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Review of 2003 Waste Rock Storage Area Seepage and Waste Rock Survey Report, prepared by SRK

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For: Ekati Independent Environmental Assessment Agency

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Executive Summary

The objectives of the annual 'Waste Rock Storage Area Seepage and Waste Rock Survey Report' are to present the results of the monitoring of water quality in three mining (Panda-Koala, Misery and Fox) and two reference (Beartooth-Bearclaw and Sable) areas, monitoring of waste rock from four pits and monitoring of thermal conditions for Panda-Koala-Beartooth WRSA, Misery WRSA and Coarse Kimberlite Reject SA. Seepage monitoring is a requirement of the Water License N7L2-1616, BHP Billiton. Characterization of the waste rock is a requirement of the 2000 Waste Rock and Ore Storage Management Plan.

The 2003 report was well organized and well-written, successfully meeting its stated objectives of presenting the monitoring results. However, the report failed to adequately address the management implications of the monitoring results. The monitoring results indicate a number of concerns regarding drainage chemistry, indicating significant uncertainty regarding future performance of some of the wastes and the ability of the present mitigation measures to achieve the post-closure environmental protection and reclamation objectives.

Proposed Action: The terms of reference for the report should be expanded to address the management implications of the monitoring results, and the impact of past and proposed waste handling on the ability to protect the environment and reclaim the site. The report needs to identify information gaps and outline where changes are required to the waste disposal and mitigation plans, what those refinements should be and / or what additional studies or monitoring information are required. To allow the reader to interpret the results, the report should outline past, current and planned future waste management and mitigation plans (e.g., CKR was originally deposited directly on tundra soils, presently it is being deposited in layers and encapsulated within granitic rock), and list any modifications, errors or omissions (e.g., where material misclassified or handled in different manner). The report should provide updated cross-sections and plan views of

the WRSAs, CKRSA and LLSA showing where different wastes are located and different disposal strategies have been used.

High concentrations of solutes such as sulphate and Mg are observed in the seepage from the CKR and may also occur in areas where kimberlite and black clay are segregated or mixed with granitic waste rock. Presently, the mine is handling this water by collecting the drainage in the Long Lake Containment Area and re-using it as process water. The question is whether this drainage poses an environmental concern and whether it is necessary to collect it after the mine closes.

Proposed Action: The mine needs to show whether the CKR drainage will affect its ability to meet receiving environment objectives after the mine closes. Included in this assessment should be the likelihood of generating similar drainage chemistry from other waste types/rock units containing the kimberlite, black clay and biotite schist.

The monitoring indicates that the drainage at a number of locations around the waste storage areas have low pH values and relatively high dissolved Fe and Al concentrations. Presently the main area of concern is the northeast corner of the Panda/Koala WRSA where the mine has constructed an interceptor sump at Seep-018B to pump drainage to Beartooth Pit and conducted detailed analysis of the upstream wastes and the flow path between the dump and Beartooth Lake. Based on results of the latter, BHPB concluded that the pH decreases result from acidity produced by the oxidation and hydrolysis of ferrous-Fe in the groundwater when it surfaces. However there remains considerable uncertainty regarding what has caused the observed decline in pH and increased metal leaching. Other plausible mechanisms for some or all of the observed pH decrease, include the oxidation of ammonium, which is contained in blasting powder, adsorption of base cations by organic acids displacing stored acidity (protons), and leaching from stockpiles of acidic till and lake sediments, or by water added with the CKR and till/lake sediments.

Proposed Action: BHPB needs to assess alternative hypotheses for the observed pH changes and develop an acceptable plan for determining the potential magnitude of future pH depression and metal loadings, where it might occur, the significance in terms of meeting discharge requirements after the mine closes, and whether some additional mitigation measures or refinements to the mine plan are required. Further controlled studies, along the lines of those in Day et al. (2003), are required to better understand the mechanisms involved and potential future implications. Better information is also required on the mechanism and capacity of natural acid neutralization at the site.

Due to the relatively low pH and presence of organic acids, tundra water has the potential to accelerate weathering, decrease NP and increase metal solubility in drainage from mine wastes.

Proposed Action: BHPB needs to avoid placing materials with high trace metals (e.g., kimberlite and black clay) or significant sulphides (e.g., biotite schist and kimberlite) in the zone of influence of acidic tundra soils. These refinements should be noted in a revised ‘Waste Rock and Ore Storage Management Plan’ for the Panda/Koala SA.

Proposed Action: Future versions of the monitoring report need to discuss the implications of past placement of potentially deleterious materials in contact with the acidic tundra soils and, if required, how the elevated metal leaching will be mitigated both during operation and after the mine closes.

Monitoring the waste rock raised a number of questions regarding the potential for significant long-term Ni leaching from wastes containing kimberlite and black clay.

Proposed Action: BHPB needs to address the question of whether there is a potential for significant long-term Ni leaching from wastes containing kimberlite and black clay. This should include microprobe assays of the relevant rock types and wastes to identify the mineral sources for potential contaminants, especially Ni, and construction of field test pads to provide information on the potential for Ni release in the various disposal environments. The field test pads may be constructed from dumps themselves, but should include adequate characterization of the material from which drainage or weathering information is derived.

The mitigation strategy to prevent ARD or significant neutral pH metal leaching from the mine wastes appears to be freezing. One question with this strategy is the extent to which freezing will be inhibited by heat produced by sulphide oxidation or compromised by future climate fluctuations. The report did not discuss the thermal monitoring results or their implications to the overall plan.

Proposed Action: Given its importance to the post-closure environmental protection, future editions of the WRSA report need to address the issue of freezing in greater detail. This should include a discussion of the impact of the spatial relationships of different materials in each stockpile, the influence of climate variability (e.g., cold versus warm years and climate change) and contingencies where conditions are warmer than was previously estimated.

Finally, the review contains a number of suggested additions to the monitoring program to verify pre-mining predictions and provide a record of the composition of the wastes.

Proposed Action: Need to add regular checks on the mineralogy of potentially problematic wastes using Rietveld XRD procedure, the composition of post-blast fines to check that drill chip analysis provides an accurate assessment of ML/ARD potential, and the weathering of potentially problematic rock units (see earlier comments).

Proposed Action: Need operational characterization of till and lake sediments. This information should already be being collected as part of the characterization of soils for reclamation, but refinements may be required to address the issues associated with waste disposal, water management and ML/ARD mitigation.

The review also contained a number of proposals regarding the methods with which analyses were conducted, values are calculated and the data is presented.

