

# Problems With Acid Rock Drainage Predictions at the Ekati Diamond Mine, Northwest Territories, Canada

K A Morin<sup>1</sup>

## ABSTRACT

The Ekati Diamond Mine is located on permafrost terrain in Canada's Northwest Territories. The mine rock consists of:

1. diamond-bearing and barren kimberlite; and
2. surrounding waste rock such as granite. The kimberlite occurs in several vertical 'pipes' that are, or will be, mined using open pits.

Early predictions of drainage chemistry at Ekati identified the potential for ARD due to sulfide oxidation from both waste rock and kimberlite. This was surprising for the kimberlite, because neutralisation potentials (NP) are typically hundreds of kg CaCO<sub>3</sub> equivalent/t. However, subsequent testwork showed that substantial portions of the NP 'disappeared' quickly, apparently due to the unusual non-carbonate mineralogy. In any case, additional predictive work concluded much of the rock was benign and there would be no ARD. Shortly after mining started, ARD appeared from both the waste rock and kimberlite, although a few years passed before the company and its consultants recognised that at least some of the acidic water was ARD. Numerous other processes have been put forward as possible explanations for the remaining acidic drainage, although none have been either confirmed or eliminated.

Because:

1. the causes of the ARD and acidity are not known;
2. no causes have been eliminated and more have been added;
3. drainage chemistry was not predicted accurately; and
4. future mining will encounter similar rock.

I believe the Ekati Diamond Mine needs high-level assistance to understand current chemistry and to avoid problems with future drainage.

Organisations like INAP, MEND3, and universities could provide this assistance.

## INTRODUCTION

There is no doubt that we can learn valuable lessons from mistakes, particularly for the prediction and control of metal leaching (ML) and acid rock drainage (ARD). Such mistakes have led to published case studies that will hopefully not be repeated (Morin and Hutt, 1997a, 1997b, 2001a and b). Although this may be embarrassing to the original authors, a greater good is served by discussing and understanding the mistakes in the hopes of preventing similar future problems. This paper presents a case study of prediction problems, but the explanations for these problems are not yet resolved to the satisfaction of all parties.

In 1989, Dia Met Minerals Ltd. found indicator minerals for kimberlite, the common host rock for diamonds, in the Lac de Gras area of the Northwest Territories of Canada (Figure 1). This area is in a region of continuous permafrost. Dia Met signed a joint venture agreement with BHP (now BHP Billiton) in 1990, and the first diamonds were found by drilling the claims in 1991 (BHP Diamonds Inc. and Dia Met Minerals Ltd, 1995?). Eventually, dozens of kimberlite 'pipes' were located on the property, which became the Ekati Diamond Mine. Early exploration and mine design focussed on the Panda and Koala Pipes using open-pit mining, followed by Misery, Leslie, Fox,

and now others. The Environmental Impact Statement (EIS) was submitted in 1995, permits were granted in 1997, and commercial production began in October 1998 (Independent Environmental Monitoring Agency, 2002).

As part of the Environmental Agreement, the Independent Environmental Monitoring Agency was formed to act as a 'watchdog' over environmental monitoring and management at the minesite (IEMA, 2000, 2001, and 2002). This involves reviews of Ekati reports, site visits, and meetings with BHP Billiton, regulators, and government agencies. Much of the information in this paper is derived from IEMA reviews and meetings, and Ekati reports submitted to IEMA.

## INITIAL PREDICTIONS OF ARD

Prior to the Ekati mine, the environmental geochemistry of kimberlite and the drainage chemistry at diamond minesites were not well documented in published literature, although alkaline drainage (LRD) at diamond minesites was generally known (Morin and Hutt, 1997b and 2001b). No published documentation of acid rock drainage (ARD) from sulfide oxidation at diamond mines could be located.

Studies for the Ekati EIS included geochemical static and kinetic tests of the diamond-hosting kimberlite as well as several units of waste 'country' rock like granite, diorite, schist, and recent sediments (Minesite Drainage Assessment Group, 1995a and b). Interpretations of the static tests, which consisted of acid-base accounting (ABA), total-metal contents, and mineralogy, led to the following observations (MDAG, 1995a).

