. In general, conservative estimates of the NP:AP ratio resulted based on the fines fraction.

Paste parameters. Paste parameters provided the basis for the first pass classification of waste rock with respect to acid generation potential. As well, paste conductivity was indicative of contained acidity.

NAP/NAG test. The NAP/NAG procedure (Coastech 1991; Miller *et al.*, 1990) was modified for specific field application. Field testing conducted on the < 2 mm size fraction provided the next selection level for acid generation potential classification of material.

NP:AP Cut-off Criteria. A plot of the final pH observed in the humidity column tests, plotted against NP and AP is shown in Figure 2. The plot indicates that an NP:AP ratio of greater than 2:1 should not result in net acid generating conditions. On the basis of these findings, the backfill selection criteria were as follows:

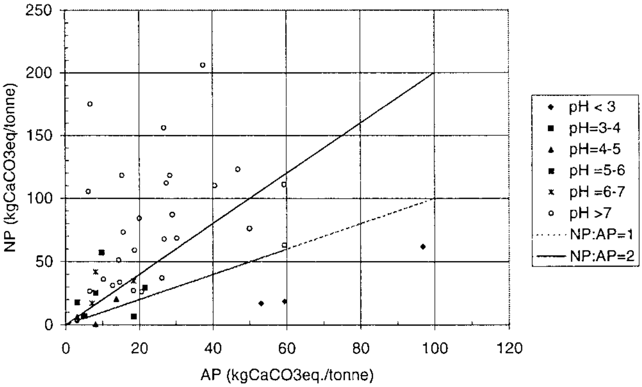

Figure 2. Comparison of humity cell leachate pH with NP and AP

- The A-Zone receives waste rock with an NP:AP ratio predominantly of less than 1;
- The C-Zone receives material with an NP:AP ratio of > 2, with predominantly calcitic carbonates (i.e. low conductivity)
- Zone B receives the balance of the waste rock, i.e. 1<NP:AP <2, the excess A-Zone material and that which is not suitable for placement in the C-Zone.

The cut-off criteria were correlated with the paste parameter and NAP/NAG results to provide a control chart for the classification of material during relocation, as shown in Figure 3.

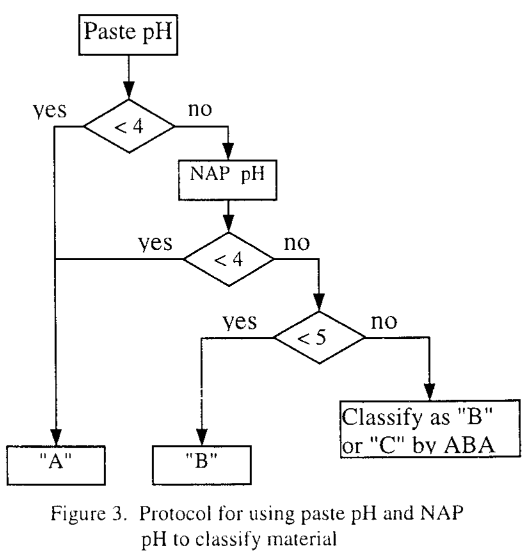

Figure 3. Protocol for using paste pH and NAP pH to classify material

Alkali Amendment. On the basis of increased uranium mobility in a carbonate anionic system, quicklime (CaO) was selected as the preferred alkali to neutralize contained acidity and reduce metal release upon recovery of the water table in the backfill. Saturated column test results indicated an alkali availability in the order of 80 %. A correlation was developed between lime demand and the paste conductivity.

Sampling Requirements. Field sampling and trial relocation operations were undertaken to assess sampling requirements for short term planning and control. The investigations showed that an acceptable accuracy could be obtained by sampling ahead of relocation on a 25 x 25 m grid.

2.4 Backfill Operation

The relocation control program is summarized in Table 3. Planning for the backfilling starts with the preparation of the long-term plans, which are based on Kriging and block modeling. Medium-term planning addresses selectivity within the larger dumps. Both long and medium term planning have been completed.