Introduction

The stated objectives of the annual 'Waste Rock Storage Area Seepage and Waste Rock Survey Report' are to present the results of:

- Monitoring of water quality in three mining (Panda-Koala, Misery and Fox) and two reference (Beartooth-Bearclaw and Sable) areas
- Monitoring of waste rock from four pits
- Monitoring of thermal conditions for Panda-Koala-Beartooth WRSA, Misery WRSA and Coarse Kimberlite Reject SA

Seepage monitoring is a requirement of the Water License N7L2-1616, BHP Billiton. Characterization of the waste rock is a requirement of the Waste Rock and Ore Storage Management Plan. Findings of these monitoring programs are reported annually in the Seepage and Waste Rock Survey Reports. Additional monitoring was conducted in 2003 in the vicinity of SEEP-018 and SEEP-019 to better understand the cause of the observed pH depression.

In addition to the report in question, background information was obtained from:

- Day, S., K. Sexsmith and J. Millard. 2003. Acidic Drainage from Calcareous Coarse Kimberlite Reject, Ekati Diamond Mine, Northwest Territories, Canada, 6th ICARD, Cairns, QLD, July 12 –18
- IEMA. 2002-2003 Technical Annual Report.
- BHP Billiton. Feb 2000. Waste Rock and Ore Storage Management Plan. Ekati Diamond Mine.
- BHP Billiton. March 2003. 2002 Waste Rock Storage Area Seepage and Waste Rock Survey Report. Ekati Diamond Mine.
- BHP Billiton. June 2002. Waste Rock and Ore Storage Management Plan (for Fox Pit). Ekati Diamond Mine.

The terms of reference for the review, which was conducted at the request of the Independent Environmental Monitoring Agency, were as follows:

1. Using the 2002 Seepage Report as background material, complete a technical review of BHPB's 2003 Seepage Report and determine:
   - if the analysis is based on the data provided
   - if the conclusions are fairly drawn from the analysis made
   - if the appropriate recommendations have been made for future work and/or management action
   - if there are emerging issues

2. Review the most recent Waste Rock Management Plan (February 2000) and Addendum #1 (related to Fox Waste Rock) and determine:
   - if the seepage reports reflect the same management regime as in the plans, and

- if the predictions from the management plans are confirmed by the seepage reports.

3. Prepare a written report of your analysis and include suggestions or recommendations for improving the report, the analysis of data, the monitoring programs and other relevant issues in accordance with communications with Director Tony Pearse.

Draft review comments were circulated to Tony Pearse of IEMA and Stephen Day of SRK. Comments that were not addressed remain inserted.

The main conclusion of my review was that there is significant uncertainty regarding future performance of some of the wastes and the impact of past and proposed waste handling on the ability of the mine to protect the environment and reclaim the site. The other main conclusion was that there was a lack of connection in the report itself between the monitoring results and the waste management and mitigation measures the monitoring is intended to address. My review comments and proposed actions are outlined in the following.

- Scope of the Survey and the Report;
- High Concentrations of Solutes in Seepage from CKR and Other Wastes;
- Potential for Wastes to Decrease the pH and Increase Metal Leaching from Tundra Soils;
- Potential for Tundra Soils to Increase Metal Leaching from Mine Wastes;
- Potential for Elevated Ni in Neutral pH Drainage from Black Clay and Kimberlite;
- Use of Freezing to Prevent ARD from the Biotite Schist from the Misery Pit and Significant Neutral pH Metal Leaching from a Variety of Rock Units; and
- Monitoring of the Wastes.

Appendix 1 contains information compiled when conducting the review, along with some questions regarding specific details in the report or the project. Appendix 2 provides a more detailed explanation of points made in the discussion of sampling and analysis techniques.

Scope of the Survey and the Report

The 2003 report was well organized and well-written, successfully meeting its stated objectives of presenting the monitoring results. However, the discussion of the results only partially addressed some of the main reasons for conducting monitoring, which are to[1]:

- verify pre-mining predictions of rock composition and waste material characteristics, freezing, weathering and the resulting drainage chemistry;

[1] The list of reasons are based on my experience at other mines.

- determine if the present monitoring is adequate and what refinements are required;
- show that the mine is meeting the discharge limits[2] and protecting the environment; and
- identify information gaps and concerns regarding future ability to protect the environment and reclaim the site and if required, where refinements are required to the waste disposal and mitigation plans, what those refinements should be and / or what additional studies or monitoring information are required.

The air photos were a good way to show the seepage monitoring sites. What was missing was a clear outline of where the different wastes were placed and different disposal strategies were used.

Proposed Action: The terms of reference for the report should be expanded to address the management implications of the monitoring results, and the impact of past and proposed waste handling on the ability to protect the environment and reclaim the site. The report needs to identify information gaps and outline where changes are required to the waste disposal and mitigation plans, what those refinements should be and / or what additional studies or monitoring information are required. To allow the reader to interpret the results, the report should outline past, current and planned future waste management and mitigation plans (e.g., CKR was originally deposited directly on tundra soils, presently it is being deposited in layers and encapsulated within granitic rock), and list any modifications, errors or omissions (e.g., where material misclassified or handled in different manner). The report should provide updated cross-sections and plan views of the WRSAs, CKRSA and LLSA showing where different wastes are located and different disposal strategies have been used.

Much of the proposed information on waste management should already be available.

Is there a ML/ARD assessment and mitigation report?

High Concentrations of Solutes in Seepage from the CKR and Other Wastes

High concentrations of solutes such as sulphate and Mg are observed in the seepage from the CKR. This is attributed to (2002 Waste Rock Storage Area Seepage and Waste Rock Survey Report):

- Mechanical disturbance during processing;
- Low annual precipitation;
- Fine grained reactive pyrite (albeit at low concentrations);
- Large surface area for weathering reactions;
- Well-graded particle size that allows unrestricted air entry;
- Abundant reactive carbonate and Mg silicate minerals;

[2] The report did a good job of addressing this item.

- Contact of CKR at base of dumps with tundra soil drainage that creates an aggressive weathering environment due to its low pH and high organic acid content;
- High solubility of Mg sulphate; and
- Magnification of pore water concentrations by freezing.

High solute concentrations may also occur in areas where kimberlite and black clay are segregated or mixed in with granitic waste rock. Seepage with high sulphate and Mg concentrations are observed at other locations around the WRSAs (e.g., 018/019/022). Presently, the mine is handling this water by collecting the drainage in the Long Lake Containment Area and re-using it as process water. The question is whether this drainage poses an environmental concern and whether it is necessary to collect it after the mine closes. One potential concern is the potential impact on tundra drainage discussed below.

Proposed Action: The mine needs to show whether the CKR drainage will affect its ability to meet receiving environment objectives after the mine closes. Included in this assessment should be the likelihood of generating similar drainage chemistry from other waste types/rock units containing the kimberlite, black clay and biotite schist.