'Various rock units contained up to 1.3 wt per cent sulfide and this sulfide typically occurred as pyrite in the reactive 'framboidal' form. ... At this time, portions of Fox granite and lake sediments and Misery kimberlite and lake sediments have a net deficiency of NP [neutralisation potential] and thus have the potential to generate net acidity in the future ... [P]ortions of Koala kimberlite, Panda till, and Misery schist may also be capable of generating net acidity ...'

'Mineralogical examinations have shown that neutralisation of acidity in the samples is not derived from carbonate minerals, but from various aluminium- and silica-bearing minerals such as olivine and plagioclase.'

Initial sulfide-based NPR criteria [Sulfide Net Potential Ratio:  $SNPR = NP / (\%S\text{-sulfide} * 31.25)$ ] for kimberlite were set at <4.0 for net acid generating and between 4.0 and 6.0 for 'uncertain', based on initial estimates of unavailable NP (measured NP not available for neutralisation). Further mineralogical work was recommended to clarify this.

Several of these findings were initially surprising. Ekati kimberlite typically contains hundreds of kg CaCO<sub>3</sub> equivalent/t of NP and thus the possibility of ARD from kimberlite was unexpected. However, the neutralising minerals in the kimberlite are relatively rare (discussed further below) and their environmental behaviour was not well understood. This was also reflected:

1. Minesite Drainage Assessment Group, 8035 Redtail Court, Surrey BC V3W 0N4, Canada.

1. in the unusually high initial SNPR criterion of 4.0 for net-acid-generating kimberlite, which is more typically around 1.0 - 2.0 at other minesites (Morin and Hutt, 1997b and 2001b); and
2. in the alkaline paste pH for core samples and in on-site underground workings of up to pH 11.

Nevertheless, the potential for ARD was suspected from portions of several rock units at this early stage.

Interpretations of additional ABAs and of standard-Sobek humidity cells led to the following observations (MDAG, 1995b).

‘This Phase 2 study demonstrated that some waste rock was capable of generating acidic drainage within a few months of exposure. ... Also, there may be small zones of kimberlite capable of generating net acidity. However, this could not be confirmed with available information. ... When dealing with a large volume of rock, nearly  $1 \times 10^9$  t for this project, [the current number of samples] cannot provide a comprehensive characterisation of this rock ... additional static and kinetic tests should be done.’



FIG 1 - Map of Canada, the Northwest Territories, and the Ekati Diamond Mine (adapted from Independent Environmental Monitoring Agency, 2002).

Thus, the potential remained at this stage for ARD from various rock units including kimberlite. These reports were rewritten by others and submitted as part of the EIS, which contained new/adjusted conclusions such as ‘This dissolved loading is very conservative because the kinetic tests is [sic] inherently conservative. ...’ (Morin, 1996).

### SUBSEQUENT PREDICTIONS OF ARD

After the EIS, public hearings, and project approval, additional predictive testwork was conducted by Norecol, Dames and Moore (Day, personal communication, 1996) and later carried on by Steffen, Robertson and Kirsten (Day, pers comm, 1999). This work focussed on the waste rock and kimberlite for the first pipe to be mined, Panda.

Around the time mining was starting, the additional work on Panda granitic waste rock led to the following observations (Norecol, Dames and Moore, 1997; BHP Diamonds Inc, 1998), with observations by me (Kevin Morin) in italics after each point.

‘Acid potential (AP) was very low, averaging <1 kg CaCO<sub>3</sub>/tonne.’ ‘Due to the very low sulfur concentration and low NP, this rock type has negligible potential to influence drainage chemistry.’ *For every 1 000 000 t of rock, there is up to 1000 t of potential acidity if the sulfide is exposed to air and moisture. Also, at the very low measured kinetic rates like 1 mg/kg/wk, this means that each 1 000 000 t of rock would generate 10<sup>9</sup> mg (1 t) of sulfate and acidity each week. The effects of scale are important here.*

‘Geochemically, the majority material to be stored in this waste rock dump is benign.’