Short term planning is achieved by sampling and testing approximately one to three months ahead of the relocation front, on a regular 25 m x 25 m grid pattern. Samples are obtained from tests pits excavated to a depth of 10 m. The material classification on the basis of the field-testing is illustrated in Figure 3, and material within a class is delineated in plan on the relocation lift. Mining is undertaken at a 10 m lift height. Material identified for relocation to the A-Zone is amended, as stated before, with quicklime by spreading a thin layer at the required rate on the top of the lift. Quality control samples are taken directly off the mining face to confirm material classifications, and to allow correction of the short-term plan where necessary. Where lime is blended, dozers are used to push the material down-slope at an angle of about 22° and the ensuing rolling action provides effective blending. At the toe of the slope, front-end loaders are used to load the material into dump trucks. Material is placed in the pit in 0.6 m to 1 m lifts where it is compacted by controlled truck traffic.

TABLE 3. Summary of WISMUT relocation control program

Objective	Data Basis	Sample Classification	Interpretation
Long and medium term planning (volume estimates, relocation plan)	Drilling	A: NP/AP <1 B: 1<NP/AP<2 C: NP/AP >2	Kriging and hand interpretation
Short Term Planning (relocation control, lime application control)	Test pits (25x25 m grid)	see Figure 3	Hand and local Kriging
QA/QC of C-Material Relocation	Face samples (3 per 50m face)	see Figure 3	Control charts and tables
QA/QC of C-Zone	in-pit composite from 5 pits/day	see Figure 3	Control charts and tables
QA/QC of B-Zone	in-pit composite from 5 pits/day	see Figure 3	Control charts and tables
QA/QC of A-Zone	in-pit composite from 5 pits/day	paste conductivity < 6000uS/cm	Control charts and tables
QA/QC of Relocation (confirmation of material behaviour)	10 samples per year from backfill	see Figure 3, chemical analyses ABA and modified column tests	(Semi-)Annual report

3. FLAMBEAU PROJECT

3.1 Project Background

At the Flambeau Mine, located near Ladysmith, WI, copper, gold and silver were recovered (also see Sevick *et al.*, 1998). The mine was permitted in 1991 and remained operational until early 1997. Backfilling of the open pit was identified as the preferred reclamation option at the design and permitting stage. As part of the operating plan, waste rock was sorted and placed in two surface facilities, namely the Type I and Type II Stockpiles. Initial testing indicated that waste rock with a sulfur content of less than 2 % generally was non-acid generating. This material was classified as Type I waste rock. Conservatively, rock with a sulfur content of greater than 1 % was classified as Type II waste rock.

In order of mining, overburden was stripped, followed by sandstone and saprolite. These materials did not show any potential to generate acid or leach metals. To develop the Type I Stockpile, a till blanket was placed. Sandstone and saprolite were placed in separate cells in the Type I Stockpile. In addition, the material classified as Type I was placed in a third cell in the Type I Stockpile. The Type II Stockpile comprised an engineered facility with a liner system for leachate collection. All Type II rock was placed in this facility. Contaminated leachate was collected and treated on site before discharge.

At the design stage it was recognized that alkali (lime) amendment to the Type II waste rock would be required prior to backfilling. Initial projections were based on the alkali demand of partially oxidized humidity cell residues. In 1996, an investigation was conducted to confirm the initial estimates of the lime demand. The results showed that the lime demand in the Type II waste rock varied considerably, and that some of the lime demands significantly exceeded the projected demand. In addition, a seep with a slightly depressed pH and elevated copper concentration was observed from Type I material. Further investigations of both stockpiles were therefore conducted.

Approximately 0.53 million m^3 of Type I waste rock were placed in the Type I Stockpile and 1.65 million m^3 of Type II waste rock were placed in the Type II Stockpile.

3.2 Backfill Objectives

At the Flambeau Mine, the backfilling concept is simply to return the rock approximately to the same spatial location from which it was extracted. As described above, five material types were encountered which, stratigraphically, approximately coincided with a vertical layering from surface down of increasing acid generation potential. The overburden represents an inert cover layer. Replacing the material in this order, i.e. placing the Type II (acid generating) at the bottom of the pit below the water table, followed by Type I (non-acid generating) etc., represents zoning within the pit similar to that described above.