Potential for Wastes to Decrease the pH and Increase Metal Leaching from Tundra Soils

By digging holes, piling up different wastes, building dams and adding water, mining can dramatically alter the local landscape, changing properties, such as the height of the water table, nutrient supply, locations and rates of flow, and water quality. For example, pit construction may depress the height of the water table, while waste disposal, especially wet waste disposal, may increase it. Some of these changes are immediate. For example, addition of process water along with CKR will raise the water table and the addition of process water and soluble constituents will increases solute concentrations in the receiving environment. Some properties may change more slowly (e.g., at the base of the dump, contact with the acidic tundra water increases weathering of Mg silicates) and some changes will be reversed when the mine closes (e.g., depression of water table adjacent to the pits).

The monitoring indicates that the drainage at a number of locations around the waste storage areas have low pH values and relatively high dissolved Fe and Al concentrations (e.g., up to and in rare cases more than 2 mg/L). Presently the main area of concern is the northeast corner of the Panda/Koala WRSA. Since mining and monitoring started, the pH has decreased and dissolved Fe and Al concentrations have increased in this area. In response to these findings, the mine:

- constructed an interceptor sump at Seep-018B to pump drainage to Beartooth Pit; and
- conducted detailed analysis of the upstream wastes and the flow path between the dump and Beartooth Lake.

Based on the results of the latter, BHPB concluded that the pH decreases result from acidity produced by the oxidation and hydrolysis of ferrous-Fe in the groundwater when it surfaces. Site features and evidence supporting this hypothesis include[3]:

- the lack of buffering in the already slightly acidic tundra drainage;
- an observed decrease in the proportion of ferrous-Fe observed along the flow path;
- observations of ferric-Fe;
- the decrease in pH observed during the summer, which may result from greater exposure of ferrous-Fe as the water table drops; and
- the decrease in sample pH in the laboratory versus the field, which is attributed to oxidation and hydrolysis of ferrous-Fe.

Site features and evidence suggesting that other mechanisms may be contributing to the observed pH decrease include:

- the only location where ferric-Fe coatings were observed was SW-321, no ferric-Fe was observed at Seep 018 at the toe of the dump, which had the lowest pH; and
- the report does not identify a source for the ferrous-Fe.

There are a number of possible sources for ferrous-Fe, but each has limitations. One source for ferrous-Fe is that waste disposal has raised the height of the water table[4], lowering the redox of the underlying soils and causing inert ferric-Fe soil coatings[5] to be reduced to ferrous-Fe. The ferrous-Fe, unlike ferric-Fe, is soluble at neutral pHs and dissolves and is transported downstream where it eventually oxidizes, lowering the pH. Waste disposal can raise the height of the water table through the addition of water with the wastes, changing flow paths or by compacting the underlying substrates. It is important to note that the acidity produced by the oxidation and hydrolysis of ferrous-Fe downstream is matched by the alkalinity that is produced by the reduction and de-hydrolysis of ferric-Fe upstream. Overall, there is no net acid production, just a spatial segregation between where the alkalinity and acidity are produced.

Another possible source of ferrous-Fe is the Fe released from pyrite oxidation in the waste rock. However, since pyrite oxidation will only be significant under aerated conditions and the waste rock in the Panda/Koala WRSA has excess NP, the drainage pH within the dump should be neutral causing the Fe to precipitate as ferric hydroxide in-situ rather than being leached into the groundwater. One possible exception may be at the base of the dumps if the waste rock NP is overwhelmed by the soil acidity. Soil organic acids may accelerate Fe release from pyrite and Fe silicate minerals in the waste rock

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[3] List is derived from Appendix C, Day et al. 2003 and my own thoughts.

[4] Mechanisms by which waste disposal may raise the height of the water table include compaction of the underlying soils, physically filling depressions, the addition of accompanying drainage in the case of lake sediments and till, and the addition of fines either directly or through physical collapse of kimberlite or black clay particles after deposition.

[5] Precipitated ferric iron coatings provide the brown coatings of mineral soils and are insoluble unless the pH is below 3.5.

mixed with tundra soils and through chelation[6] increase Fe movement downstream. If the released Fe is immediately chelated, it may remain in the ferrous state until the groundwater surfaces or the chelates are degraded. Since the waste rock has excess NP, it would be expected to add alkalinity raising the pH of any soils it is in contact with, but as in the previous hypothesis there may be a spatial segregation between where the alkalinity and acidity are produced.

There are a number of other plausible mechanisms for some or all of the observed pH decrease, in addition to Fe oxidation. Acidity will be generated from the oxidation of ammonium, which is contained in blasting powder and therefore likely to be present in all the wastes. Oxidation of ammonium is responsible for acidification of the water cover over the tailings at the Equity Silver Mine. Another possible explanation for the decrease in pH is cation exchange. Base cations occurring in high concentrations in the pore water, (e.g. Mg, Ca and Na), can be adsorbed by organic acids therefore displacing stored acidity (protons) into the surrounding water and lowering the pH. Using this mechanism, sulphate salts are often used to acidify agricultural soils. Supporting evidence includes:

- the high acidity after mixing of tundra soil and CKR, which suggests the soils have a high reserve of acidity;
- much of the site drainage has significantly higher hardness than alkalinity;
- the high drainage sulphate/cation concentrations at many of the sites with a low pH (007D, 007E, 008, 011, 011A, 024A, 025 and SW318); and
- the relatively low TOC (<10 mg/L) for low pH sites 018B and 019 and higher TOC (16 to 20 mg/L) at the more alkaline site 018, which may result from the greater precipitation of organic acids after the replacement of protons by base cations.

One question with this hypothesis is whether continual additions of alkaline mine drainage will eventually reverse the trend, raising the soil pH.

In some locations, the lower downstream seepage pH values may result from the leaching of organic acids, Al and Fe either directly from stockpiles of the acidic till and lake sediments, or indirectly from the underlying soils by water added with the CKR and till/lake sediments. The relatively low TOC concentration (<10 mg/L) for low pH sites 018B and 019 and higher TOC (16 to 20 mg/L) at the more alkaline site 018 suggest that organic acids leaching is not an important mechanism in this area, but it may be important in other locations.

The previous discussion serves to illustrate that there remains considerable uncertainty regarding what has caused the observed decline in pH and increased metal leaching. There are likely to be a combination of mechanisms and factors contributing to the observed pH decreases, with products from the mine wastes directly creating acidity (e.g.,

[6] A chemical compound in which a metallic ion combines with an organic molecule by means of multiple chemical bonds. The resulting compound is often more soluble than other metal compounds.

oxidation of ammonium) or enhancing the re-distribution of soil acidity causing local impacts.