‘Neutralisation potential (NP) for the granite was also low, reporting an average of 6 kg CaCO<sub>3</sub>/tonne. ...’ *At several minesites with sulfide-bearing rock, a NP <10 kg/t provides no neutralisation under field conditions and is called ‘unavailable NP’ (see Initial Predictions above, and Morin and Hutt, 1997b and 2001b).*

Based on humidity-cell post-test analyses, ‘No significant changes were noted in neutralisation potentials (NP) [in the granitic waste rock] ... suggest[ing] that there were no readily soluble neutralising minerals within the samples.’ *This indicates the negligible NP levels are not fast-reacting, and thus may not fully neutralise acidic water to pH above 6 - 7.*

For the rock dumps, ‘pH was not predicted but is expected to be between 7.5 and 8.5 (this range was used in the model).’

Additional work on Panda kimberlite led to the following observations (Norecol, Dames and Moore, 1997; BHP Diamonds Inc, 1998), with observations by me in italics after each point.

‘Acid potential (AP) ranged from 6 to 33 kg CaCO<sub>3</sub>/tonne and averaged 13 kg CaCO<sub>3</sub>/tonne.’ *For every 1 000 000 t of kimberlite, there will be an average of 13 000 t of potential acidity if the sulfide is exposed to air and moisture.*

‘As a result of the high NP values, NP/AP ratios had a relatively high mean value of 18 ..., indicating no potential for acid generation.’ Based on humidity-cell post-test analyses, ‘Neutralisation potential (NP) decreased significantly from 175 - 300 kg CaCO<sub>3</sub>/tonne to approximately 75 kg CaCO<sub>3</sub>/tonne in the kimberlite samples ... reflect[ing] the leaching of readily soluble neutralising minerals ... [and] suggest[ing] that there is a second, less soluble mineral present. ...’ *This indicates that the NP is depleted from kimberlite at a faster rate than the acid-generating sulfide, and that all remaining NP may not fully neutralise pH to above 6 - 7.*

Further to the last quote, Mills (1998a and b) stated to IEMA, ‘I recommend most strongly that NP values obtained [from] static (ABA) testing of kimberlitic materials such as barren kimberlite, coarse mill tailings and fine mill tailings [kimberlite] not be used in calculations of neutralising capability. ...’ This highlighted the concern that the measured NP in kimberlite could not be counted on for long-term neutralisation, which is partly due to relatively unusual neutralising minerals (Howe, 1997) like brucite (Mg(OH)<sub>2</sub>) which can be altered to other minerals after contact with air. However, the concern was dismissed by Ekati and its consultants.

### THE ONSET OF ARD

By 1999 and within a year of startup, aqueous pH in drainage chemistry at some monitoring locations had fallen to values around 4.0 while aqueous sulfate concentrations rose as high as roughly 4000 mg/L (Figure 2), based on Ekati’s 1999 seepage survey (Ekati Diamond Mine, 1999). The company explained that this acidic drainage was acidic tundra water draining through and around the pH-neutral Panda waste-rock dump and coarse-kimberlite storage areas. The problem with this explanation was that background tundra water had:

1. a pH greater than the most acidic minesite drainage, and
2. sulfate concentrations much lower than the minesite drainage at any pH (Figure 2).

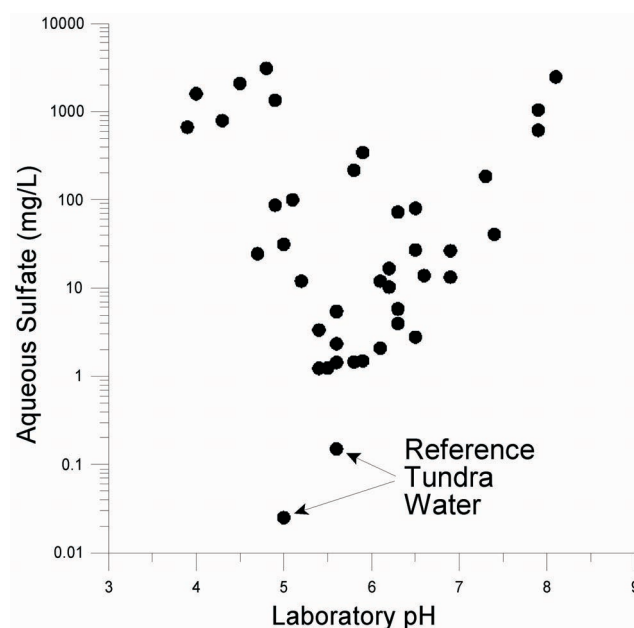


FIG 2 - Laboratory pH versus aqueous sulfate in the 1999 Ekati water-chemistry database.

