# Appendix 2:
# Development of Permafrost in Waste Rock Dumps – Preliminary Geotechnical Evaluation

THURBER ENGINEERING LTD.

TECHNICAL MEMORANDUM

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| **To:** | John Binns | **Date:** | 23 Nov 2011 |
| cc | Harry Charalambu ,Ramli Halim | **Rev:** | 1 |
| **From:** | Bruce Smith, Steve Sather, Sabia Remtulla | **File:** | 19-1605-126 |

**MARY RIVER PROJECT**
**DEVELOPMENT OF PERMAFROST IN WASTE ROCK DUMPS**
**PRELIMINARY GEOTECHNICAL EVALUATION**

## 1. PURPOSE

This memorandum presents the results of a preliminary literature review to assess the factors that are expected to control the development of permafrost within the proposed waste rock dump at the Mary River Mine, specifically with respect to the development of permafrost within the waste rock dump as it reaches its final configuration with a volume of about 600 Mt.

A plan map showing the layout of the Mary River Iron Mine, including the open pit mine and waste rock dump, is attached as Figure A.1 in Appendix A. As shown on the map, the waste rock will be placed on the north side of the open pit mine.

This technical memorandum presents a summary of the information that has been gathered to date with respect to the development of permafrost in waste rock dumps in Northern Canada and describes a number of options that can be considered to ensure permafrost will develop in the dump at the Mary River Mine.

## 2. HEAT TRANSFER PROCESSES

For the purpose of this discussion, permafrost may be defined as any soil or rock which remains below freezing (0°C) during the thaw season each year. There are three heat transfer processes, as discussed in more detail in the following sections, which will have a major influence on the development of permafrost within the proposed waste dump at the Mary River Mine:

1. Convective air flows;
2. Heat conduction; and
3. Exothermic chemical reactions.

Solar radiation is an important source of heat, of course, but it will only influence the surface temperature of the waste rock dump and will not be discussed further.

Mass transport of heat, due to the flow of water in drainage courses though embankments, is also an important heat transfer mechanism in permafrost regions, however it is not considered further in this memorandum since it is understood that measures will be taken to prevent the flow of large volumes of water through the waste rock dump.

## 3. CONVECTIVE AIR FLOWS

Theoretical methods of modelling convective air flows in waste rock dumps have been developed and, together with temperature measurements in a test waste rock pile at the Diavik Mine, have demonstrated that air convection can have a major influence on ground temperatures and the development of permafrost within waste rock dumps (Arenson et al, 2007; and Pham et al, 2008).

These investigations have shown that air convection dominates the thermal regime in dry, porous rock dumps that have a high permeability to air. In contrast, the influence of convective air flow is negligible in well graded waste rock which has a low air permeability, particularly if the void spaces are partially or completely filled with water or ice.

If the waste rock dump is porous, such that it has a high permeability to air flows, then during the winter months, cold dense air flows into the waste dump, displacing warm air so that the interior temperatures in the dump can fall to minus 20°C or lower. If the rock dump is very permeable to air, then the temperatures within the dump can fluctuate in response to daily changes in the ambient air temperature.

During the thaw season, when ambient air temperatures are warmer, the cold air within the waste dump may remain within the rock dump because the cold air is denser than the ambient air. The degree to which the cold air is contained within the dump depends on the physical configuration of the waste dump, the variability and distribution of porous zones within the dump and wind speeds and directions.

For example, if the waste dump is raised above the surrounding ground surface and the air permeability is high, the denser, cold air will flow out of the dump and be replaced by warmer ambient air during the thaw season.

Similarly, if a strong wind blows for several days from one direction, then the air pressure on the windward side of the dump will be higher than on the lee side and the cold air can be blown out of the dump and be replaced with warm air. This situation is exacerbated, of course, if the waste dump is higher than the surrounding area and particularly if the height of the dump is high relative to its width.

Finally, the orientation and continuity of porous layers within the waste dump can have a major influence on interior temperatures throughout the year.

Figure A.2 in Appendix C illustrates the ground thermal regime that could develop in a porous waste dump at the Mary River Mine, late in the thaw season. The depth of thaw due to convective air flow during the thaw season is difficult to predict since it will depend on the distribution and continuity of porous layers within the dump. However, under unfavourable conditions, the depth of annual thaw could range up to tens of meters or more. Therefore, during the early stages of mine operations, when the waste dump is relatively small, the entire mass of waste rock could thaw during each thaw season.

## 4. HEAT CONDUCTION

In most natural soil deposits in Northern Canada, where the void spaces are filled with water or ice, the soil is effectively impervious to air flows, convection has a negligible effect on the temperature regime and heat conduction dominates heat transfer processes.

Heat conduction in permafrost is a process that has been studied extensively over several decades and is well understood. Numerical models have been developed and calibrated against field measurements, such that it is possible to make reasonably accurate predictions of ground temperatures and the development of permafrost, provided an adequate set of input data is available.

Ground temperatures have been measured as a function of depth in the vicinity of the Mary River Mine for several years. A typical distribution of ground temperature with depth, which illustrates the ground temperatures during late March (when ground temperatures are lowest) and in late August (when ground temperatures are a maximum), is presented on the upper portion of Figure A.3. As shown, ground temperatures near the ground surface vary significantly throughout the year, being very cold in the winter and rising well above freezing during the thaw season.

As illustrated, annual ground temperatures attenuate with depth and become more or less constant at about minus 10°C below a depth of about 10 metres in the vicinity of the Mary River Mine. This temperature, which is referred to as the average annual ground temperature, is a function of the average annual air temperature at each particular location and generally increases at lower elevations and latitudes. For example, the average annual ground temperature in the vicinity of the Ekati Diamond Mine has been found to be about minus 6°C (Arenson et al, 2007).

Ground temperatures reach a maximum in the late fall when the maximum depth of thawing occurs. In the example shown in the upper portion of Figure A.3, the maximum depth of thaw occurs at a depth of about 1.5 metres, which is the point at which the temperature curve crosses the freezing point (0°C). The zone above 1.5 metres is not considered to be permafrost (since it thaws every year) and is referred to as the active layer, while the zone below the active layer is permafrost, since it never thaws.

Heat conduction in moist soils is dominated by the latent heat of fusion of ice to water (and vice versa) and therefore by the water content of the soil. The curve shown on the lower portion of Figure A.3 illustrates the significant influence that water content has on the depth of thaw in a well graded gravel.

As illustrated on the figure, at high water contents, the maximum annual depth of thaw at a location near the Mary River Mine will be about 2 metres, depending on the average water content in the near surface soil. In contrast, the depth of maximum thaw can range up to about 5 metres, due to heat conduction alone, if the near surface soil is well drained and contains no moisture. Convective air flows, which begin to dominate in dry, porous material, could increase the depth of thaw even further, depending on the air permeability in the dry gravel; however this effect has not been included in the curve shown on the lower portion of Figure A.3.

If, over a very long period of time, the soil in the upper layers of the dump were to dry out completely, (for example if there were many years with no precipitation), then the depth of annual thawing could increase, depending on the extent to which convective air flows begin to affect the heat transfer process. Under very dry climate conditions however, ARD caused by surface water infiltrating into the dump would not be of concern.

## 5. EXOTHERMIC CHEMICAL REACTIONS

It is understood that exothermic chemical reactions, such as the oxidation of pyrite and other minerals, may have a significant influence on the temperatures within a waste rock dump, depending on the concentration of the reactive chemicals, the ground temperatures within the dump (warmer ground temperatures can accelerate the chemical reaction and the rate at which heat is generated) and other factors which have not been investigated as part of this review (Morin, 2003).

The heat from such reactions would be transferred by conduction to the surrounding ground and could degrade the permafrost. It is recommended that the potential for exothermic reactions occurring in the waste rock dump be investigated by a qualified geochemist, since such reactions could have a significant influence on the development of permafrost within the dump.

If necessary, a number of methods for dealing with this potential source of heat can be considered, including segregation of the highly reactive material and submerging it in water; segregating the highly reactive material within the waste rock dump and cooling it with ventilation ducts; or distributing the reactive material throughout the waste dump so that the critical mass of reactive material required to generate high temperatures cannot occur.

## 6. DISCUSSION

*General*

If convective air flow and exothermic reactions in the waste rock dump can be limited, such that only conduction dominates the process of heat transfer and the water content within the upper 3 or 4 metres can be increased to about 5 percent, then, as illustrated on Figure A.4, it can be expected that the annual depth of thaw would be less than 2 metres and the internal temperature within the dump at depth would stabilize after a few years to converge to the average annual ground temperature in this area (minus 10$^{o}$C).

That is, it should be possible to develop permafrost within a major portion of the waste rock dump at the Mary River Mine, particularly in view of the relatively low average annual ground temperatures that have been recorded in this area.

*Minimizing Convective Air Flows*

If the waste rock is dry and porous, convective air flows will dominate the heat transfer process and may prevent the development of permafrost within a significant portion of the waste dump. Heat flows due to air convection appear to be difficult to predict and control and therefore it is believed that the most effective approach will be to implement methods to limit or prevent convective air flow. Limiting air flow is also an advantage because it will reduce the availability of oxygen to potential acid generating (PAG) rocks within the dump.

A number of methods for minimizing convective air flows in the waste rock dump can be considered as follows:

1) Waste rock is normally placed by end dumping the rock, which causes a porous layer of cobbles and boulders to form near the base of each bench that can be highly permeable to air. Methods of end dumping the waste rock in cells that will break up the continuity of these porous layers have been used successfully to reduce air flow into rock dumps at other mines and should be considered during detailed design of the waste rock dump at the Mary River Mine (Chamber of Mines of South Africa, 1996).

2) A second option which can be considered is to locate the waste rock dump in a closed depression, (or surround the dump with containment dikes) so that surface water flows into, and remains within, the dump. The water will fill the void spaces in the waste rock and freeze, reducing the permeability to air and minimizing the depth of thaw that occurs each thaw season.

   In non-permafrost regions, this approach would be unacceptable because surface water which flowed into the waste rock dump would infiltrate into the ground below the dump and contaminate the ground water. In this case, however, the site is underlain by permafrost to depths of several hundred metres, so that water from the dump cannot infiltrate into the ground below the dump.

3) It may be possible to develop cost effective methods of blasting the waste rock in the mine such that most of the material is well graded, so that it will limit convective air flows within the dump. This approach might be feasible at the Mary River Mine; however it will depend on the mechanical properties of the waste rock formations, the blasting pattern and other factors. The feasibility of controlling the gradation of the waste rock cannot be determined until the mine begins operations.

4) Another approach would be to reduce the air permeability of the waste rock dump by placing one or more layers of well graded material (such as the local sandy till) to a depth of 2 or 3 metres over the surface of the waste rock dump during mining operations. The effectiveness of this approach could be enhanced significantly by watering the sandy till as it is being placed, to reduce the annual depth of thaw within the dump.

   It is understood that implementation of this method is being considered on a trial basis at the Diavik Mine; however it has not been possible to confirm this. If the use of a sandy till cover is considered for the Mary River Mine, it would be important to undertake trials during the early stages of mine operations to confirm its effectiveness and refine the placement procedures.

5) Finally, consideration can be given to covering the final surface of the waste dump with an impermeable capping layer of natural material or a synthetic membrane liner, which would prevent convective air flow into the dump and in addition, if the layer were properly designed and installed, would prevent snow melt and rainfall from infiltrating into the dump.