Proposed Action: BHPB needs to assess alternative hypotheses for the observed pH changes and develop an acceptable plan for determining the potential magnitude of future pH depression and metal loadings, where it might occur, the significance in terms of meeting discharge requirements after the mine closes, and whether some additional mitigation measures or refinements to the mine plan are required. Further controlled studies, along the lines of those in Day et al. (2003), are required to better understand the mechanisms involved and potential future implications. Better information is also required on the mechanism and capacity of natural acid neutralization at the site. For example, why is the pH in Beartooth Lake 7 when the pH is < 6.5 in the soil drainage going into the lake? What is the neutralization mechanism?

Potential for Tundra Soils to Increase Metal Leaching from Mine Wastes

Due to the relatively low pH and presence of organic acids, tundra water has the potential to accelerate weathering, decrease NP and increase metal solubility in drainage from mine wastes. Consequently, the pore water of non-PAG wastes mixed with underlying soils or acidic lake sediments may become acidic, accelerating future weathering of silicate minerals and leaching of the weathering products. The potential for acidic tundra soils underlying, deposited peripherally or mixed in dumps to significantly increase metal leaching from waste rock is indicated by the relatively high total acidity in the soil/CKR mixing experiment and the relatively high Al and Fe in the reference areas.

The material with the lowest potential metal solubility and sulphide content is the granitic rock. However, increased leaching of Al may occur even from granitic materials. To date, the temperature data suggests that this will not be a concern, as these wastes will be frozen.

It is important to note that while chelation by organic acids has the potential to increase iron and trace metal solubility in the receiving environment, it can also reduce their toxicity. A number of mine sites with high TOC in receiving waters have developed site-specific water quality objectives that are higher than provincial aquatic guidelines and criteria (e.g., Bell Mine, BC and Detour Lake, Ontario) reducing both the perceived risks and liability.

If BHPB is to avoid placing potentially problematic rock units, such as the black clay and kimberlite in contact with the acidic tundra soils they need to be able to identify and segregate them. While this is done to some degree, BHPB uses the inclusion of kimberlite-like material to explain high sulphur values in the granitic waste rock ABA results to the inclusion of kimberlite-like material. The impact is question came up again in the 'Detailed Investigations of the SEEP-019 Area (Appendix C)', the chemistry of dump seepage from the northeast corner of the Panda/Koala SA was attributed to kimberlite mixed in with the granitic waste rock. However, the report does not discuss the waste handling objectives for the different rock units and whether the inclusion of some kimberlite with the granitic waste rock creates an environmental concern.

Proposed Action: BHPB needs to avoid placing materials with high trace metals (e.g., kimberlite and black clay) or significant sulphides (e.g., biotite schist and kimberlite) in the zone of influence of acidic tundra soils. These refinements should be noted in a revised 'Waste Rock and Ore Storage Management Plan' for the Panda/Koala SA.

Proposed Action: Future versions of the monitoring report need to discuss the implications of past placement of potentially deleterious materials in contact with the acidic tundra soils and, if required, how the elevated metal leaching will be mitigated both during operation and after the mine closes.

Potential for Elevated Ni in Neutral pH Drainage from Black Clay and Kimberlite Rock

One of the challenges in ML/ARD work is our limited ability to predict how bedrock will alter when broken apart and exposed to air and water[7]. Consequently, most mines have some degree of uncertainty associated with their ML/ARD prediction. My review of the waste management plans raised concerns that not all potential drainage chemistry concerns have been identified and that as a result may not be adequately addressed by the waste management plans. For example, the Ekati 2000 report states that 'Alkaline drainage concerns are considered short-term, except for small portion of kimberlite ore.' This conclusion was based on the leaching observed in short-term humidity cells. It is important that these predictions be field checked. My cursory review raised a number of questions and concerns regarding the potential for significant long-term Ni leaching from wastes containing kimberlite and black clay.

Proposed Action: BHPB needs to address the question of whether there is a potential for significant long-term Ni leaching from wastes containing kimberlite and black clay. This should include microprobe assays of the relevant rock types and wastes to identify the mineral sources for potential contaminants, especially Ni, and construction of field test pads to provide information on the potential for Ni release in the various disposal environments. The field test pads may be constructed from dumps themselves, but should include adequate characterization of the material from which drainage or weathering information is derived.

Use of Freezing to Prevent ARD from the Biotite Schist from the Misery Pit and Significant Neutral pH Metal Leaching from a Variety of Rock Units

The mitigation strategy to prevent ARD or significant neutral pH metal leaching from the mine wastes appears to be freezing. One question with this strategy is the extent to which freezing will be inhibited by heat produced by sulphide oxidation or compromised by future climate fluctuations. The method to be used to freeze the Misery schist includes

[7] The alteration that occurs when bedrock is broken apart and exposed to ambient conditions such air and water is called weathering.

encapsulating it with granitic waste rock. The results appear mixed with freezing of the Misery schist occurring in some locations (WRP#3) and not in others (WRP#1). The thermal data from two monitoring stations in the CKR (#1468 and 1469) indicates that the CKR presently remains at or above $0^{o}C$. The reasons for these results and their implications to the overall plan are not discussed. Potential consequences of a failure to freeze include ARD from the Misery schist and significant Ni leaching from various kimberlite wastes and black clay waste rock.

Proposed Action: Given its importance to the post-closure environmental protection, future editions of the WRSA report need to address the issue of freezing in greater detail. This should include a discussion of the impact of the spatial relationships of different materials in each stockpile, the influence of climate variability (e.g., cold versus warm years and climate change) and contingencies where conditions are warmer than was previously estimated.

Monitoring of the Wastes

The objectives in waste monitoring are to:

- verify pre-mining predictions of rock composition and the ML/ARD potential;
- check that that different rock types or geochemical units are being segregated in the planned manner; and
- provide a record of the initial composition of the wastes.

From what I can gather there is presently no plan to separately handle the kimberlite and granitic rock , except at the Fox pit, and thus the primary objectives are to verify pre-mining predictions and provide a record of the initial composition of the wastes. To achieve these objectives the following are recommended.

Proposed Action: Need to add regular checks on:

- the mineralogy of potentially problematic wastes using Rietveld XRD procedure[8];
- composition of reactive fine size fraction of the waste rock, using analysis of post-blast fines and coarse fragments to check that drill chip analysis provides an accurate assessment of the composition of fines and whether a correction is required; and
- weathering and changes in drainage chemistry of potentially problematic rock units (see earlier comments).

Note that ABA results for the fines composite analyzed as part of this years characterization in Seep 019 area had 3 times higher total-S than the average total-S (0.06% versus 0.02%).

[8] Unlike other XRD procedures, the Rietveld procedure provides quantitative data.

Proposed Action: Need operational characterization of till and lake sediments. This information should already be being collected as part of the characterization of soils for reclamation, but refinements may be required to address the issues associated with waste disposal, water management and ML/ARD mitigation.

Proposed Action: Should list as non-detectable rather than the detection limit for calculations of CO3-NPR when CO2 inorg is < detection limit of 0.2% (0.2% = 5 kg/t).