Thus acidic tundra water could not be a valid explanation (MDAG, 2000).

Although previous ABAs had shown sulfide and sulfate levels were low (see quotes above on acid potentials), one X-ray-diffraction scan was presented in 1999 to show that the high sulfate concentrations could be explained by the dissolution of gypsum (Ekati Diamond Mine, 1999). The problem with this explanation was that gypsum dissolution releases one mole of calcium for every mole of sulfate (MDAG, 2000), but the water was substantially depleted in calcium (Figure 3).

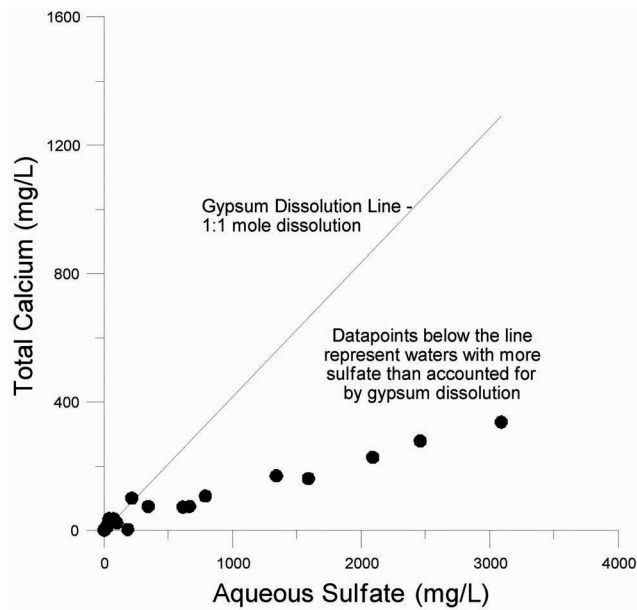


FIG 3 - Aqueous sulfate versus total calcium in the 1999 Ekati water-chemistry database.

Therefore, the water-chemistry data was apparently showing the onset of moderate-strength ARD, and time-series plots showed sulfate was increasing through 1999 at a number of monitoring stations (MDAG, 2000). The company's response in 2000 was (Ekati Diamond Mine, 2000):

'It has been BHP's view that that [sic] pH levels in the range measured at SEEP-002 may be reflective of natural characteristics of the local tundra environment and snow melt conditions. Other potential causes for low pH, like the onset of acid rock drainage (ARD) have also been suggested, but are not likely, based on the predictive geochemistry work that was completed on the Panda granite, prior to the commencement of mining operations.'

The 2000 monitoring data continued to show some acidic drainage around the Panda waste rock and kimberlite storage area (Figure 4). Ekati concluded (BHP Diamonds Inc, 2001):

'The key results ... in the 2000 Seepage and Waste Rock Survey Report submitted to you in February 2001 were as follows:

- Low pH observed from seepage monitoring stations in the Beartooth-Bearclaw Drainage were primarily the result of natural rain water and the decomposition of naturally occurring organic tundra material. ...
- The Panda granite is not a likely source of acidity in seepage waters due to its uniformly low sulfide content.
- One seepage monitoring location (SEEP-022) had a low pH that was thought to originate from the complex interactions between tundra water and small quantities of kimberlite that became entrained with the Panda waste granite. ... A soil perimeter [toe] berm has been constructed at this location to test the perimeter berm concept [the seepage area was buried under metres of waste rock].'

Despite the arguments against ARD, the territorial regulatory agency was concerned and issued the following instructions to Ekati (Mackenzie Valley Land and Water Board, 2001).