   The use of a membrane liner may be a cost effective solution, however if the waste rock in the dump remains dry, then the annual depth of thaw due to heat conduction could still range up to about 5 meters. Field observations have demonstrated that membrane liners such as high density polyethylene (HDPE) can be expected to last for at least 50 years without deteriorating, provided they are covered to protect them from sunlight and ground settlements are limited. While there is no conclusive evidence available at this time, it is possible that such liners will deteriorate over periods as long as several hundred years.

Whatever option is chosen to promote the development of permafrost within the dump and minimize the depth of annual thaw, it will be essential to install thermistor strings and other instrumentation in strategic locations throughout the dump to measure actual ground temperatures and verify that permafrost is developing within the dump as expected.

*Climate Change*

While there is considerable debate about the causes of climate warming, most scientists agree that average air temperatures in the northern hemisphere have been increasing since the end of the Little Ice Age about 200 years ago. The predicted rate of temperature increase over the next few centuries is also the subject of much debate however, recent estimates (Natural Resources

Canada, 2011) indicate that mean annual air temperatures on northern Baffin Island will increase between 1995 and 2060 by 4 to 5 degrees Celsius, which corresponds to a rate of increase of between 6.2 and 7.7 degrees per century.

Average annual ground temperatures in Northern Canada are generally proportional to the average annual air temperature at each location and will therefore increase at about the same rate that the average annual air temperature increases. As mentioned, the average annual ground temperature at the Mary River Mine Site is about minus 10$^{o}$C and therefore if the average annual air temperature were to increase at the predicted rates, then the mean annual ground temperature will be close to 0$^{o}$C, 130 to 170 years from the present. It may take an additional 50 or 100 years before permafrost at the Mary River Mine site degrades completely, due to latent heat effects.

As described on the Natural Resources Canada website, future climate predictions must be treated with caution, since they are subject to change based on the acquisition of additional climate data and refinements to the predictive models.

## 7. IMPLICATIONS OF PERMAFROST FOR PREVENTING ARD FORMATION

It is understood that geochemical tests on rock samples from the open pit mine indicate that only a small portion of the waste rock is likely to generate acid rock drainage (ARD), however further testing is required to confirm this.

It is understood that consideration is being given to minimizing ARD from the waste rock dump by segregating the potential acid generating (PAG) waste rock within the dump and encapsulating it in non-PAG material to minimise the infiltration of air and water. In addition, the formation of permafrost within the dump would inhibit ARD. The technique of minimizing ARD by freezing waste rock has been attempted at a number of other hard rock mines in Northern Canada and Alaska and a number of organizations have and are continuing research into methods for long term containment of ARD in permafrost regions. Thurber Engineering has completed a preliminary review of relevant published literature concerning this issue; however it has not been possible to interview mine operators in Northern Canada and Alaska

An overview of the difficulties of predicting and containing ARD from the waste rock dumps at the Ekati Diamond Mine, which is located about 400 km north of Yellowknife, Northwest Territories, has been published by Morin (Morin, 2003). During initial mine planning, it had been expected that permafrost would quickly aggrade into the waste rock dumps at the Ekati Mine and therefore it was expected that seepage and ARD from the dump would be negligible.

However, within a year after the start of mine operations in 1998, ARD was observed at several monitoring stations, which led to further investigations and the development of mitigation measures; which are reported to have been successful. (Hayley, 2011). It is understood that ground temperature measurements in the waste rock dumps have established that the annual depth of thaw in the dumps ranges to a maximum of about 5 metres.

The waste rock dumps at the lead-zinc mine at Nanisivik in northern Baffin Island were decommissioned at least 5 years ago, when they were covered with about 2 metres of well graded material to prevent convective air flows and minimized the infiltration of surface water. It is understood (Cassie, 2011) that the waste rock dumps have remained frozen and annual site inspections have found no water seepage (and therefore no ARD) emanating from the dumps.

The experience at these northern mines has prompted further research into the factors affecting the development of permafrost in waste rock dumps, including the development of convective thermal models and the construction and monitoring of a small waste rock pile at the Diavik Diamond Mine, which is located about 30 km south of the Ekati Mine (Arenson et al., 2007).

## 8. RECOMMENDATIONS

The results of this preliminary review have identified at least one (Nanisivik) cost effective method to ensure that permafrost will develop in the waste rock dump and be effective at preventing ARD from the dump. It is recommended however, that as currently proposed, seepage water from the Mary River waste rock dump be controlled and contained in holding ponds, where it can be monitored and treated as necessary during mine operations.

Thermal analyses of the waste rock dump to predict the long-term distribution of permafrost within the dump will be required. The heat transfer processes can be simulated with available computer models, however, none of the models can confirm that permafrost will develop within the dump, without more reliable input data regarding the method of placing the waste rock and the resulting properties of the waste rock in the dump. In addition, it will be important to calibrate the thermal analyses against existing case histories including, in particular, the Nanisivik mine. Therefore it is recommended that detailed thermal analyses be postponed until detailed information from the monitoring program of the waste rock dump at Nanisivik can be obtained and more information becomes available with respect to the properties of the proposed waste rock dump at Mary River.

During the first few years of mine operations, once the properties of the waste rock are better defined, including the grain size distribution and the chemistry and distribution of the PAG rocks, methods of containing and treating the PAG rock in the waste rock dump can be further developed, tested and refined, with the objective of establishing those procedures that will ensure that ARD can be minimized in the long term.

Monitoring of ground temperatures and the development of permafrost within the waste rock dump and measuring the properties and volume of seepage water from the dump should continue during mine operations and after decommissioning of the dump. This work should include periodic updating of the thermal analyses, which should be calibrated to actual measured ground temperatures and incorporate any changes to the climate change predictions produced by Natural Resources Canada.

It is recommended that a qualified geochemist review the potential for exothermic chemical reactions occurring in the Mary River waste rock dump, so that the most effective methods for mitigating this potential source of heat can be established.

The scope of this review has been limited by time constraints and it is recommended that a more comprehensive study and review of the literature and other sources of information be undertaken since there may be additional published information concerning the control of ARD using permafrost in northern regions.

It is recommended that environmental scientists at some of the other mines in permafrost regions be contacted, including the Ekati and Diavik Mines in the Northwest Territories, the decommissioned Nanisivik Mine at Arctic Bay on Baffin Island and the Red Dog Mine in Alaska. These mine operators will have practical experience in the control of ARD from waste dumps in permafrost that should be of benefit to the design of the waste rock dump at Mary River.

It is recommended that Baffinland Iron Mines Corporation consider becoming involved in some of the studies that other agencies are undertaking into various methods for controlling ARD from waste rock dumps in Northern Canada. Full access to the various research programs will provide Baffinland with the most recent information concerning this issue and will, in turn, allow Baffinland to influence the direction of some of the research and provide researchers with practical experience from the mining operations at Mary River.

## 9. CLOSURE

We trust that the foregoing evaluation and recommendations meet your current requirements. Please contact us at any time if you have questions or require additional information.

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Attachements:

References
Statement of General Conditions
Appendix A - Figures

PERMIT TO PRACTICE
THURBER ENGINEERING LTD.
Signature
Date 23 Nov 2011
PERMIT NUMBER: P0176
The Association of Professional Engineers, Geologists and Geophysicists of the NWT / NU

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# STATEMENT OF LIMITATIONS AND CONDITIONS

## 1. STANDARD OF CARE

This study and Report have been prepared in accordance with generally accepted engineering or environmental consulting practices in this area. No other warranty, expressed or implied, is made.

## 2. COMPLETE REPORT

All documents, records, data and files, whether electronic or otherwise, generated as part of this assignment are a part of the Report which is of a summary nature and is not intended to stand alone without reference to the instructions given to us by the Client, communications between us and the Client, and to any other reports, writings, proposals or documents prepared by us for the Client relative to the specific site described herein, all of which constitute the Report.

IN ORDER TO PROPERLY UNDERSTAND THE SUGGESTIONS, RECOMMENDATIONS AND OPINIONS EXPRESSED HEREIN, REFERENCE MUST BE MADE TO THE WHOLE OF THE REPORT. WE CANNOT BE RESPONSIBLE FOR USE BY ANY PARTY OF PORTIONS OF THE REPORT WITHOUT REFERENCE TO THE WHOLE REPORT.

## 3. BASIS OF REPORT

The Report has been prepared for the specific site, development, design objectives and purposes that were described to us by the Client. The applicability and reliability of any of the findings, recommendations, suggestions, or opinions expressed in the document, subject to the limitations provided herein, are only valid to the extent that this Report expressly addresses proposed development, design objectives and purposes, and then only to the extent there has been no material alteration to or variation from any of the said descriptions provided to us unless we are specifically requested by the Client to review and revise the Report in light of such alteration or variation or to consider such representations, information and instructions.

## 4. USE OF THE REPORT

The information and opinions expressed in the Report, or any document forming part of the Report, are for the sole benefit of the Client. NO OTHER PARTY MAY USE OR RELY UPON THE REPORT OR ANY PORTION THEREOF WITHOUT OUR WRITTEN CONSENT AND SUCH USE SHALL BE ON SUCH TERMS AND CONDITIONS AS WE MAY EXPRESSLY APPROVE. The contents of the Report remain our copyright property. The Client may not give, lend or, sell the Report, or otherwise make the Report, or any portion thereof, available to any person without our prior written permission. Any use which a third party makes of the Report, are the sole responsibility of such third parties. Unless expressly permitted by us, no person other than the Client is entitled to rely on this Report. We accept no responsibility whatsoever for damages suffered by any third party resulting from use of the Report without our express written permission.

## 5. INTERPRETATION OF THE REPORT

a) Nature and Exactness of Soil and Contaminant Description: Classification and identification of soils, rocks, geological units, contaminant materials and quantities have been based on investigations performed in accordance with the standards set out in Paragraph 1. Classification and identification of these factors are judgmental in nature. Comprehensive sampling and testing programs implemented with the appropriate equipment by experienced personnel, may fail to locate some conditions. All investigations utilizing the standards of Paragraph 1 will involve an inherent risk that some conditions will not be detected and all documents or records summarizing such investigations will be based on assumptions of what exists between the actual points sampled. Actual conditions may vary significantly between the points investigated and the Client and all other persons making use of such documents or records with our express written consent should be aware of this risk and this report is delivered on the express condition that such risk is accepted by the Client and such other persons. Some conditions are subject to change over time and those making use of the Report should be aware of this possibility and understand that the Report only presents the conditions at the sampled points at the time of sampling. Where special concerns exist, or the Client has special considerations or requirements, the Client should disclose them so that additional or special investigations may be undertaken which would not otherwise be within the scope of investigations made for the purposes of the Report.

b) Reliance on Provided Information: The evaluation and conclusions contained in the Report have been prepared on the basis of conditions in evidence at the time of site inspections and on the basis of information provided to us. We have relied in good faith upon representations, information and instructions provided by the Client and others concerning the site. Accordingly, we cannot accept responsibility for any deficiency, misstatement or inaccuracy contained in the Report as a result of misstatements, omissions, misrepresentations, or fraudulent acts of the Client or other persons providing information relied on by us. We are entitled to rely on such representations, information and instructions and are not required to carry out investigations to determine the truth or accuracy of such representations, information and instructions.