Proposed Action: Check how PPW 345-43 1A had a Sobek-NP of 153 kg/t when fizz rating of 2 is only equivalent to 100 kg/t (see discussion of Sobek-NP in Appendix). A similar check is required for KK-Dump-5A Koala Kimberlite with Sobek-NP of 76 kg/t, since a fizz rating of 1 is only equivalent to 50 kg/t. Hopefully these discrepancies do not uncover something generically wrong with the analysis or reporting of the data (see Appendix 2).

Proposed Action: Distribution plots and tables showing descriptive statistics should be repeated for all rock unit/pipe combinations. Distribution plots should highlight the current year's data.

If BHPB is to avoid placing potentially problematic rock units, such as the black clay and kimberlite in contact with the acidic tundra soils they need to be able to identify and segregate them from the more inert, low metal granitic waste rock. If the granitic rock can be visually distinguished from other rock types, it may be more cost effective to replace ABA analysis on every drill hole with a more thorough visual geological assessment of the drill chips and the volume of rock it represents. Another option would be to use S and Ni analysis for waste segregation, with less frequent complete ABA and elemental analysis retained as a check on the less intensive methods and when ever geological changes occur.

Appendix 1 – Background Information and Questions

Mine Plan and Waste Materials

The mine started production in November 1998primarily mining open pits. The exceptions are the planned underground mining below the Panda and Koala open pits. The sequence of mining is Panda open pit (1998-spring 2003), Koala open pit (since 2000), Koala North open pit (since 2001), Koala North underground (since 2002), Beartooth open pit (since 2003), Misery open pit (mined until 2003, shut down for a year, but planned to be reopen) and Fox open pit (under development). Bedrock is broken apart using 311 mm diameter drill holes on roughly a 7.5 m grid and then blasting takes place with ammonium nitrate. The drill chips are used for rock identification and ABA analysis.

Waste materials include waste rock, processed kimberlite (coarse and fines) and naturally unconsolidated surficial materials (i.e., till and lake sediments). Rock types in the waste rock are also exposed in mine walls and the resulting talus. Two hundred and eighteen tonne trucks are used to remove blasted waste rock to the waste rock storage areas (WRSA) adjacent to each pit.

The majority of the waste rock is granitic rock containing low concentrations of sulphide-S and trace metals and little or no carbonate. The other rock units in the waste rock, the kimberlite and black clay in the waste rock from the Koala pipe, biotite schist and diabase in the Misery waste rock, and minor amount of diabase and kimberlite in the Fox waste rock, have higher sulphide and trace element concentrations. ABA data and humidity cell tests indicate that a portion of the biotite schist and diabase in the waste rock is potentially ARD generating.

Leachate chemistry from the various rock units were predicted using short-term humidity cell rates assuming: 10% of the rock is leached, the majority of the rock is granite, and reactions rates were 4 times lower than observed in the humidity cells due to lower temperature. An exception was made in terms of the lower reaction rates for the Misery Schist due to the potential heat from sulphide oxidation. The predicted drainage chemistry for the Panda/Koala WRSA was pH 7.5 – 8.5, Al 0.5 – 1.0 mg/L and Zn > Cu > Pb > As > Ni.

Overburden consists of till and lake bottom sediments. Most of the focus has been on lake bottom sediments, which are quite fine, have a high water content and unless they are frozen, difficult to handle. The disposal plan is for till and lake sediments to be placed in areas with drainage control and surrounded by waste rock. pH values of lake sediments are typically from 5 to 6.

- *Is the pH of 5 to 6 for the lake sediments crushed or rinsed? What produces the acidity and low pH? How fine are the lake sediments?*

The ore, which consists entirely of kimberlite, is moved to the main ore storage area or to the interim storage area on the rim of the Misery open pit. The coarse size fraction of the processed kimberlite is first stored in a temporary stockpile and then moved to the Panda/Koala WRSA. Processed kimberlite fines are now stored in the Long Lake containment area. Later in the mine life they will be disposed of in the Panda pit.

Mineralogy of Mine Wastes

Quartz diorite: (> 5%) plagioclase, biotite, quartz > (1-5%) K feldspar, amphibole, chlorite, epidote, muscovite, sericite, sphene > calcite, apatite, chalcopyrite, tourmaline, pyrite

Biotite Schist: plagioclase, biotite, quartz > (1-5%) K feldspar, amphibole, chlorite, sericite > sillimanite, pyrrhotite, ilmenite, rutile, apatitie, tourmaline

Diabase: plagioclase, clinopyroxene, amphibole > (1-5%) chlorite, magnetite, sericite, biotite > sphene, K feldspar, pyrrhotite, pyrite

Kimberlite: highly variable, olivine, phlogopite, serpentine, chlorite, chromite, chrome, diopside, calcite, garnet, quartz

Sable and Beartooth-Bearclaw Reference Areas

Drainage collected from Sable monitoring sites generally has low TSS, although there are exceptions, lab pH of 5 to 6.5 and < 5 mg/L sulphate. TOC concentrations range from 7 to 30 mg/L, with 10 to 20 mg/L in most samples.

- *Was there a soil survey to establish similarity of surficial materials and soil chemistry in Sable and Beartooth-Bearclaw Reference Areas to mined areas?*

Long-Lake Containment Facility

The Long-Lake Containment Facility (LLCF) consists of a number of cells. It receives:

- Drainage from Beartooth pit, Panda pit, Koala pit and Koala underground after portable flocculant/coagulant treatment;
- Fox pit water after portable separate flocculant/coagulant treatment;
- Pigeon pit water;
- Processed Kimberlite fines, a mix of solids and water; and
- Treated sewage effluent and site drainage.

- What happens to the wastes from various portable flocculant/coagulant treatments?

The decline observed in zooplankton abundance and diversity in cells is attributed to flocculants and coagulants. A thin organic layer on the surface is thought to prevent similar toxicity to benthic recolonization.

Processed kimberlite fines (< 0.5mm) are hydraulically transported to Long Lake Containment Area. In pre-mining test work, simulated processed kimberlite from Panda had a pH of 8.5 and from Fox had a pH of 10. Both sites had Sobek-NP > 330 kg/t, but carbonate NP < 100 kg/t. Three of four samples were subjected to 8 weeks column leaching (one Fox sample was too fine to produce leachate). Resulting column leachate was pH 7-8 for Panda and pH 8.5 – 9, with high Ni and Al, for Fox.

According to Stephen Day:

- high non-carbonate-NP is due to solubility of Mg silicates under acid conditions;
- carbonate-NP comes mainly from Mg carbonate minerals; and
- precipitous decline in non-carbonate-NP in humidity cell tests resulted from the use of lower fizz rating for post-test analyses.

One challenge identified in pre-mining characterization was the potential difficulty in settling high smectite kimberlite fines from Fox pit.