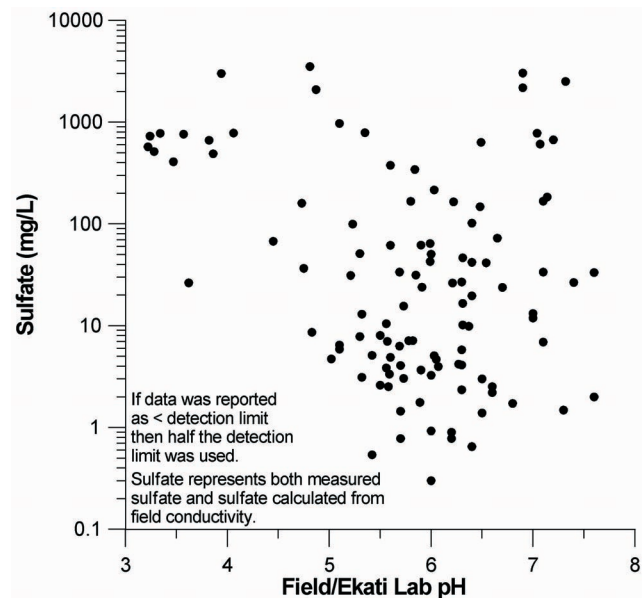


FIG 4 - Field pH versus aqueous sulfate in the 1999 - 2000 Ekati water-chemistry database (waters with low sulfate concentrations represent background tundra water).

- 'Re-establish seepage [monitoring] locations that were covered by the toe berm [of the waste-rock dump] at a location below the toe berm. This is to be done in conjunction with the Inspector and Board staff;
- Monitor seepage below toe berm on a weekly basis;
- Provide details on the characterisation of the toe berm materials, include a full suite of parameters as well as Acid Base Accounting. This is to be submitted to the Board by **30 June 2001** [Board's emphasis – in less than one month, because the berm was built without regulatory approval and was not characterised geochemically prior to construction] ...;
- The [monitoring program] is [currently] focusing on a specific location on the site, however, this experience is expected to impact operations throughout the site'.

Meanwhile, minimum aqueous pH values had fallen further, to around a minimum of 3.0 (Figures 4 and 5). Also, some monitoring stations were showing increasing sulfate concentrations (Figure 6).

By 2001, Ekati's consultant explained, 'We consider approximately one quarter (25 per cent) of existing seep analyses [those fitting into the incomplete classification scheme] to represent ARD' and 'These results show that the waste rock is making ARD ... [which] contradicts the laboratory tests that show granite and kimberlite waste rock could not generate ARD' (SRK, 2001). This implied there was at least another, more widespread source of the acidic minesite drainage. SRK (2001) and S. Day (personal communication) explained five typical characteristics of ARD, which were not met at Ekati and thus indicated most of the acidic drainage was not ARD:

1. 'A 1:1 molar relationship between titratable acidity and sulfate is expected based on the [sulfide-oxidation] reactions.'
2. 'A 2:1 molar relationship between sulfate and iron is expected if iron has not been precipitated and there is no other source of soluble iron.'

3. 'A pH below 3.5 and the presence of acid generating materials is a reasonable indicator of acid generation.'
4. 'A ratio of between 2:1 and 1:1 for alkali earth metal concentrations to sulfate concentrations in pH-neutral waters.'
5. 'Presence of elevated zinc and manganese concentrations in pH-neutral water.'

In reality, these are not necessary characteristics of ARD, since many exceptions are known and can be easily envisioned (Morin and Hutt, 1997b and 2001b).

In any case, a search began for the other suspected widespread causes of acidic drainage. Proposed processes included acidification by precipitation, acidification by organic decomposition, aluminium buffering, and oxidation of ammonia (SRK, 2001). More recently, another possible mechanism was added, ferrous-iron oxidation at the toe of rock piles, while none of the previous causes were eliminated (SRK, 2002). Also, the earlier cause of sulfate dissolution was resurrected as a possibility, as was the possibility that kimberlite incorporated into waste rock might account for any ARD from granitic waste rock. None have been eliminated.

### DRAINAGE-CHEMISTRY CONTROLS

During mine design and initial construction at Ekati, no detailed management and control plans were included for ARD, because predictions indicated there would be no acidic drainage and that the waste rock and kimberlite were benign. The limited concerns over drainage chemistry were dismissed (eg Morin, 1996), because the rock piles were expected to freeze quickly in the permafrost environment so that little water would drain through and from the rock.

However, such freezing is not assured where sulfide minerals are oxidising or where elevated aqueous concentrations develop (Geocon, 1993; Dawson and Morin, 1996), including areas of continuous permafrost in Canada where natural ARD was documented decades ago (Cameron, 1977). Also, the temperature model used for Ekati rock piles did not include self-generation of heat and non-idealities (MEND, 1997). Therefore, there was substantial uncertainty on whether freezing could be counted on at Ekati for drainage-chemistry control, at least in the short term.