3.3 Investigations

Oxygen Transport
Hydrological modeling has indicated that a period of between 15 to 20 years could elapse before the water table fully recovered. During this time, oxygen entry to the backfill would result in additional acid generation. Oxygen transport modeling was therefore completed to estimate the additional alkali amendment that would be required to ensure that the potentially acid generating Type II waste did not cause acidic pore water.

Field and Laboratory Investigations
Field and laboratory investigations were undertaken in two stages to confirm findings obtained during permitting. The scope of the initial investigation was limited to obtaining an indication of the alkali demand and its variability within the Type II Stockpile. Consequently, the program was limited to leach extraction testing and alkali demand testing. Based on the findings of the first phase, the scope of the second phase was designed. The second phase investigation also included sampling and testing material contained in the Type I Stockpile. Table 4 summarizes the scope of both stages of testing. Samples were obtained from test pits excavated to a depth 4.6 m (15 ft) in the Type II Stockpile, and 3 m (10 ft) in the Type I Stockpile. The sampling grid was 18.3x18.3 m (60x60 ft) on the Type II Stockpile, while samples were obtained randomly from the Type I Stockpile to obtain representation of each type of material present.

An 'alkali demand' test was developed to rapidly and under field conditions provide an estimate the alkali required to neutralize the contained acidity of the waste. The test was based on a correlation between the contained acidity and the paste pH and conductivity. To complete the test, three shake flasks were prepared containing representative splits of the sample. Distilled water was added to provide a solid to liquid ratio of 1:1, and using the correlation between the pH and contained acidity, milk of lime was added to the first flask to neutralize the estimated acidity. To the second flask, sufficient lime was added neutralize the estimated acidity plus a percentage in excess, and the third flask received lime to neutralize the estimated acidity less a percentage. The objective was to obtain a neutral pH in at least 1 shake flask after a contact period of 24 hours, from which the contained acidity could be estimated.

TABLE 4. Summary of Field and Laboratory Investigations Completed at Flambeau Mine

Test Description	Field and Laboratory Programs		Operational
	Phase I	Phase II	Control
Test Pits (Stockpiles)	18	99	2833
Test Pits (Backfill)	0	15	356
Alkali Demand	29	102	932
Leach Extraction	41	12	18
Shake Flask Equilibrium Tests	-	-	89
Acid Consumption Test	-	48	81
ABA	-	22	20
Anoxic Column	-	28	11
Field Density Measurements (Stockpile)	-	-	79
Field Density Measurements (Backfill)	-	-	812
Modified Proctor	-	-	89
Sieve Analysis	-	-	89
Hydraulic Conductivity	-	-	15

Results

The most significant findings of the investigations are summarized below.

Oxygen transport modeling indicated the need for an alkali application rate of about 0.013 $mgCaCO_3/g/year$ at approximately 10 m (30 ft) below the final surface of the Type II rock, which represents the estimated depth of penetration of oxygen into the waste rock. The maximum oxidation rate is predicted to occur at the surface of the sulfidic Type II waste rock, which will require a maximum alkali amendment of 0.13 $mgCaCO_3/g/year$ at the surface of the Type II waste rock.

Particle Size. Leach extraction tests completed on < 6 mm (< ¼ inch) and 6 mm to 75 mm (¼to 3 inch) size fractions showed that approximately 50 to 60 % of the total contained acidity of the waste rock was associated with the < 6 mm (< ¼ inch) size fraction, while the < 6 mm (< ¼ inch) size fraction represented less than 50 % (w/w) of the waste rock. The < 6 mm (< ¼ inc) size fraction was used in all future testing to indicate conservatively the total contained acidity.

Paste Conductivity. Based on the correlation between contained acidity and the paste parameters, it was possible to classify waste rock into distinct classes with upper boundaries of alkali demand.