Panda/Koala/Beartooth Waste Rock and Overburden Storage Area

Planned to eventually contain:

- Waste granite 193 million tonnes, not including 11 million used as construction material around the site, 11 years production
- Till and lake sediments from P and K pits, 15 million tonnes
- Barren kimberlite from K pit, 4.5 million tonnes, which is less than 3% of total
- Coarse kimberlite reject, 31 million tonnes
- Non-hazardous solid waste, 1000 tonnes, scrap metal, incinerator ash, sewage sludge, etc., disposed in several locations and will eventually be covered with waste rock,

Disposal objectives:

- Most of the drainage will report to LLCA, although it may go via Panda Pit or Koala Pit/sump
- Drainage from the extreme NE portion will drain towards Beartooth Lake and northern remnant of Panda lake (note sump now in place to collect drainage and send it to Beartooth Pit)
- Low height and irregular surface topography, stoney ridges and outcrops
- Avoid drainage to u/g shafts

P/K Topsoil Storage Area (TSA) contains lake sediments from Panda and tills from Koala, Koala North and Beartooth open pits, plus a limited amount of waste rock that was added during tranportation. Kimberlite mudstone is stockpiled next to the TSA. Waste kimberlite is placed in several areas and co-disposed of with the granite. Koala and Beartooth lake sediments that are considered not useful for reclamation are mixed with thewaste rock in the western portions of WRSA.

- *When mixed with granitic WR, does leachate from lake sediments remove NP making granitic PAG and lowering NP and increasing Ni leaching from the kimberlite?*

The receiving environment for different parts of Panda/Koala storage area are as follows:

Panda WRSA – Long lake Cell C (via Koala catchment), Beartooth and Bearclaw Lakes
Panda Sediment Storage Areas – Long Lake Cell C (via Koala catchment)
Koala Sediment Storage Areas – Long Lake Cell C (directly and via Koala catchment)
Koala WRSA/Coarse Rejects Storage Area – Long Lake Cell C and D
Ore Storage Area - Long Lake Cell C (via site drainage collection)

Water quality from LLCA is presently acceptable, although there are concerns with ammonium. Also concerns that acidity attributed to oxidation and precipitation of ferric hydroxide will leach Al and Zn from tundra soils.

Coarse Kimberlite Rejects

Coarse kimberlite rejects (CKR) are 0.5 – 8 mm in size, with the consistency of beach sand. CKR are 40-53% of kimberlite feed and are generated at 200 tonnes per hour. Material is initially stockpiled and then permanently stored in Koala waste rock storage area (KWRSA), which drains into Long Lake CA. In the test work, CKR produced leachate that was initially high in Cu and Al. The disposal site at KWRSA is constrained by abutments of granite waste rock. Granite also provides insulation and will eventually be used as a cover to keep CKR out of the active permafrost zone. WRSA now fully surrounds CKRSA.

Panda Granitic Waste Rock

In 2003, as in previous years, almost no AP (< 1 kg/t), no CO3-NP (<0.2 % detection limit) and Sobek-NP of 10 to 20 kg/t, with fizz rating of 1. As a result, the Sobek-NPR is >> 2. Low total trace metals and exceedances of typical background concentrations are rare. Lack of sulphate-S permits the use of total-S in calculating the AP. With a couple of exceptions, noted in the previous comments on waste monitoring, the correct fizz rating was used in the NP measurement. Monitoring results are for drill chips providing a measure of whole rock rather than fines. ABA results for the fines composite analyzed as part of this year's characterization in Seep 019 area had 3 times higher total-S than average total-S (0.06% versus 0.02%).

- *Granite lacks buffering capacity. What is impact on drainage chemistry when mixed with acidic overburden? For example, does mixing granite with acidic overburden result in a low pH that subsequently cause a flush of P.*

- *Material characterization for waste rock should include regular checks on the composition of the fines versus the drilling rock chips (whole rock).*

<u>Koala Blast Rock</u>

ABA results separated for granite, black clay and kimberlite. For granite, 5^{th} and 95^{th} percentile are low for both %S (0.01-0.1%) and Sobek-NP (8-24 kg/t). Maximum %S is only 0.26%. Most samples with higher %S (0.1 and 0.26% S) were taken close to kimberlite pipes. 5^{th} and 95^{th} percentile NPR values are 4.9 and 77.

Black clay and kimberlite rock units have higher %S and very much higher NP. For black clay, 5^{th} and 95^{th} percentiles are 0.32 to 0.47 %S (max of 0.93%), 216 to 326 kg/t Sobek-NP and 73 to 175 kg/t CO3-NP. For kimberlite, 5^{th} and 95^{th} percentile are 0.11 to 0.28 %S (max of 0.31%), 91 to 296 kg/t Sobek-NP and 29 to 42 kg/t CO3-NP. Note that ankerite noted to be part of carbonate mineralogy. There is also likely to be significant MgCO3.

Other comments include:

- *What is the mass of black clay?*

- *Total-S > acid soluble sulphate-S plus sulphide-S. Can this be explained by the low total-S and significant non-acid soluble sulphate (e.g., Ba and Sr – see Appendix)?*

- *The large discrepancy between Sobek-NP and CO3-NP in the kimberlite and the black clay may indicate that Sobek-NP greatly overestimates the neutralizing capacity. There is a need to perform regular checks on the mineralogy using Rietveld XRD to assess potential sources for CO3-NP and Sobek-NP as well as an assessment of what can be considered neutralizing under site conditions. A discussion of these issues and potential action to resolve these is needed. In reporting of the ABA results, BHPB should replace NNP column with data for Sobek-NP minus CO3-NP.*

Metals in Koala granite are similar to, although slightly higher than the Panda granite. The main difference in trace element concentrations between the granitic waste rock, and the black clay and kimberlite are the elevated Cr and Ni present in the latter.

- 400 to 1300 ppm Cr and 250 to 750 ppm Ni in black clay.
- 400 to 1200 ppm Cr and 700 to 1800 ppm Ni in and kimberlite.

It is important to note that significant Ni leaching can occur under neutral pH conditions, and other mines have noted that a delay can impede its detection in pre-mining test work (e.g., Raglan Mine). There is no mention of Ni sulphides so presumably the Ni occurs in silicate minerals such as serpentine.

- *The mine should conduct microprobe analysis to identify minerals containing Ni and assess/understand their weathering properties under different potential disposal conditions.*

- *Again there is no data on the composition of the waste rock fines versus the drill chips,which are more representative of the whole rock (see discussion in Appendix).*

Thermal Monitoring

The freezing in the Koala granite waste rock is noted to be occurring faster than expected in the Panda granitic portion of WRSA. Cold temperatures are expected to reduce reaction rates and minimize leaching.