*(see over . . . . )*

c) Design Services: The Report may form part of the design and construction documents for information purposes even though it may have been issued prior to the final design being completed. We should be retained to review the final design, project plans and documents prior to construction to confirm that they are consistent with the intent of the Report. Any differences that may exist between the report recommendations and the final design detailed in the contract documents should be reported to us immediately so that we can address potential conflicts.

d) Construction Services: During construction we must be retained to provide field reviews. Field reviews consist of performing sufficient and timely observations of encountered conditions to confirm and document that the site conditions do not materially differ from those interpreted conditions considered in the preparation of the report. Adequate field reviews are necessary for Thurber to provide letters of assurance, in accordance with the requirements of many regulatory authorities.

## 6. RISK LIMITATION

Geotechnical engineering and environmental consulting projects often have the potential to encounter pollutants or hazardous substances and the potential to cause an accidental release of those substances. In consideration of the provision of the services by us, which are for the Client's benefit, the Client agrees to hold harmless and to indemnify and defend us and our directors, officers, servants, agents, employees, workmen and contractors (hereinafter referred to as the "Company") from and against any and all claims, losses, damages, demands, disputes, liability and legal investigative costs of defence, whether for personal injury including death, or any other loss whatsoever, regardless of any action or omission on the part of the Company, that result from an accidental release of pollutants or hazardous substances occurring as a result of carrying out this Project. This indemnification shall extend to all Claims brought or threatened against the Company under any federal or provincial statute as a result of conducting work on this Project. In addition to the above indemnification, the Client further agrees not to bring any claims against the Company in connection with any of the aforementioned causes.

## 7. SERVICES OF SUBCONSULTANTS AND CONTRACTORS

The conduct of engineering and environmental studies frequently requires hiring the services of individuals and companies with special expertise and/or services which we do not provide. We may arrange the hiring of these services as a convenience to our Clients. As these services are for the Client's benefit, the Client agrees to hold the Company harmless and to indemnify and defend us from and against all claims arising through such hirings to the extent that the Client would incur had he hired those services directly. This includes responsibility for payment for services rendered and pursuit of damages for errors, omissions or negligence by those parties in carrying out their work. In particular, these conditions apply to the use of drilling, excavation and laboratory testing services.

## 8. CONTROL OF WORK AND JOBSITE SAFETY

We are responsible only for the activities of our employees on the jobsite. The presence of our personnel on the site shall not be construed in any way to relieve the Client or any contractors on site from their responsibilities for site safety. The Client acknowledges that he, his representatives, contractors or others retain control of the site and that we never occupy a position of control of the site. The Client undertakes to inform us of all hazardous conditions, or other relevant conditions of which the Client is aware. The Client also recognizes that our activities may uncover previously unknown hazardous conditions or materials and that such a discovery may result in the necessity to undertake emergency procedures to protect our employees as well as the public at large and the environment in general. These procedures may well involve additional costs outside of any budgets previously agreed to. The Client agrees to pay us for any expenses incurred as the result of such discoveries and to compensate us through payment of additional fees and expenses for time spent by us to deal with the consequences of such discoveries. The Client also acknowledges that in some cases the discovery of hazardous conditions and materials will require that certain regulatory bodies be informed and the Client agrees that notification to such bodies by us will not be a cause of action or dispute.

## 9. INDEPENDENT JUDGEMENTS OF CLIENT

The information, interpretations and conclusions in the Report are based on our interpretation of conditions revealed through limited investigation conducted within a defined scope of services. We cannot accept responsibility for independent conclusions, interpretations, interpolations and/or decisions of the Client, or others who may come into possession of the Report, or any part thereof, which may be based on information contained in the Report. This restriction of liability includes but is not limited to decisions made to develop, purchase or sell land.

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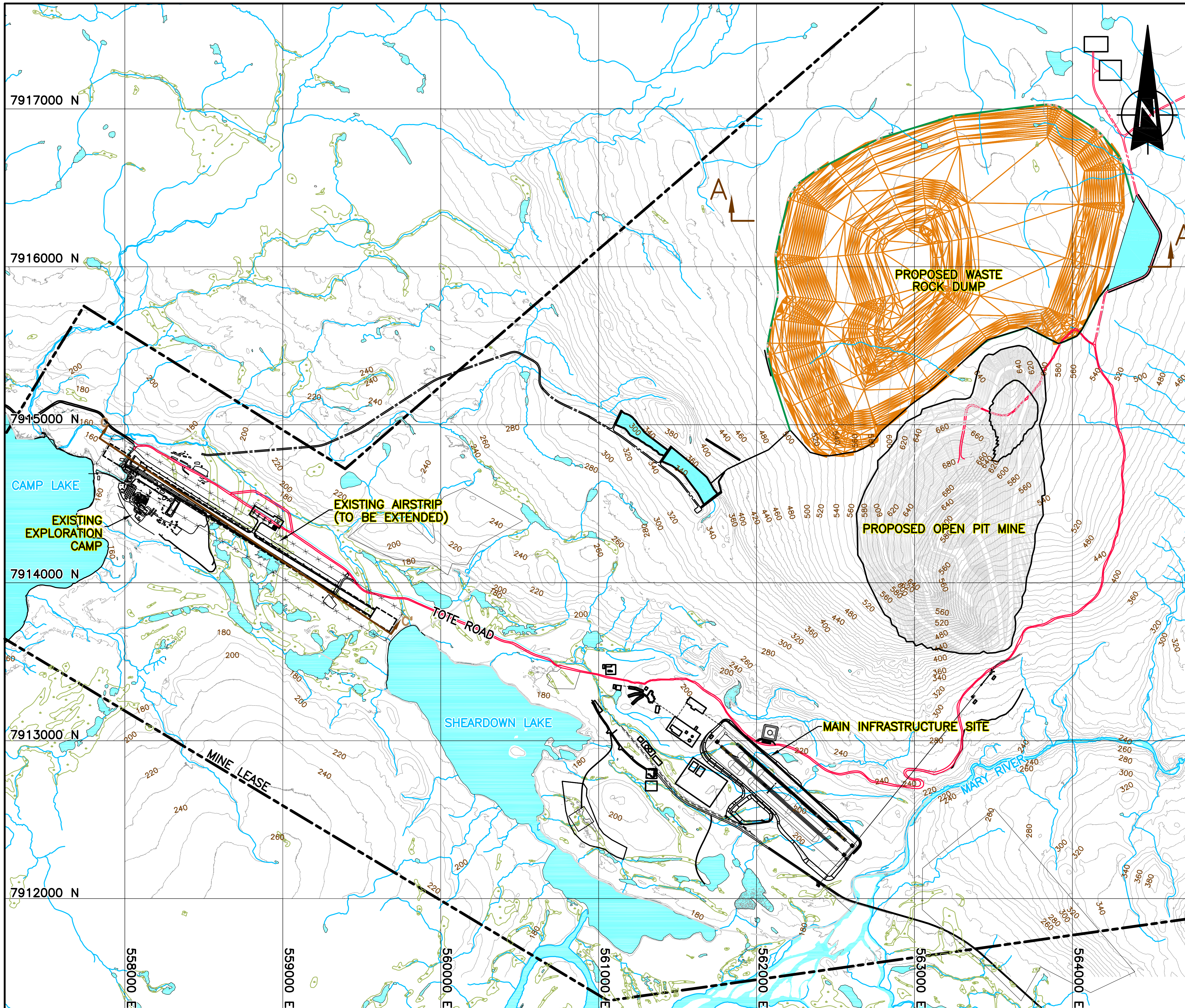
## APPENDIX A

### Figures




NOTES:

1 BASE PLAN SUPPLIED BY HATCH ENGINEERING GROUP FILE "H337697-4060-10-014-0002.dwg" DATED 11/08/08.

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**MARY RIVER PROJECT**

**OVERVIEW MAP OF THE MARY RIVER MINE SITE**

**FIGURE A.1**

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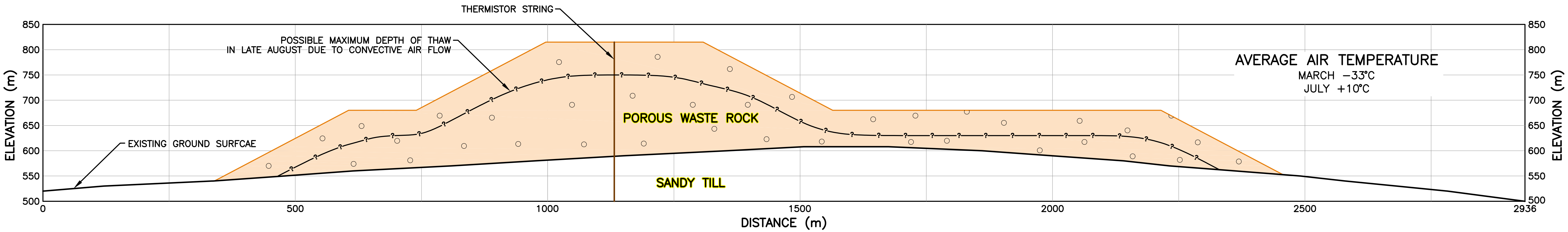
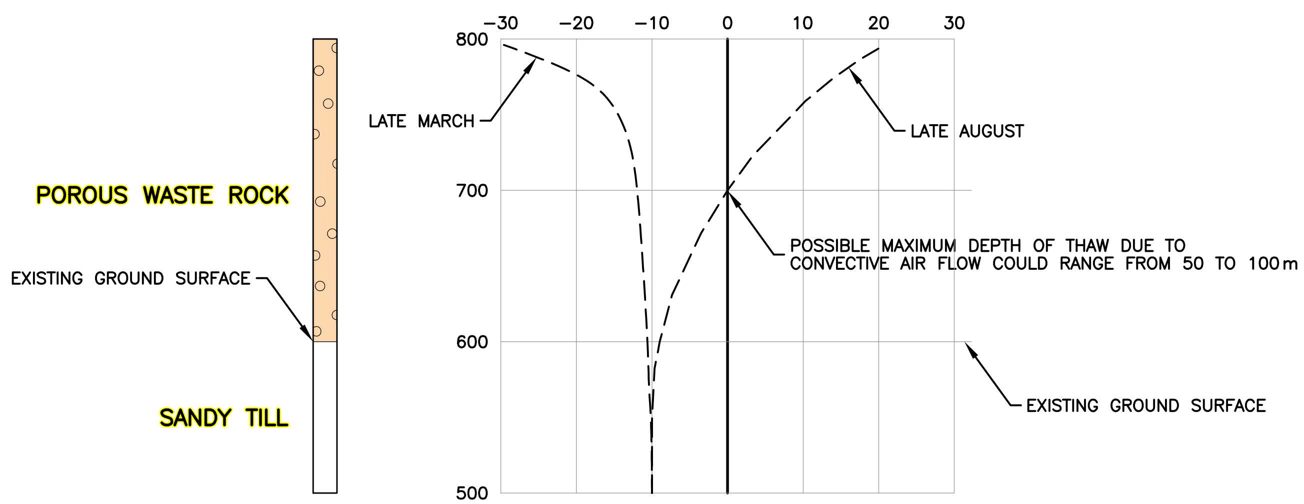



CROSS SECTION A–A'