Alkali Type and Availability. Saturated column tests completed on amended material indicated that limestone was the alkali of choice since i) it buffers the pH within the circum-neutral range, even if limestone is applied in excess, ii) it leads to the formation of stable carbonate secondary mineral phases, iii) its availability was high (approximately 70 % based on saturated column tests), iv) it did not require special handling methods or present a hazard, v) it was easily applied, vi) it is relatively insoluble and will not be washed out, and, vii) it proved to be cost effective.

3.4 Backfill Operations

Backfill operations at the Flambeau mine were simplified due to the selective placement of the waste rock in the Type I (net acid consuming) and Type II (net acid generating) Stockpiles which eliminated the need for determining the acid generation potential of the rock. Consequently, only the amendment requirements of the waste rock needed to be established. To this end, a classification system was developed, as shown in Figure 4, which resulted in the classification of the waste rock into one of A-, B- or C-type. The alkali demand of each type of material was as follows:

Class A: <0.8 mgCaO/g
Class B: (>0.8) <1.6 mgCaO/g
Class C: > 1.6 mgCaO/g

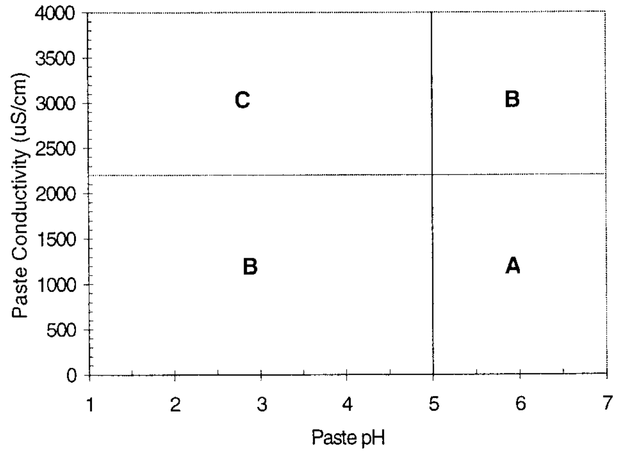

Figure 4. Classification of Type II rock using paste parameters

Conservatively, each of types A and B was amended at the respective upper limit of the category. The alkali amendment rate for the C-type material was obtained directly from the alkali demand test. The above application rates were supplemented for alkali required for neutralization of future acidity.

Control of limestone amendment during relocation was obtained by sampling 1 to 3 days ahead of relocation on a regular 18.3 m (60 ft) grid. The side-slopes were sampled at an interval of 9.2 m (30 ft). Vertical test pits were excavated to the depth of the relocation lift 4.6 m (15 ft) and a representative sample of the entire lift height was obtained. Samples were obtained on the side-slopes by excavating a trench representative of the relocation lift height to a depth of 0.3, 1 and 2 m (1, 3 and 6 ft) and scraping along its length. Within the 18.3 m (60 ft) grid-spacing where C-type material was encountered, infill samples were obtained at a 9.2 m (30 ft) grid spacing. Areas of similar alkali requirements were delineated and using scrapers, limestone was placed on the surface of the lift to attain the required amendment rate. Relocation was accomplished in one of two ways. First, working from above, a backhoe was used to load rock into haul trucks. Secondly, a front-end loader was used; the front-end loader 'dressed' the material by caving the face of the lift to achieve initial blending. The collapsed material was then loaded into the haul truck. Both methods of blending were found to be effective, as discussed below. The material was placed in the pit in three-foot lifts and compacted by truck traffic. A sheeps-foot compactor was used to compact the material in close proximity to the pit walls.

Quality control samples were obtained from the pit by excavating test pits to the depth of the placement lift and obtaining representative samples on a daily. Paste parameters were obtained for each sample. Leach extraction testing was then completed on a composite sample. Selected composite samples were also submitted for extended leach extraction testing and column testing to provide confirmation of circum-neutral pH buffering and predicted pore water quality. Confirmation of sufficient residual calcite to neutralize future acidity was obtained from an acid consumption test, specifically developed for this purpose.

The effectiveness of the calcite amendment and the blending techniques is borne out by the paste parameters for the in pit samples. These are illustrated in Figure 5, and as shown, the target pH of 6.5 in the pore water was effectively achieved.