2003 thermal monitoring data provided in Appendix D.1, but there was no discussion of results.

General Seepage Monitoring

Monitoring sites generally have low TSS, although there were more exceptions than at Sable reference sites and excursions were higher, often over 50 mg/L. Compared to the reference site, there also appeared to be more samples with a lab pH of 4.5 to 5. 5 and 6.5 to 8.0, and a slightly wider range in TOC (i.e., 5 to 40 mg/L). Sulphate concentrations were highly variable. According to the text, Ni, Mn and sulphate concentrations have increased at a number of sites where the monitoring location was moved due to dump expansion.

A number of seepage monitoring sites had a lab pH < 4.5 (7D, 7E, 8, 24A, 25 and 318), in addition to Seep 019 area.

Seep 018/019 Area

As a result of the proximity to the receiving environment (this is the area of the WRSA that does not naturally report to the LLCA), increasing sulphate concentrations and a concern regarding low pH and high Al in Seep 018/019 Area, in 2003 BHPB:

- constructed a sump to collect drainage and pump it to Beartooth Pit; and
- conducted a detailed evaluation of water chemistry along the flow path between Panda WRSA and Bearclaw Lake.

The sump and pump has enabled the mine to stay in compliance with its water license.

Results of the evaluation of water chemistry along the flow path in 2003 were provided in Appendix C, a memo from Stephen Day to Jim Millard. The flow path is a well-defined draw, approximately 450 m long. The first visible flow is a series of stagnant pools along the WRSA toe (018). Flow then collects in pools against the Sable Road (SW-320), emerges on the other side of the road and flows in a channel for 120 m, disappears for 75 m, re-appears at a break in the slope (019) and continues in a channel before flowing diffusely into Bearclaw Lake (SW-321). SW-321 is an area of stagnant pools and was the only area where orange precipitates and coatings were noted to occur.

The lowest pH occurs in area 018. From 2001 to 2003, the pH in this area has decreased from 6.5 to 3.4, nitrate, ammonium and TDS have decreased, Fe has increased to 17.1 mg/L and Ni has increased to 2.1 mg/L. Drawing on results of monitoring of the CRKSA in 2002 (SRK 2003), SRK concluded that reducing conditions in the tundra soil permitted migration of ferrous-Fe, whose subsequent oxidation and hydrolysis to ferric-Fe hydroxide produced the decline in pH.

Compared to drainage samples collected further downstream, those in area 018 had more than an order of magnitude greater Fe, Al, Cr, Cu, Ni and Zn concentration, double the sulphate, but lower Mg and nitrate concentrations. The increased Ni, Cr, Cu, Zn and sulphate at 018 can be attributed to kimberlite weathering, and their decrease in downstream drainage to natural attenuation. Visual observations of the waste rock in the area led SRK to conclude that there were relatively high proportions of kimberlite mixed with granite in this part of the WRSA. Water chemistry at 019 has varied seasonally, generally with higher pH values and lower iron concentrations during the earlier part of the open water season.

Misery Pit and Storage Facilities

Misery Pit is 29 km from the process plant. Construction started in August 2000. The Misery Storage facilities will eventually contain:

- Granitic waste rock, 26 million tonnes, some of this granite will be used as construction material around the site
- Biotite schist waste rock, 22 million tonnes
- Diabase dyke, 3 million tonnes
- Till and lake sediments from M pit, 2 million tonnes
- Barren kimberlite from M pit, 1 million tonnes
- No coarse kimberlite reject
- Non-hazardous solid waste, which will be placed in several locations and eventually covered with waste rock

In test work, Fox Pipe Diabase and Misery Schist produced low pH water; but only Misery Schist was said to produce a low enough pH for significnat metal release. The conclusion was that acid generation would be at a low rate and would be a relatively short-lived phenomenon in the diabase. Other conclusions were that there would be a large excess NP in the kimberlite and that the PAG portion was only 2% of the diabase.

There are a number of concerns noted with biotite schist, both in the storage area and pit. At least three seeps from Misery waste rock pile show evidence of acid generation. In humidity cells, Misery Schist reacted quickly, but due to small amount of sulphides, high sulphate was present for only a short amount of time after which metal concentrations returned to acceptable levels, although the pH remained depressed.

- *With only 10% of waste rock assumed leaching in the actual dump, how long is removal of metals from biotite schist predicted to take?*

Proposed mitigation measures for PAG Schist include:

- Overall encapsulation by granitic waste rock and sandwiching 10 m layers between 5 m layers of granite; far more porous granite will remove heat and increase freezing
- Raise the pH
- "Blend" with high NP kimberlite

Rapid freezing of biotite schist is attributed to convection due to its high porosity

Kimberlite storage areas include an area of temporary ore storage area and an area used to store material undergoing further diamond testing. In both cases, the storage area was prepared by stripping away organic soils and adding a granite waste rock base.

The receiving environment for Misery Storage Areas are Cujo Lake, Shining and Christine Lake. Mine water management includes various ponds and catchments. To restrict seepage to Lac de Gras, waste rock dam created downstream of MWRSA in 2001/2002. Two coffer dams were also created south of Desperation Pond to capture seepage from MWRSA. The discharge from the dams is to King Pond, a licensed mine water settling facility, it is then pumped to Cujo Lake. Water flows through four lakes before entering Lac De Gras.

<u>Blasted Rock</u>

- *There is a need for a similar table of descriptive statistics for different rock types as provided for other WRSA.*

Misery granite appears to have almost no AP (<1 kg/t), no CO3 and Sobek-NP < 10 kg/t. Trace metals also appear relatively low.

Diabase has an AP of 2 to 3 kg/t, appears to have almost no CO3 and Sobek-NP of 10 to 30 kg/t < 10 kg/t. Trace metals are not particularly high.

Biotite schist has an AP of 1 to 7 kg/t, almost no CO3 and Sobek-NP of 7 to 13 kg/t. NPR is > 1, but the reactivity of Sobek-NP is questioned, given the ARD generated in humidity cells where a maximum sulphate release of 70 mg/kg/week was measured from a low S sample.

- *Need 'field test pads' for potentially problematic rock types such as biotite schist to verify predictions of future weathering and drainage chemistry, and assumptions made in assessing downstream drainage chemistry. Pads could consist of segregated portions of waste dump.*

Ten samples of kimberlite had similar compositions and therefore the same issues as kimberlite from Koala pipe exist.

<u>Thermal Monitoring</u>

No discussion. Results provided in Appendix D.1.

<u>Seepage Monitoring</u>

Seepage generally had low TSS, although there were more exceptions than Sable and excursions were often over 50 mg/L. Also there was a slightly wider range in TOC (5 to 76 mg/L). Of the seepage monitoring locations, only site 060 had drainage samples with a lab pH < 4.5. The text notes that pH values are below the range specified in the water license. Increases in nitrate and ammonium concentrations are noted at one set of sites and they are lower at another. The reverse is true for sulphate and trace metals.