CONCEPTUAL TEMPERATURE DISTRIBUTION
IN WASTE ROCK DUMP IF CONVECTIVE AIR FLOW DOMINATES

| | | | | |
|---|---|---|---|---|
| 0 | FINAL REPORT | ICB | LBS | 11/7/11 |
| REV | DESCRIPTION | DRAWN BY | APPROVED BY | DATE (MM/DD/YY) |

| | | |
|---|---|---|
| DRAWN BY ICB | DESIGNED BY LBS | APPROVED BY LBS |
| SCALE 1:8000 | DATE SEPTEMBER 30, 2011 | FILE No. 19–1605–126–C2A |

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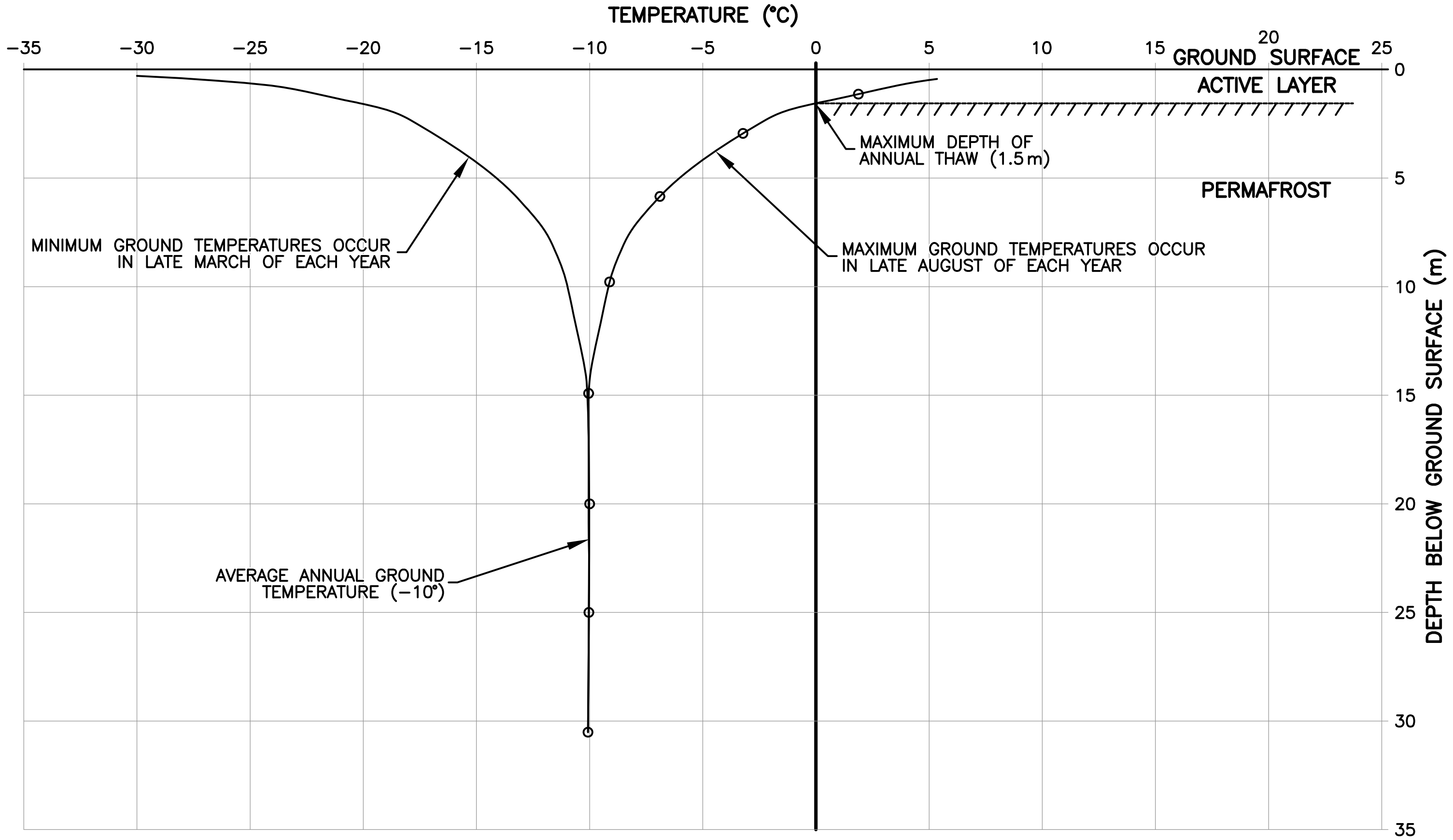
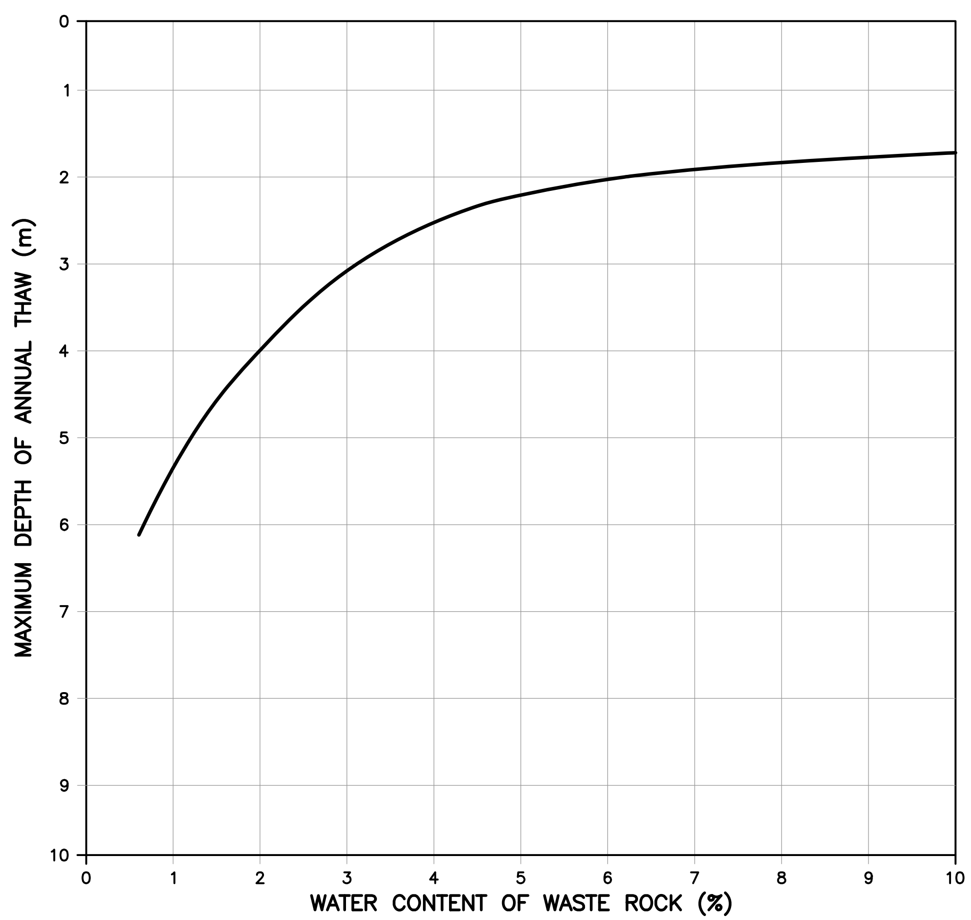
**CONCEPTUAL GROUND TEMPERATURES IN A POROUS WASTE ROCK DUMP DUE TO CONVECTIVE AIR FLOW**

FIGURE A.2

THURBER ENGINEERING LTD.




**ANNUAL GROUND TEMPERATURES IN THE VICINITY OF THE MARY RIVER MINE SITE**




**APPROXIMATE DEPTH OF MAXIMUM ANNUAL THAW AS A FUNCTION OF SOIL WATER CONTENT**

| REV | DESCRIPTION | DRAWN BY | APPROVED BY | DATE (MM/DD/YY) |
|---|---|---|---|---|
| | | | | |
| 0 | FINAL REPORT | ICB | LBS | 11/7/11 |

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| DRAWN BY ICB | DESIGNED BY LBS | APPROVED BY LBS |
| SCALE AS SHOWN | DATE NOVEMBER 7, 2011 | FILE No. 19−1605−126−D0A |

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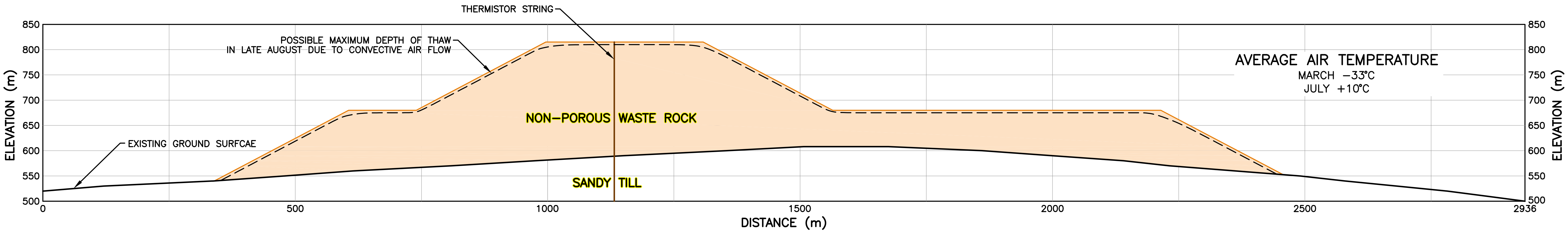
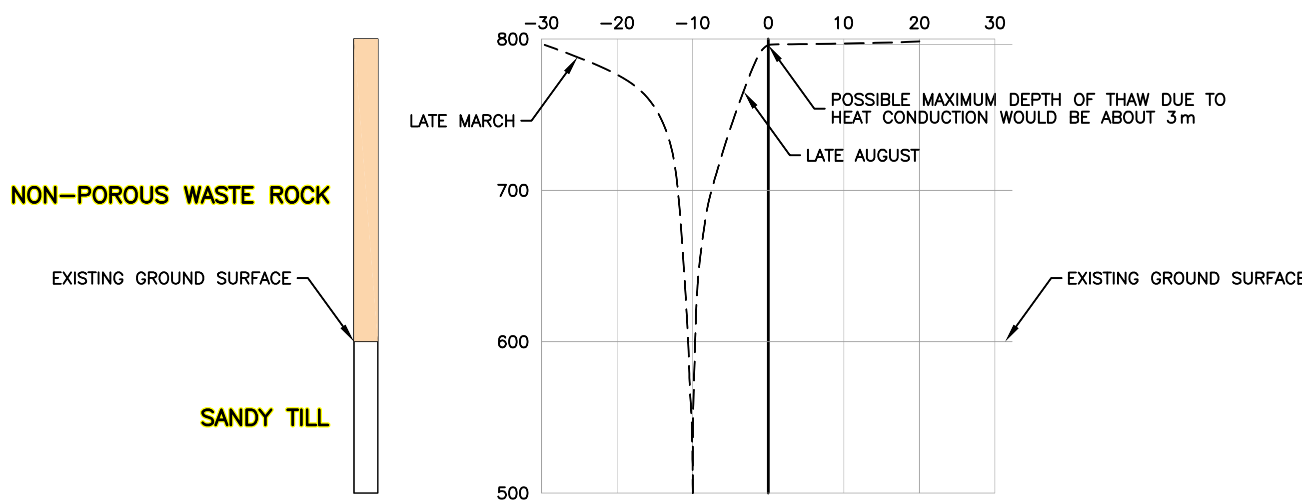
**DEPTH OF THAW DUE TO HEAT CONDUCTION IN PERMAFROST**

**FIGURE A.3**

THURBER ENGINEERING LTD.