In general, the rock piles at Ekati have shown little evidence of internal freezing, although recent data have shown basal freezing has begun in some locations (SRK, 2002). However, SRK (2002) explained that there was insufficient data to conclude freezing conditions can be maintained in all the rock piles, and that

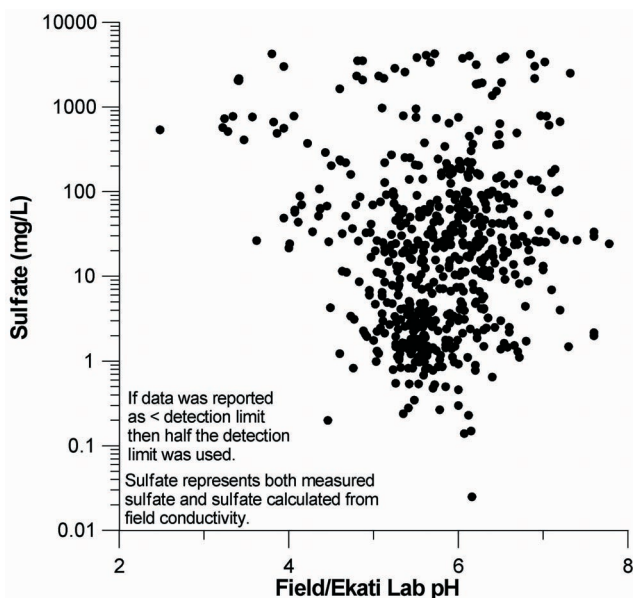


FIG 5 - Field pH versus aqueous sulfate in the 1999 - 2001 Ekati water-chemistry database (waters with low sulfate concentrations represent background tundra water).

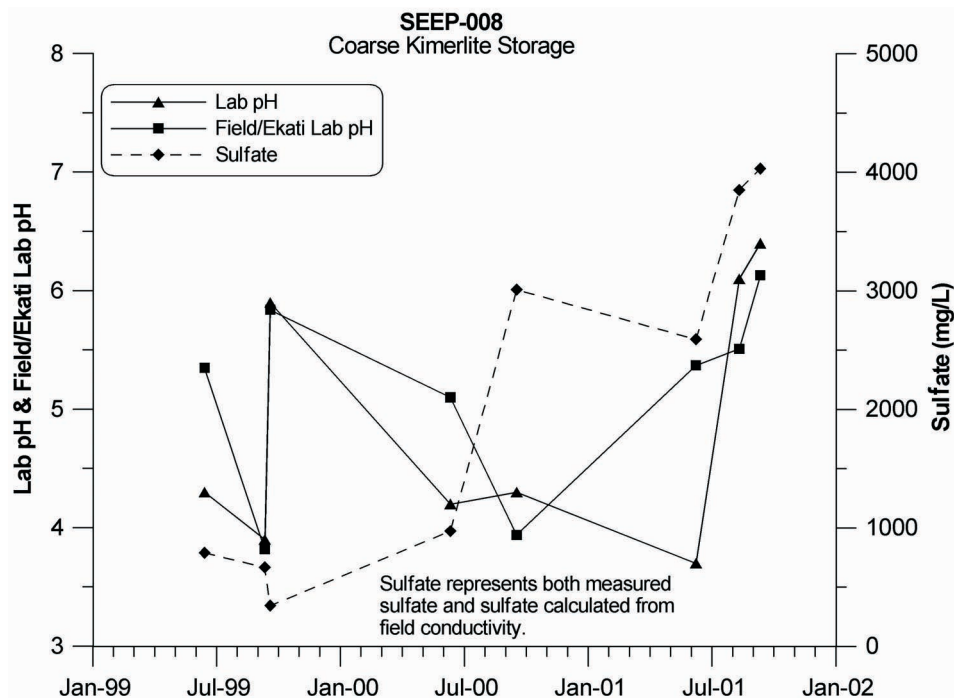


FIG 6 - Temporal trends in aqueous pH and sulfate at one monitoring station near the coarse-kimberlite storage area.