<u>Kimberlite Storage Area</u>

At some sites, there were increases in solutes such as sulphate and Ni.

Fox Pit and Waste Rock and Overburden Storage Area

Stripping of the pit began in 2002. The storage facility will contain till, lake bottom sediments, waste country rock (granite plus minor amount of diabase) and waste kimberlite. Granite will be co-disposed of with till and lake bottom sediments. Kimberlite is segregated and stored in the south-central and northwest side. Toe berms to limit seepage will be constructed in the fall and winter of 2004.

- *What is the implication of adding acidic lake sediments to granitic waste rock with neglible NP?*

In test work, pH 10 water released from Fox and Leslie kimberlite were presumed due to the abrasion of olivine and the release of Mg hydroxides. BHPB predicted a subsequent decline to pH 7 due to buffering by Mg carbonates.

The receiving environment for Fox Storage Areas is Nero, Nema and Martine Lakes.

Blast Rock – Granite

Similar to other sites, 5th and 95th percentile are low for both %S (0.01-0.06%) and Sobek-NP (12-204 kg/t). Maximum %S is only 0.09%. Nothing above normal background as far as metals go.

Thermal Monitoring

Cables were only installed during the winter of 2003 and the spring of 2004, therefore there were no results reported.

Seepage Monitoring

Monitoring sites generally have low TSS, although there were more exceptions than Sable and excursions were often over 50 mg/L. Compared to reference sites and other mined areas, there were more samples with a lab pH of 6.5 to 8.0. But unlike other WRSA, there was a lack of drainage with a pH < 4.5. Other observations include: that the field pH was less than the lab pH (e.g., samples 305 to 313) and the wide range in TOC, 4 to 76 mg/L. Sulphate is also highly variable.

High TSS and total-Al concentrations were attributed to lake sediments and the freshet. Silt-fences and interceptor pumps successfully lowered the TSS, but total-Al was above the range specified in the water license (2.0 mg/L versus 5.5 to 31.9 mg/L). A total-Al concentration much higher than the dissolved Al indicates that the source of elevated Al is TSS. BHPB established additional monitoring stations to study the issue and later in the year the total-Al concentration dropped below the required concentration. There is evidence that higher Al concentrations were in part due to disturbance of underlying sediments during the sampling of clear shallow drainage with syringes

There was a slight decrease in the pH compared to previous year's (5.8 – 5.9 versus 6.2 – 6.3). pH values were comparable to Fox reference stations and thought to be a feature of the natural tundra water.

Appendix 2 – Background Comments about the Sampling and Analysis of Wastes

Sobek-NP

A comparison of the CO_3–NP and Sobek-NP is commonly used to roughly assess the relative amounts of CO_3–NP and silicate-NP in the Sobek-NP. Quantitative mineralogical information is required to assess the potentially contributing silicates and their reactivity. If the Sobek-NP is measured properly, it is 5 to 15 kg $CaCO_3$/t higher than the CO_3–NP, which is the amount of silicate-NP. The main cause of higher contributions of silicate-NP is the addition of too much acid (i.e. acid additions far in excess of the neutralizing CO_3–NP). A simple way to check whether excess acid was added is to compare the amount of acid added (check the fizz rating) with the CO_3–NP and resulting Sobek-NP values.

Amount of Acid Corresponding to Each Sobek Fizz Rating:

None	20mL of 0.1 N HCl	= 50 kg $CaCO_3$/tonne
Slight	40 mL of 0.1 N HCl	= 100 kg Ca CO_3/tonne
Moderate	40 mL of 0.5 N HCl	= 500 kg $CaCO_3$/tonne
Strong	80 mL of 0.5 N HCl	= 1000 kg $CaCO_3$/tonne

The acid addition should be only slightly higher than the CO_3–NP and the resulting Sobek-NP values, and should be repeated using a more appropriate acid addition if either is not the case. For example, moderate or strong fizz ratings are too high if the CO_3–NP and resulting Sobek-NP are less than 50 kg $CaCO_3$/tonne. Important considerations resulting from the above include:

- the need to report the fizz rating,
- the potential to substitute the CO_3–NP for the fizz rating in selecting the appropriate acid addition, and
- the potential problems caused by an uncertain but significant amount of Fe and Mn CO_3.

Acid -Insoluble Sulphate

The concentration of acid-soluble sulphate is typically measured directly as part of the ABA analysis. However, there is presently no procedure for measuring acid insoluble sulphate. When sulphide-S is calculated from the difference between total-S and acid-soluble sulphate-S, rather than directly, acid insoluble sulphate-S reports as sulphide-S. Usually sulphide-S is much higher than the acid insoluble sulphate-S and this is not a concern. However when sulphide-S is low, as is the case for most of the rock units at Ekati, acid insoluble sulphate-S can potentially contribute a significant portion of the total-S and sulphide-S. It is therefore very important to check.

The primary acid insoluble sulphate-S minerals are Ba, Pb and Sr SO_4. The maximum potential concentration of acid insoluble sulphate can therefore be estimated from the

XRF or ICP data assuming all the Ba, Pb and Sr are in this form (see p 48 of Price, 1997 which reference is this?). At Ekati, Pb concentrations are typically < 50 ppm, and therefore $PbSO_4$ is not likely to be significant. However, Ba and Sr concentrations are 100s and 1000s of ppm. The concentration of Ba was 500 to 1000 ppm in the Kaola granite, 1000 to 2000 ppm in the kimberlite and 1000 to 3000 ppm in the black clay (Appendix A2). Assuming the entire Ba in the black clay occurs in barite, 3000 ppm Ba would result in approximately 700 ppm or 0.07 % barite-S. Microprobe and XRD analysis can be used if more accurate estimates of the potential portion of Ba occurring as acid insoluble sulphate is required.

Concentration of AP and NP in the Fine Fraction versus Larger Size Fractions of Waste Rock

Sulphide minerals may occur in veins or on fractures and therefore preferentially report to the finer particles or occur on surfaces. As a result they are more reactive per unit weight than neutralizing minerals, resulting in an effective NPR that is lower than the overall NPR values. This is a concern in waste rock, where the finer particles (< 2 mm grains) will be almost entirely exposed to oxygen and water, while most of the mineral grains in the coarse fragments are occluded and unable to react. Often the NPR of the reactive fines is significantly lower than that predicted from a 'whole waste rock' ABA.

Segregation After Deposition of Tailings

For tailings, the concern is with the composition of the sandy material that settles near the discharge point versus that of finer slimes in the center of the impoundment. The sandy material is both more likely to contain heavy minerals like sulphides and be well drained, and is therefore more of a concern than slimes, which due to their silt-size are likely to remain saturated.