CROSS SECTION A–A'




CONCEPTUAL TEMPERATURE DISTRIBUTION
IN WASTE ROCK DUMP IF HEAT CONDUCTION DOMINATES

| REV | DESCRIPTION | DRAWN BY | APPROVED BY | DATE (MM/DD/YY) |
|---|---|---|---|---|
| 0 | FINAL REPORT | ICB | LBS | 11/7/11 |

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| DRAWN BY | ICB | DESIGNED BY | LBS |
| APPROVED BY | LBS | SCALE | 1:8000 |
| DATE | SEPTEMBER 30, 2011 | FILE No. | 19–1605–126–C2A |

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MARY RIVER PROJECT

## CONCEPTUAL GROUND TEMPERATURES IN A NON-POROUS WASTE ROCK DUMP DUE TO HEAT CONDUCTION

FIGURE A.4

THURBER ENGINEERING LTD.

# Appendix 3:
# Waste Rock Geological and Geochemical Characterization Program

# WASTE ROCK GEOLOGICAL AND GEOCHEMICAL CHARACTERIZATION PROGRAM (2012-2014)

## MARY RIVER PROJECT - DEPOSIT NO. 1

January 2012

## ACKNOWLEDGEMENTS

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**BAFFINLAND IRON MINES CORPORATION**

**WASTE ROCK GEOLOGICAL AND GEOCHEMICAL CHARACTERIZATION PROGRAM (2012-2014)**

**MARY RIVER PROJECT - DEPOSIT NO. 1**

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## APPENDICES

# SECTION 1.0 - INTRODUCTION

## 1.1 BACKGROUND

A waste rock disposal area designed for permanent storage of waste rock will be located northwest of the Deposit No. 1 open pit (refer to attached Figure 3-2.3 (Appendix A), taken from the FEIS). Based on the current mine plan for Deposit No. 1, an estimated 570 Mt of waste rock will be generated over a period of 21 years. The shell of the open pit will eventually fill with meteoric water to an approximate volume of 45 million $m^3$ (Knight Piésold. 2008a).

As detailed in the associated Waste Rock Management Plan, open pit mining will generate large quantities of waste rock that will be stored at a dedicated location adjacent to the open pit. These waste rock materials have been characterized and grouped on the basis of geological characteristics and the results of geochemical static and kinetic test work. Environmental management plans are developed for each material group based on projected ltihology and mineralogy and chemical reactivity and physical properties to ensure long-term environmentally acceptable storage.

The results of the geochemical characterization of waste rock to date have been used to develop predictive water quality models. These models integrate the geochemical static and kinetic test results for the currently available sampling program with the overall geological, physical, and hydrological setting of the site, the proposed mine plan, and the operational waste rock management practices outlined in the Waste Rock Management Plan. These management practices are intended to minimize risk to the receiving environment from potential acidic, metal rich runoff and seepage. Similarly, a water quality model has been developed to generate predictions of pit water quality both during mine operations and post closure. The water quality models that have been developed are adaptable and will be updated over the next several years as new geochemical and physical data and interpretation become available, the mine plan is finalized, and environmental management practices are further refined.

Baffinland has recognized that there is a need to for an ongoing geological and geochemical characterization gap-filling program that will assist in confirming water quality model assumptions and predictions. During and subsequent to the NIRB pre-hearing technical meetings held in Iqaluit during late October, 2011 Baffinland acknowledged this requirement and committed to the following:

> "A sampling and testing program for the characterization of the waste rock for the period of 2012-2014 will be developed and will involve devising a representative sampling program for the waste rock based on the configuration of the ore body and the mining plan; analysis of the lithology, morphology and mineralogy of the waste rock; additional testing (both static and humidity cell). An independent expert will review and provide

guidance for this program. The characterisation program will be ongoing for the Life of the Project and will guide the development adaptive management strategies for waste rock management (should this be required over the life of the Project). This program will be presented in the FEIS.[1]"

### 1.2 PROGRAM COMPONENTS AND APPROACH

A waste rock geological and geochemical characterization program (the "Program") for the period 2012 to 2014 has been developed to address gaps in the existing database and to evaluate and adjust as warranted current assumptions used in predictive models. The Program is focussed on information gaps in the following component areas:

- Waste rock geology on the deposit scale utilizing surface mapping and drilling techniques;
- Predictive geochemical sampling and testing programs using mineralogical, static testing, and kinetic testing methodologies; and
- Sensitive input parameters (i.e., climate, hydrology, permafrost, and geochemical source terms) used to make water quality predictions for waste rock and open pit.

In the following sections of this document, the current data base is reviewed in relation to the above component areas, information gaps are identified, and programs to address gaps are proposed.

In addition, a preliminary operational and verification monitoring program is proposed for the post-2014 period when the commencement of pre-strip and mining of the open pit is scheduled to commence. This program will be subject to further adjustment based on the results of the 2012-2014 work.

[1] Commitment No. 233 as outlined in November 4, 2011, letter from Baffinland to NIRB, Re: Revised List of Commitments from Technical meeting.

## SECTION 2.0 - MINE PLAN AND BASELINE SITE CONDITIONS

The mine plan, waste rock management plan, and baseline site conditions for the Project are described in detail within the FEIS. The reader is referred to the following sections of the FEIS for further information:

- Mine Plan – FEIS Volume 3, Project Description:
  - Section 3.4, Mine Site – Operation Phase
  - Table 3-3.1 Preliminary Schedule of Waste Rock Production
  - Figure 3-2.3 Mine Site Layout (Appendix A to this report)
- Waste Rock Management Plan – FEIS Volume 3, Appendix 3B, Attachment 5
  - Annex 2. Technical Memorandum from Thurber Engineering Ltd. to Hatch, dated November 23, 2011, Re: Development of Permafrost in Waste Rock Dumps – Preliminary Geotechnical Evaluation
  - Annex 4. Interim Waste Rock Stockpile Seepage Quality Model Report, Mary River Project. Dated January 2012. Prepared by AMEC
  - Annex 5. Interim Open Pit Water Quality Model Technical Memorandum, Mary River Project. Dated January 2012. Prepared by AMEC.
- Climate – FEIS Volume 5, Atmospheric Environment:
  - Section 1.0 – Climate
  - Tables 5-1.1 to 5-1.7, incl. – Climate normal, forecasts, and return periods for extreme temperature events
- Terrestrial Environment – FEIS Volume 6:
  - Section 2.1 – Landforms, Soils and Permafrost Baseline Summary, includes geochemical, geotechnical, geomechanical, and hydrological conditions
  - Appendix 6B-1 – Geochemical Evaluation of Ore and Waste Rock
  - Figure 6-2.3 – Surficial Geology in the Mine Site Area
- Freshwater Environment – FEIS Volume 7:
  - Section 1.0 – Regional Freshwater Setting
  - Section 2.1 – Freshwater Quantity Baseline Summary
  - Section 3.1 and 3.2 – Water and Sediment Quality Baseline Summary

A description of the regional and local geology for Deposit No. 1 is provided in Section 3.1.

# SECTION 3.0 - GEOLOGY

## 3.1 OVERVIEW OF REGIONAL AND LOCAL GEOLOGY

The detailed description of the regional and local ore deposit geology is provided in Volume 6 of the FEIS, particularly Section 2.1 and Appendix 6B-1. Figure 6-2.3 (Appendix A to this report), is taken from the FEIS and shows the surficial geology of the mine site area. Figure A-1 (Appendix A to this report) shows the bedrock geology of Deposit No. 1 and exploration / environmental drill holes that have intersected and sampled the deposit and adjacent wall rock within the proposed pit perimeter. A description of the regional and local geology of Deposit No. 1, taken from Appendix 6B-1 of the FEIS, is provided below.

### 3.1.1 REGIONAL GEOLOGY

The northern part of Baffin Island consists of the ca. 3.0-2.5 Ga Committee Fold belt which lies within the Rae domain of the western Churchill Province (Jackson and Berman, 2000). The Committee belt extends north-east for around 2000 km from south-west of Baker Lake, Nunavut Territory to northwestern Greenland. Four major assemblages of Precambrian rocks have been identified within the Committee Belt. The iron ore deposits occur as part of the supra-crustal rocks of the Neoarchean aged (2.76-2.71 Ga) Mary River Group in the region. The Central Borden Fault Zone passes within 1 km to the south-west of the site. This fault separates the highly deformed Precambrian rocks to the north-west from the early Paleozoic relatively flat lying sedimentary rocks to the southwest. The generalized stratigraphic sequence of the Mary River group from top to base according to Young et al. (2004) and Johns and Young (2006) is:

- interbedded ultramafic and intermediate volcanic rocks;
- quartzite;
- Algoma–type oxide– and silicate–facies iron formation;
- amphibolite; and
- psammite and sedimentary migmatite.

The thickness of individual units varies considerably across the area. Ultramafic and gabbroic intrusions in the form of small sills and dykes (<10 m in thickness) may occur within the sedimentary rocks, iron formation and amphibolite units (Johns and Young, 2006). Locally these intrusions have been observed to contain thin sulphide veinlets and disseminated sulphides. At the deposit scale, the overall sequence can be complicated by inferred early isoclinal folds and ramp and flat thrust faults (Young et al., 2004) which create complex and variable stratigraphic relationships. The contact between the Mary River group and gneiss basement rock are generally not directly exposed, being obscured by younger granitic intrusions.

Iron formation within the Mary River Group occurs as an oxide- and silicate- facies unit. Oxide facies iron formations vary from lean magnetite-chert to iron-ore quality deposits of magnetite and hematite (Johns and Young, 2006). Genesis of high grade iron ores is the result of the Hudsonian age deformation and metamorphism of enriched Archean Banded Iron Formation. The silicate–facies iron formation is generally thin and found in association with the oxide–facies, although it also occurs on its own. It commonly contains coarse garnet, anthophyllite, cummingtonite, and actinolite porphyroblasts.

### 3.1.2 DEPOSIT GEOLOGY

Deposit No.1 occurs at the nose of a syncline plunging steeply to the north-east (Aker Kvaerner, 2008). The iron formation occupies the nose and two limbs of this feature with an ~1300 m long northern portion and an ~700 m long southern portion. The footwall to the iron formation mainly consists of gneiss with minor schist, psammitic gneiss (psammite) and amphibolite. The hanging wall is primarily composed of schist and volcanic tuff with lesser amphibolite and metasediment.

The hanging wall primarily encompasses chlorite–actinolite schist and garnetiferous amphibolites. Meta-volcanic tuff is also a significant lithology identified in the hanging wall. The footwall mainly consists of quartz-feldspar-mica gneiss with lesser meta-sediment (greywacke) and quartz-mica schist. Microcline and albite are the predominant feldspars within the gneiss and biotite is generally more abundant than muscovite.