'thermokarsting' due to waste and process waters was occurring. Therefore, there are no short-term proactive (pre-planned) controls on drainage chemistry at Ekati, and it may require several decades after the mine closes for the rock piles to freeze entirely (Ekati Diamond Mine, personal communication, 2001), if they do so at all. Additionally, the Geological Survey of Canada predicts 'moderate' permafrost thawing in the area around Ekati in the decades ahead (Smith and Burgess, 1998).

As a result, Ekati is now in 'reactive' mode, collecting the drainage that cannot be released as it appears. In the Panda area, much of the ARD drains by gravity into the large alkaline tailings impoundment. However, ARD has begun migrating through the shallow groundwater system during summer thawed conditions in the opposite direction, towards the receiving environment (MDAG, 2001 and 2002), and thus more effort and cost may have to be expended to collect and treat ARD in the Panda area.

Furthermore, and of critical importance, several Ekati reports have explained that the rock at other pipes to be mined is geochemically similar and can thus produce the same water-quality problems. For example (BHP Ekati Diamond Mine, 1999),

'Most waste rock [from the Sable Pit] will be a two-mica granite similar to that found at the [existing] Panda Pit. This granite has been shown to be inert with respect to run-off quality and will therefore be stored in waste rock storage piles. ... Preliminary studies do not identify a potential for acidic drainage from waste rock at this site.'

'The majority of waste rock from the Pigeon Pit will be biotite granite, similar to that found at the [existing] Panda Pit. This granite has been shown to be benign with respect to run-off quality.'

## CONCLUSION

Early predictions of drainage chemistry at Ekati included the potential for ARD due to sulfide oxidation from both waste rock and kimberlite. Additional predictive work concluded much of the rock was benign and there would be no ARD. Shortly after mining started, ARD appeared from both the waste rock and kimberlite, although a few years passed before the company and its consultants recognised that at least some of the acidic water was ARD. However, numerous other processes have been put forward as possible explanations for the remaining acidic drainage, although none have been either confirmed or eliminated.

Because:

1. the causes of the ARD and acidity are not known;
2. no causes have been eliminated and more have been added;
3. drainage chemistry cannot be predicted; and
4. future mining will encounter similar rock;

I believe the Ekati Diamond Mine would benefit from external assistance to understand and control current chemistry and to avoid problems with future drainage.

Organisations like INAP, MEND3, and universities could provide this assistance.