4. CONCLUSIONS

The similarity between planning and handling of material for backfill operations and ore grade control during mining is obvious. The difference, however, arises from the controls that are applied to achieve the objective of backfilling. To fully utilize the benefits of backfilling waste rock, a clear understanding of the behavioural geochemistry of the materials to be backfilled under the different placement conditions is required. Further, it is necessary that the materials be identified and selectively mined. This requires advance sampling and testing to allow planning of mining and placement. Sampling requirements need to be established on the basis of the variability of the material within the waste rock dump. In some cases it may also be necessary to develop site specific testing protocols to address specific needs. In both case studies, the paste parameters proved to be key to the rapid field assessment of material characteristics and classification into specific material types and establishing alkali amendment rates. The modified NAP/NAG test was useful in identifying potentially acid generating materials. However, advance planning such as in the case of Flambeau, could eliminate the need for 'in field' identification of potential acid generating waste rock.

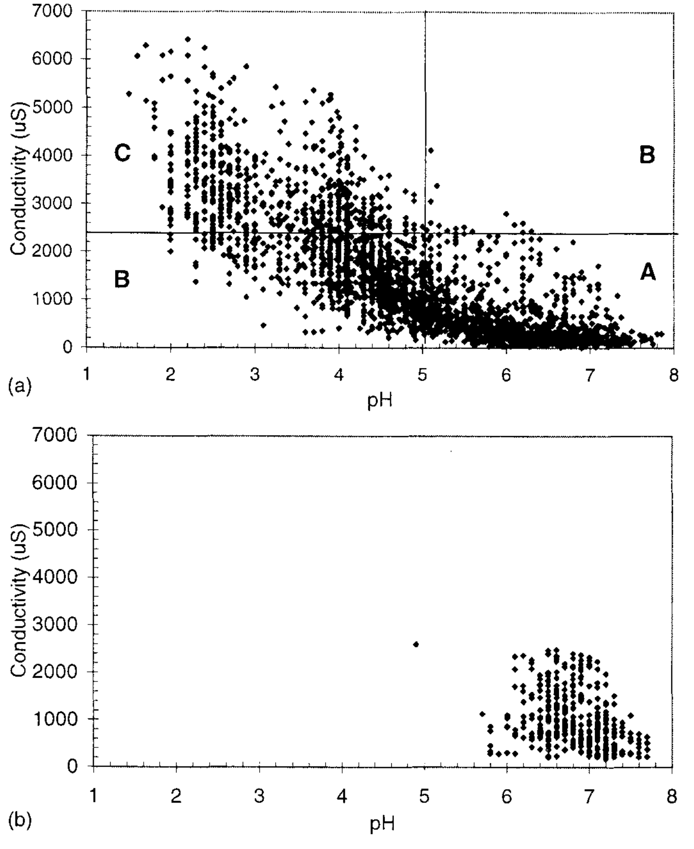

Figure 5. Paste conductivity as a function of paste pH before (a) and after (b) calcite amendment of the Type II waste rock.

5. REFERENCES

Coastech Reasearch Inc (1991), Acid Rock Drainage Prediction Manual, *MEND Project 1.16.1b, CANMET.*

Miller S.D., Jeffrey, J.J. and Murray G.S.C. (1990), Indication and Management of Acid Generating Wastes – Procedures and Practices in South East Asia and Pacific Regions, *in Proc. of GAC-MAC Annual Meeting, May 1990.*

Hockley, D., M. Paul, J. Chapman, S. Jahn and W. Weise (1997) Relocation of Waste Rock to the Lichtenberg Pit Near Ronneburg, Germany, *in Proc. Fourth International Conference on acid Rock Drainage (Vancouver, Canada), p. 1167 – 1283.*

Sevick, G., J. Hutcheson, J. Murphy and J. Chapman (1998). Engineered Open Pit Mine Backfilling, *in Proc. of the Tailings and Mine Waste '98 Conf., Fort Collins, Colorado. USA, January 26-29, 1998.*