The iron ore deposits at the Mary River project represent high-grade examples of Algoma-type iron formation and are composed of hematite, magnetite and mixed hematite-magnetite-specular hematite varieties of ore (Aker Kvaerner, 2008). The iron deposits consist of a number of lensoidal bodies that vary in their proportions of the main iron oxide minerals and impurity content of sulphur and silica in the ore. The massive hematite ore is the highest grade ore and also has the fewest impurities, which may indicate it was derived from relatively pure magnetite or that chert, quartzite and sulphides were leached and oxidized during alteration of the iron formation.

Intense deformation and lack of outcrop limit the ability to subdivide by lithology on the basis of future mined tonnages. Rather, the waste material has been subdivided on the basis of zonal relationships around the iron ore as described in Table 1.

## 3.2 EXISTING GEOLOGICAL DATABASE

The existing geological database for Deposit No. 1 was obtained primarily from drilling with surfacing mapping and geophysics providing only a minor source of data.

### 3.2.1 SURFACE MAPPING AND GEOPHYSICS

The exposed portions of Deposit No. 1 have been mapped systematically using standard geological mapping techniques since 2006. Some detailed mapping of individual outcrops has been performed on the southwest facing slope of the deposit to gain an understanding of the complexity of the structure that has affected the ore zone and wall rocks. Within the area of the proposed open pit, there is very little bedrock exposure of waste rock across the footwall and hanging wall. The exposure is estimated to be less than 10%. Based on discussions with senior Baffinland geological staff, there is no more information to be gained from ground work across this area. The overburden thickness maps for the deposit in the vicinity of the waste rock hanging wall and footwall areas are still in development.

**Table 3-1 Summary of Waste Types and Tonnages**

| Waste Type | In-Pit Tonnage (t) | % of Waste | Lithologies (in approximate order of abundance) |
|---|---|---|---|
| Hanging wall (HW) | 114,506,831 | 20.0 | meta-volcanic (tuff); greywacke; amphibolite; chlorite, mica or amphibole schist; ultramafite; and gneiss |
| Hanging wall schist (HWS) | 103,479,188 | 18.1 | chlorite, mica, or amphibole schist; amphibolite; greywacke; and meta-volcanic (tuff) |
| Internal waste (IW) | 2,982,893 | 0.5 | schist; amphibolite; and meta-volcanic (tuff) |
| Deleterious ore (DO) | 13,672,193 | 2.4 | high grade iron formation (elevated Mn, S or P); and banded iron formation |
| Footwall schist (FWS) | 45,917,213 | 8.0 | chlorite, mica, or amphibole schist; gneiss; greywacke; amphibolite; and meta-volcanic (tuff) |
| Footwall (FW) | 291,226,388 | 50.9 | gneiss; metasediments (e.g. greywacke); chlorite, mica or amphibole schist; and amphibolites |
| Total | 571,784,706 | 100.0 | |

The entire area of Deposit No. 1 was covered by airborne magnetic survey flown in 2008. Limited ground magnetic work was performed in 2010 and 2011 covering selected areas along the east and northernmost parts of the deposit. Ground gravity surveys were performed along the eastern edge and northeast portion of the deposit in 2011. The geophysics completed to date has been utilized primarily for ore zone delineation. It is the opinion of Baffinland geological staff that geophysical techniques would not be helpful in differentiating different waste rock lithologies on the scale required.

### 3.2.2 DRILLING

The existing geological database and interpretation of the Deposit No. 1 ore zone and waste rock is derived mainly from rotary core drilling, core logging, and core sampling. Since 2004, a total of 26,852 metres of drilling in 136 holes has been completed on Deposit No. 1. There has been drilling on Deposit No. 1 annually from 2004 to 2010. The locations of the drill holes that have been used as part of the geochemical characterization program and database are presented in Figure A-1.

The drilling season on Deposit No. 1 is of short duration (mid-June to end of August); therefore, most of the drilling completed in the early years was focused on ore delineation rather than waste rock delineation. It is of note, however, that most of the drill holes that intersected the ore zone were also continued for approximately 20 m into the wall rock (waste rock) providing some opportunity to characterize waste rock materials near the ore zone.

Since 2010, there has been a concerted effort to characterize the wall rock and three drill holes were advanced in 2010 through the footwall lithologies, specifically to provide representative information on the waste rock to be produced during mining. There was no drilling completed in 2011 since that program was focussed exclusively on geotechnical assessments. However, much of the wall rock core was relogged and resampled in an attempt to increase the existing waste rock geological and geochemical database.

### 3.3 IDENTIFIED DATA GAPS AND PROPOSED DRILLING PROGRAM

Based on a review of the deposit geology and drill hole locations shown on Figure A-1, there are large volumes of wall rock within the proposed pit perimeter that have not been systematically characterized by drilling. These areas occur mainly in the footwall of the deposit, but also within the hanging wall area. Figure A-1 shows these areas delineated by red cloud-like polygons. These delineated areas will be the focus for a 2000 to 3000 m drilling program using rotary core drill rigs to be completed during the summer of 2012. The drilling will be focussed on a series of eight to ten vertical cross-sections across the hanging wall and the footwall of the deposit at a section spacing yet to be finalized, but likely to be around 400 or 500 m. The recovered drill core will be logged and sampled in accordance to methods based on MEND (2009) and Price (1997). The drill core loggers and samplers will be trained and work under the direction and training of the project geochemists to ensure that core logging and sampling methodologies are consistently applied and will address the identified data gaps.

In an attempt to share available resources, the drilling locations for the 2012 geochemical characterization drilling program will be optimized so as to fill gaps related to the geotechnical and geomechanical aspects of the pit design. The recovered drill core will be used to assess both geochemical and geotechnical/geomechanical aspects of the pit design.

## SECTION 4.0 - PREDICTIVE GEOCHEMICAL SAMPLING AND TESTING PROGRAMS EXISTING DATABASE

### 4.1 SAMPLING

Assessment of the potential for ML/ARD from mine rock has been undertaken primarily by sampling of the Project's archived exploration drill core. Sampling and analysis has been conducted in stages since 2006 (Knight Piésold 2008, Knight Piésold 2009, AMEC 2010a and AMEC 2012a). The highly deformed nature of the deposit and the relatively high metamorphic grade has largely restricted interpretation of waste material tonnages to a spatial (hanging wall and footwall) rather than a lithological basis. In addition to the archived drill core, three drillholes (318 m in total) were advanced in 2010 to specifically address a lack of representative waste material in the footwall of the deposit. Limited sampling of overburden material in the area has been completed.

Work in 2011 included collection of an additional 377 samples of waste rock material on the basis of a revised waste type model that subdivided the hangingwall (HW) and footwall (FW) zones to incorporate more schist dominated regions (HWS and FWS) occurring generally in close proximity to the iron ore. It has been observed that sulphide content in these regions while variable is typically higher than that in the more distal hanging wall and footwall material. The revised waste model also incorporated an internal waste (IW) subdivision (waste fingering within the ore zone) and a deleterious ore (DO) zone that has been identified as probable waste in the footwall.

### 4.2 STATIC TESTING

Static testing has included modified Sobek acid base accounting (ABA) with sulphur speciation and carbon analysis, net acid generation (NAG) testing, total element analyses, and short term leach analyses. Materials tested have primarily included waste rock (613 samples) with some testing of ore (21 samples) and overburden (seven near-surface outside of pit area).

Waste rock is characterized by generally low modified Sobek neutralization potentials (NP) and low sulphide contents with resulting low acid potentials (AP) (Figure 4-1). Carbonate NP typically represents < 30% of the modified Sobek NP. Sulphide content in excess of 0.5% is generally predictive of an NPR (the ratio of NP/AP) less than 2 (Figure 4-2). A summary of static ABA waste rock results by waste type are provided in Table 4-1. Overall, assuming that a NPR ≤ 2 is representative of PAG material and based on the current understanding of waste distributions in the pit, an estimated 15% of waste rock is expected to be PAG.