## REFERENCES

- BHP Diamonds Inc and Dia Met Minerals Limited, 1995?. NWT Diamonds Project Summary of Environmental Impact Statement.
- BHP Diamonds Inc, 1998. Waste Rock and Ore Storage Management Plan, Rev 2, dated July 31.
- BHP Diamonds Inc, 2001. Water License N7L2-1616: Request for Continuation of Enhanced Monitoring and Confirmation Plan for Beartooth-Bearclaw Drainage, letter to Mackenzie Valley Land and Water Board, dated 16 May.
- BHP Ekati Diamond Mine, 1999. Proposed Development of Sable, Pigeon, and Beartooth Kimberlite Pipes (Revision 3), dated October 1999.
- Cameron, E M, 1977. Geochemical dispersion in mineralized soils of a permafrost environment, *Journal of Geochemical Exploration*, 7:301-326.
- Dawson, R F and Morin, K A, 1996. Acid Mine Drainage in Permafrost Regions: Issues, Control Strategies and Research Requirements, Canadian Mine Environment Neutral Drainage Program MEND Report 1.6.1.2.
- Ekati Diamond Mine, 1999. 1999 Waste Rock Storage Area Seepage Survey.
- Ekati Diamond Mine, 2000. Waste Rock Storage Area Enhanced Monitoring and Confirmation Plan, dated July 2000 (Appendix A of 2001 report).
- Geocon, 1993. Preventing AMD by Disposing of Reactive Tailings in Permafrost, MEND New Ideas Projects.
- Howe, D J, 1997. The Physical and Chemical Characteristics of Kimberlite Fines, MASc thesis, Department of Mining and Mineral Process Engineering, University of British Columbia, pp 217
- Independent Environmental Monitoring Agency, 2000. Annual Report 1999-2000 ([www.monitoringagency.net](http://www.monitoringagency.net)).
- Independent Environmental Monitoring Agency, 2001. Annual Report 2000-2001 ([www.monitoringagency.net](http://www.monitoringagency.net)).
- Independent Environmental Monitoring Agency, 2002. Annual Report 2001-2002 ([www.monitoringagency.net](http://www.monitoringagency.net)).
- Mackenzie Valley Land and Water Board, 2001. Panda Wasterock Storage Area Beartooth Bearclaw Drainage 2000 BHP Diamonds Inc, Water License N7L2-1616, letter to BHP Diamonds Inc dated 4 June.
- Mills, C, 1998a. A Critical Review of 'BHP Tailings Characterization Study' and 'Wastewater and Tailings Management Plan Ekati Diamond Mine', dated September, pp 28.
- Mills, C, 1998b. A Technical Review of 'Acid/Alkaline Rock Drainage and Geochemical Characterization Program' and 'Waste Rock and Ore Storage Management Plan', dated March, pp 30.
- Mine Environment Neutral Drainage (MEND) Program, 1997. Summary Notes of the MEND Workshop 'Managing Mine Wastes in Permafrost Environments', University of Alberta, dated May 5.
- Minesite Drainage Assessment Group (MDAG), 1995a. Prediction of Future Minesite Drainage at BHP Diamonds/Diamet NWT Diamonds Project: Phase 1 Static Testing for Acidic and Alkaline Drainage.
- Minesite Drainage Assessment Group (MDAG), 1995b. Prediction of Future Minesite Drainage at BHP Diamonds/Diamet NWT Diamonds Project: Phase 2 Results of Kinetic Tests.
- Minesite Drainage Assessment Group (MDAG), 2000. Geochemical Review of Ekati Diamond Mine's 1999 Waste Rock Storage Area Seepage Survey, submitted to the Independent Environmental Monitoring Agency, dated 31 January.
- Minesite Drainage Assessment Group (MDAG), 2001. Review of Ekati Information on Seepage and Waste-Rock Geochemistry, March 2001, submitted to the Independent Environmental Monitoring Agency, dated 2 April.
- Minesite Drainage Assessment Group (MDAG), 2002. Ekati Minesite Review of 2001 Waste Rock Storage Area Seepage and Waste Rock Seepage Report, submitted to the Independent Environmental Monitoring Agency, dated 4 May.
- Morin, K A, 1996. RE: BHP Diamonds Project Misrepresentation of Authorship and Technical Conclusions, letter to BHP Diamonds Inc dated 22 March.
- Morin, K A and Hutt, N M, 1997a. A comparison AMD predictions with historical records, in *Proceedings Workshop on Acid Mine Drainage*, 15 - 18 July, Darwin, Northern Territory, Australia, Australian Centre for Minesite Rehabilitation Research, (Eds: R W McLean and L C Bell), pp 33-44.
- Morin, K A and Hutt, N M, 1997b. *Environmental Geochemistry of Minesite Drainage: Practical Theory and Case Studies* (MDAG Publishing ([www.mdag.com](http://www.mdag.com)), Vancouver, British Columbia).
- Morin, K A and Hutt, N M, 2001a. A comparison of past predictions to current conditions at Bell Mine, British Columbia, Canada, in *Proceedings Securing the Future, International Conference on Mining and the Environment*, Volume 2, pp 576-585 (The Swedish Mining Association).

- Morin, K A and Hutt, N M, 2001b. *Environmental Geochemistry of Minesite Drainage: Practical Theory and Case Studies, Digital Edition*, (MDAG Publishing (www.mdag.com), Vancouver, British Columbia.
- Norecol, Dames and Moore, 1997. Final Report: Acid/Alkaline Rock Drainage (ARD) and Geochemical Characterization Program, dated December.
- Smith, S L and Burgess, M M, 1998. Current Research 1998-E, (see also pp 41, Canadian Geographic, May/June 2002).
- Steffen, Robertson Kirsten Consulting (SRK), 2001. Panda Waste Rock Storage Area Beartooth-Bearclaw Drainage 2000 Seepage And Waste Rock Survey Report Ekati Diamond Mine [sic], report for BHP Diamonds, dated February 2001.
- Steffen, Robertson Kirsten Consulting (SRK), 2002. 2001 Waste Rock Storage Area Seepage and Waste Rock Survey Report, dated March.