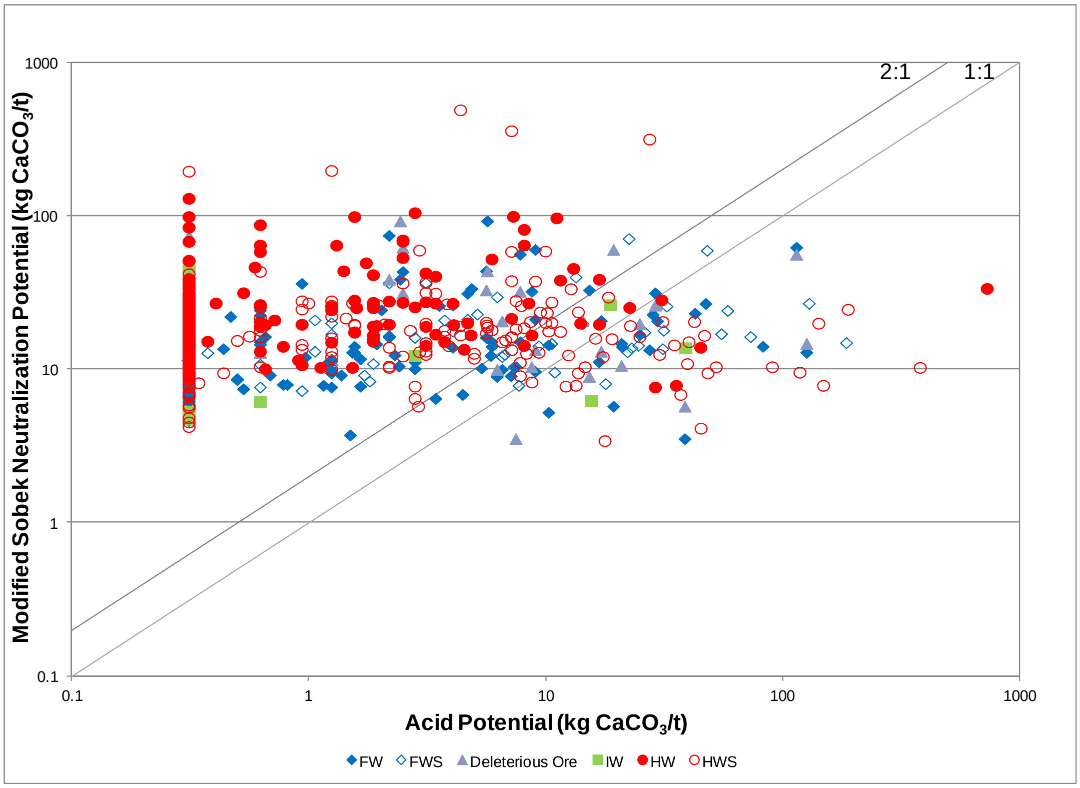


**Figure 4-1 Neutralization Potential (NP) vs. Acid Potential (AP)**

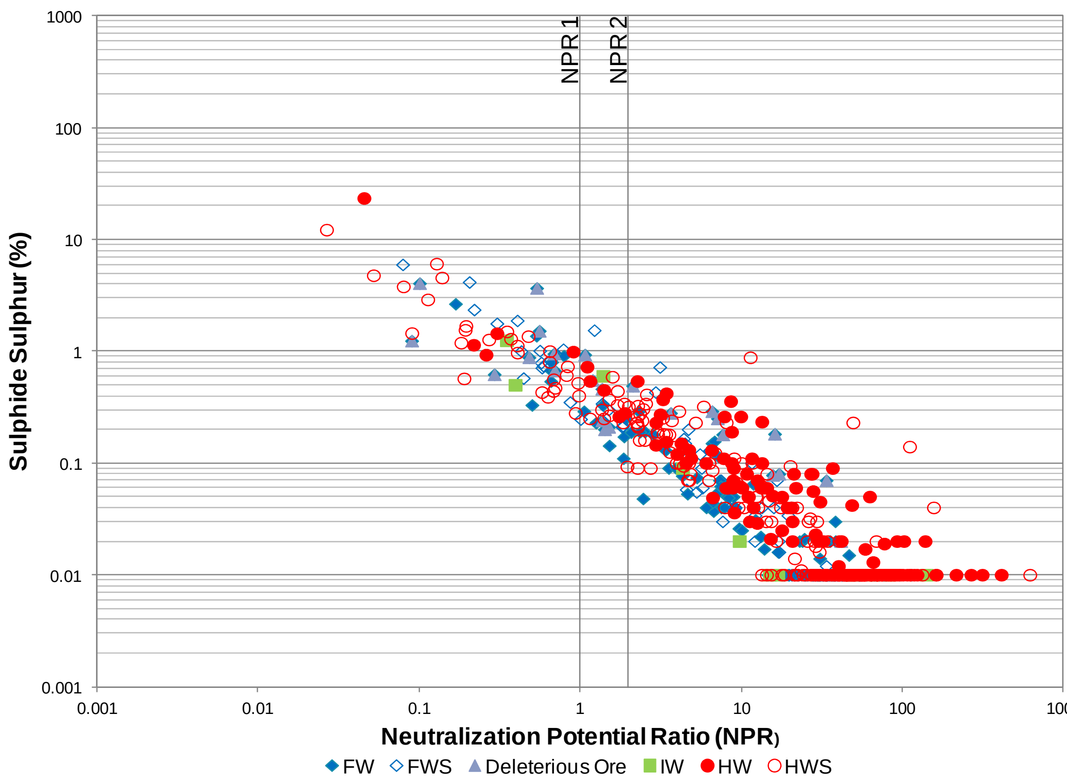


**Figure 4-2 Neutralization Potential Ratio vs. Sulphide Sulphur**

**Table 4-1 Summary of Waste Rock Static ABA Test Results**

| Waste Type | Number of samples | NPR* < 2 | | Modeled In-Pit Tonnage | Estimated PAG Tonnage |
|---|---|---|---|---|---|
| | N | n | % | t | t |
| HW | 142 | 10 | 7.0 | 114,506,831 | 8,063,861 |
| HWS | 207 | 48 | 23.2 | 103,479,188 | 23,995,174 |
| IW | 11 | 3 | 27.3 | 2,982,893 | 813,516 |
| DO | 27 | 15 | 55.6 | 13,672,193 | 7,595,662 |
| FWS | 99 | 23 | 23.2 | 45,917,213 | 10,667,635 |
| FW | 127 | 14 | 11.0 | 291,226,388 | 32,103,696 |
| | | | | | |
| Total | 613 | 113 | 18.4 | 571,784,706 | 83,239,546 |
| | | | | | |
| * NPR = mod. Sobek NP/AP | | % PAG normalized to tonnage = | | | 15 |

The static ABA sampling program completed in 2011 included a component of mineralogical work (see below) to improve the overall understanding of ML/ARD of the waste rock and particularly the source of non-carbonate acid neutralizing potential in the waste rock. This, along with kinetic testing, has been identified as a critically important consideration to support and better understand the adequacy of non-carbonate neutralization capacity in waste rock to limit acidic drainage.

Overburden from the pit volume has not been specifically tested. However, selected sampling of overburden from potential borrow areas around the site and along the proposed tote road to the north have been completed (Knight Piésold 2008, AMEC 2010b). Testing of these largely glacially derived surficial materials indicated they were generally low in sulphide content and in many cases contained abundant carbonate presumably derived from the local Palaeozoic carbonate rocks that outcrop in the region.

## 4.3 MINERALOGY

Selected samples have been characterized by qualitative and Rietveld XRD (R-XRD), optical microscopy and SEM to better understand the waste rock mineralogy in terms of ML/ARD. The work initiated in late 2011 is continuing and will be reported in 2012; however, initial results indicate the following:

Sulphides

- The most common sulphide mineral present is pyrite.
- Chalcopyrite is the next most abundant sulphide though usually at trace concentrations.
- Sphalerite (sometimes Cd bearing), pyrrhotite, pentlandite, cobalt-pentlandite and marcasite have also been identified as trace sulphide constituents;

Carbonates

- The most common carbonate minerals observed are dolomite-ankerite and siderite, with the latter more common in proximity to the ore. The siderite and the Fe-component of the dolomite-ankerite carbonates are not expected to provide significant neutralization potential.

Silicates

- Quartz, plagioclase, k-feldspar, amphiboles (e.g. cummingtonite and hornblende), biotite, muscovite, and chlorite (Fe-rich and Mg-rich) are the major silicate rock forming minerals present.
- Plagioclase ranged from albite (Na rich) to anorthite (Ca rich) in composition.
- Silicate minerals occurring in more typically in minor to trace amounts include garnet, epidote, staurolite, cordierite, and andalusite.

Oxides

- Oxide minerals identified include magnetite, hematite, goethite, ilmenite and chromite with granular magnetite in waste iron formation.

The mineralogical work underway is being directed to better understand the potential non-carbonate NP sources among the different waste rock types

### 4.4 KINETIC TESTING

Ten waste rock samples were run in humidity cells for 53 weeks in 2008 and 2009. A further 17 waste rock samples were initiated in humidity cell tests in May 2011. Nine of these samples were standard humidity cells and eight were NP depleted humidity cells designed to assess drainage quality in the absence of carbonate NP. Available humidity cell results have produced pH in the circum-neutral to weakly acidic (pH 5) range, but no strongly acidic drainage (pH<5) has occurred. All 2011 humidity cell tests are continuing.

Humidity cell metal leaching results are generally consistent with the sulphide mineralogy identified, with measureable loadings of copper, nickel, zinc and cobalt present in some humidity cells. Based on limited kinetic data, total sulphide content of samples is weakly correlated with sulphate release rates; however, through the current periods of testing metal release rates and trends vary among the cells. Overall, metal release rates for the weak acid (pH 5 to 6.5) humidity cells are higher than those of neutral pH cells. The metals copper, nickel, zinc and cobalt discussed above were also consistently identified at elevated levels in NAG leachate analyses of the net-acidic samples tested.

Two field lysimeters are in operation at the Mary River site. The two lysimeters were constructed by placing lump and fine ore left over from the 2008 bulk sampling program on an impermeable membrane to allow collection of run-off water. Though minor gypsum has been locally identified with some ore, the presence of sulphate and some elevated dissolved metals (e.g. nickel) has been inferred to be related to sulphide oxidation in these materials. Long-term storage of ore during operations is not expected; however, continued monitoring of these ore lysimeters may provide field scale and climate driven data pertinent to low NP sulphide oxidizing material.

Shallow hydrogeological investigations of the active zone in overburden adjacent to existing ore stockpiles were intiated during 2011 with the installation of four shallow monitoring wells. These wells will be monitored and sampled during the 2012 field season.

### 4.5 IDENTIFIED GEOCHEMICAL DATA GAPS AND ADDITIONAL WORK

The following data gaps and planned work to address them is outlined below.

Sampling

- The large extent of presently unsampled footwall material and smaller gaps in hanging wall material within the pit volume and adjacent to the ultimate pit on the HW side is to be drilled and sampled in 2012 (see Section 3).
- Overburden material within the pit volume is presently unsampled. Sampling of this material will be included to the extent possible in the additional planned drilling program or coordinated with other site work.

Static Testing

- In addition to the geological characterization of the above currently unsampled waste rock materials, static testing of these footwall, and hanging wall materials will be conducted as part of the planned drilling and sampling program in 2012. Sampling and analytical methods will be consistent with previous Project work.
- Static testing of representative overburden material samples within the pit volume is also planned.

Mineralogy

- Mineralogical characterization of drill core to better understand the effective neutralization potential of waste rock for the range of lithologies and waste types will continue in 2012.
- Detailed mineralogical characterization by R-XRD, optical microscopy and SEM is also planned for selected humidity cell samples that will include an attempt to identify and assess accumulated alteration products to support the understanding of metal attenuation during oxidative weathering of waste rock.

PAG Segregation

- The following work will continue or be initiated to identify the importance and ability to segregate PAG materials.
    - The overall percentage and distribution of PAG will be updated on the basis of the expanded footwall and hanging wall sampling program planned for 2012.
    - Continuous sampling over several targeted long sections of core will be completed in 2012 to better assess continuity of PAG materials at the bench scale.

- Mineralogical and kinetic testing work will continue to be integrated with static testing results to improve the understanding of potential simplified surrogate relationships that can be used to assist in PAG segregation during operations should this be required.

Kinetic Testing

- A continued expansion of the laboratory kinetic testing program consistant with previous Project work is planned to include:
  - Humidity cell testing of deteterious footwall ore not presently represented in kinetic testing data base;
  - Humidity cell testing (as required) of presently unsampled lithostratigraphic units to be drilled in 2012;
  - Column or humidity cell testing of a range of non-PAG materials of various sulphide contents to better understand metal leaching from this material, and
  - Comparative kinetic testing of cold and room temperature leaching of selected PAG materials.
- On-going sampling of drainage from the existing lysimeters, other ore and waste stockpiles and rock-face seepage in the vicinity of the pit will continue for at least 2012 through 2014.
- Where possible, upgrades to existing lysimeters and adjacent active zone monitoring will be made to better quantify and constrain metal loadings released from these facilities.
- If suitable material is identified, field test piles will be setup and instrumented for both thermal monitoring and drainage quality.
- Where field test piles are established, laboratory testing representative of the test pile material will also be completed to provide direct comparison and insight into the scaling factors from lab to field.

# SECTION 5.0 - WATER QUALITY PREDICTIONS – WASTE ROCK AND PIT

## 5.1 BASIS OF WASTE ROCK SEEPAGE AND PIT DRAINAGE WATER QUALITY MODELS

Mass loading models with limited geochemical attenuation modeling have been developed to predict water quality from the waste rock stockpiles and future pit water drainage. Detailed descriptions of the models are described in AMEC (2012b) and AMEC (2012c). Water inputs to the waste rock stockpile and pit models were based on monthly precipitation values provided by Knight Piésold (2011). Drainage only occurs during the summer months (June to September). Expected release rates for the mine rock were derived from available humidity cell data. There is presently no humidity cell data available for acidic drainage conditions. Therefore, where acidic drainage was required to be modeled preliminary source terms were established using NAG leachate metal data proportioned to a sulphate release rate set at five times the non-acidic sulphate rate. Key assumptions used in application of the source terms include:

- Sulphide oxidation rates were assumed to be 100% of laboratory rates during the summer months (June to September) and 50% during the remainder of the year (winter months) due to reduced temperatures (MEND 1996);
- The effective reactive surface area of waste rock in the pile was assumed to be 50 $m^2$/ton;
- The effective reactive surface area of the pit walls was assumed to be 50 times the calculated pit wall surface (calculated from pit dimensions) to allow for surface roughness and fracture influences (Morin and Hutt, 2004); and
- An ARD onset time of 5 years was assumed for the PAG mine rock in the stockpiles and pit walls based on the estimated average carbonate neutralization potential (carbonate NP) depletion time derived from humidity cell testing of PAG materials.

## 5.2 EXISTING STATUS OF WASTE ROCK WATER QUALITY MODEL

The material balance used for the waste rock model was based on the current mine plan and a number of assumptions regarding the mine operation and mine waste management that are consistent with BIM plans and commitments.

Key assumptions in the current waste rock seepage model include the following:

- Construction of the waste rock stockpile is complete and the mine site is in Closure;
- A thermal steady-state condition has been achieved in the waste pile, with established permafrost conditions occurring in all but an outer 10 m active layer of the pile;
- Hydrology of the stockpile is in a steady-state condition;
- Seepage only occurs from the active layer of the stockpile and there are no groundwater inflows to the pit;
- Annual seepage flows equal annual infiltration rates, no infiltration is lost to the permafrost zone;
- Sulphide oxidation occurs within the active layer, but not within the permafrost zone;

- The rate of sulphide oxidation in the active layer is temperature dependent;
- PAG and non-PAG rock will be effectively segregated during mining such that:
  - PAG rock will be placed within the core of the stockpile; and
  - Only non-PAG waste rock will be present within the active layer.
- Waste management practices will be utilized in the waste rock stockpile construction to:
  - Promote permafrost development within the piles, and
  - Minimize the active layer thickness of the waste stockpiles.

### 5.2.1 MODELING RESULTS

The estimated seepage concentrations (in process) for the waste rock model base case are provided in Table 5-1. Full details including discussion and sensitivity analysis of these results are provided in AMEC (2012b). These mass balance derived values may exceed geochemical solubility limits and therefore, the results were checked through geochemical equilibration in PHREEQC. The resulting equilibrated values are also provided in Table 5-1.

**Table 5-1 Estimated Water Quality of Waste Rock Stockpile Seepage**

| Parameters | MMER values | Maximum | | | |
|---|---|---|---|---|---|
| | | West Catchment | | East Catchment | |
| | | Unequilibrated | Equilibrated* | Unequilibrated | Equilibrated* |
| pH | | 6.9 | 6.9 | 6.9 | 6.9 |
| Sulphate (mg/L) | | 124 | 124 | 99 | 99 |
| Arsenic (mg/L) | 0.5 | 0.012 | 0.012 | 0.010 | 0.010 |
| Copper (mg/L) | 0.3 | 0.022 | 0.022 | 0.018 | 0.018 |
| Lead (mg/L) | 0.2 | 0.001 | 0.001 | 0.001 | 0.001 |
| Nickel (mg/L) | 0.5 | 0.006 | 0.006 | 0.005 | 0.005 |
| Zinc (mg/L) | 0.5 | 0.075 | 0.075 | 0.060 | 0.060 |
| Aluminum (mg/L) | | 0.554 | 0.321 | 0.443 | 0.295 |
| Antimony (mg/L) | | 0.012 | 0.012 | 0.009 | 0.009 |
| Boron (mg/L) | | 0.096 | 0.096 | 0.077 | 0.077 |
| Cadmium (mg/L) | | 0.0002 | 0.0002 | 0.0001 | 0.0001 |
| Chromium (mg/L) | | 0.022 | 0.022 | 0.018 | 0.018 |
| Cobalt (mg/L) | | 0.0030 | 0.0030 | 0.0024 | 0.0024 |
| Iron (mg/L) | | 0.137 | <0.002 | 0.109 | <0.002 |
| Manganese (mg/L) | | 0.0358 | 0.00002 | 0.0286 | 0.00003 |
| Mercury (mg/L) | | 0.004 | 0.004 | 0.003 | 0.003 |
| Molybdenum (mg/L) | | 0.039 | 0.039 | 0.031 | 0.031 |
| Selenium (mg/L) | | 0.047 | 0.047 | 0.038 | 0.038 |
| Silver (mg/L) | | 0.0005 | 0.0005 | 0.0004 | 0.0004 |
| Thallium (mg/L) | | 0.004 | 0.004 | 0.003 | 0.003 |
| Vanadium (mg/L) | | 0.006 | 0.006 | 0.005 | 0.005 |
| Barium (mg/L) | | 0.241 | 0.241 | 0.193 | 0.193 |
| Sodium (mg/L) | | 1.535 | 1.535 | 1.227 | 1.227 |

**Table 5-1 Estimated Water Quality of Waste Rock Stockpile Seepage (Cont')**

| Parameters | MMER values | Maximum | | | |
|---|---|---|---|---|---|
| | | West Catchment | | East Catchment | |
| | | Unequilibrated | Equilibrated* | Unequilibrated | Equilibrated* |
| Potassium (mg/L) | | 46.8 | 46.8 | 37.4 | 37.4 |
| Calcium (mg/L) | | 57.8 | 57.8 | 46.2 | 46.2 |
| Magnesium (mg/L) | | 32.4 | 32.4 | 25.9 | 25.9 |

* Results oversaturated with respect to $Al(OH)_3$, ferrihydrite (poorly crystalline Fe oxide) and manganite (MnO(OH)) were equilibrated in PHREEQC (AMEC 2012b).

### 5.3 EXISTING STATUS OF PIT DRAINAGE WATER QUALITY MODEL

The material balance used for the pit drainage water quality model was based on the current mine plan, modeled waste distribution within the pit and a number of assumptions regarding the mine operation and pit management that are consistent with BIM plans and commitments. In order to model pit water quality during operations, additional information on mine progress over time has been provided by Hatch (2012).

Key assumptions in the current pit drainage model include the following:

- Water flow into the pit is by direct precipitation (rain and snow) within the pit/mined perimeter and no additional natural drainage or catchments drain to the pit;
- Draining water within the pit/mined perimeter collects at either perimeter drains (early time) or to pit sump(s) for management during operations;
- No groundwater inflow occurs to the pit and no evaporation loss from the pit surface;
- After closure, the pit will be filled to overflow at elevation 320 masl within five years; and,
- Overall pit water quality at a given point in time is derived by:
    - complete mixing of drainage proportioned on the basis of exposed (unflooded) incremental surface areas and the pit lake surface area (post flooding);
    - incremental surfaces are assigned on the basis of exposed (unflooded) surfaces from the block model within the pit (e.g. HW, FW, HWS, FWS, IW, DO, Ore and overburden);
    - source terms are assigned to each of the incremental surfaces on the basis of the percentage PAG for that material type;
    - metal release rates based on acidic conditions are allowed for PAG expected to have been exposed for more than 5 years; and,
    - total flushing of accumulated metals on surfaces is assumed during drainage period (June to September).

The pit drainage water quality model is presently under development and results are currently unavailable.

### 5.4 IDENTIFIED GAPS IN INPUT PARAMETERS AND SENSITIVITIES IN INPUT PARAMETERS AND PLANNED WORK

The mass balance waste rock and pit models were prepared using a number of assumptions in lieu of supporting data. Several items have been identified where additional work could either verify such assumptions or improve values estimated or assumed for the purposes of the modeling. These items are described below.

Hydrology

Modeling of the waste rock stockpile and pit identified that the models were sensitive to the volume of water flushing through the system. Therefore, any update to the understanding of pit and waste rock stockpile hydrology should be incorporated into the model.

Source Terms

The source terms for the waste rock and pit models for non-acidic conditions are presently based on available humidity cell data. Source terms for acidic drainage for pit water models are based on scaling of NAG leachate data with acidic drainage. This approach is considered highly conservative and could lead to significant overestimations regarding concentrations in acidic drainage. In general, source terms are sensitive parameters in predicting mass inputs into the system. Therefore, these source terms will be reevaluated with additional humidity cell data as they become available. Acidic leachate data in particular should it become available (e.g. with continued operation of the NP depleted humidity cells) may substantially increase the reliability of modeling acidic drainage at the site. Estimation of drainage inputs from non-PAG rock is presently based on largely PAG humidity cells operating under non-acidic drainage conditions. The planned addition of a range of humidity cells or column tests for non-PAG materials with a range in sulphide concentrations (Section 4) including samples without detectable sulphide could substantially improve reliability in the estimation of non-PAG drainage quality for the waste rock stockpile and pit.

Proportion of PAG Rock

The percentage PAG in the waste rock stock pile and at pit limits is an important and sensitive factor in predicting future water quality due to potential acidic drainage. Additional sampling and ML/ARD characterization work to be completed in 2012 will provide an update on the percentage and distribution of PAG material in the pit and resulting waste rock stockpile. This can then be incorporated in the existing models.

ARD On-set Time

The ARD on-set time for PAG rock is also a critical factor in predicting the timing of potential future acidic drainage. The current selection of 5 years on the basis of the average NP depletion time is believed to be a conservative (short) assumption. On-going humidity cell testing and a better understanding of the waste rock mineralogy and contributions to NP will be utilized to update the ARD on-set time for modeling efforts.

Surface Areas and Permafrost

The reactive surface area in both models as defined by scaling assumptions and, for the waste rock model, the active zone thickness, is a critical assumption in the model with high sensitivity. Direct estimation of the effective surface area is challenging. Some experience based guidance may be possible from expected rock behaviour during blasting. However, this parameter should continue to be managed through the use of sensitivity analysis. If a field test pile is to be constructed, comparison of representative lab data and field data may provide an indirect confirmation or assessment of this and other scaling factors. Thermal modeling of the waste rock stockpile is planned to estimate the expected active zone thickness of the waste rock stockpile, including global warming conditions. Modeling will also include an assessment of thermal effects from sulphide oxidation to evaluate the assumption that these effects are inconsequential for the relatively low-sulfide rock at Mary River and do not limit freeze-back into the waste rock stockpile.

A related issue to permafrost aggradation, active zone development and water flows through the system is the fate of water infiltrating into the permafrost zone of the stockpile. Currently, modeling assumes a steady state where flows into the pile equal flows out. However, water loses to permafrost formation are likely especially following placement of fresh rock. In the event a field test pile is constructed, instrumentation and monitoring will be utilized to provide data on the magnitude, duration and importance of such losses in the model. This work also will allow direct measurement of solute concentrations, which then can be used to calibrate the mass-balance modeling approach.

Mineralogy

Results determined by the model are equilibrated with respect to selected solid phases. In order to conduct the equilibration step, assumptions must be made with respect to sorption and precipitation reactions that may occur. With increased quality of site data, additional modeling considerations may be possible to improve predicted model results. Presently precipitation of assumed solid phases has been carried out using equilibrium thermodynamic assumptions in PHREEQC for a limited range of solutes; no sorption is currently modeled. Additional mineralogical work on post operational humidity cells is planned that could improve the understanding of metal leaching in the context of metal sorption and solid phase precipitation behaviour.

## Section 6.0 - PROPOSED VERIFICATION AND OPERATIONAL MONITORING OF WASTE ROCK STORAGE AREA AND OPEN PIT (POST-2014)

A preliminary verification and operational monitoring program is proposed for the post-2014 period when the commencement of pre-strip and mining of the open pit is scheduled to commence. This program will be subject to further adjustment based on the results of the 2012-2014 work. The results of the verification and operational monitoring program will help to confirm long-term predictions related to, for example, active zone thickness/permafrost aggradation and waste rock/pit water quality. The monitoring program results will be carefully tracked over time, particularly during early years of operation, to ensure that condtions correspond with the predictions made. Trends showing potential divergence between predicted and actual conditions will be identified early on so that appropriate corrective actions can be evaluated and implemented as necessary to minimize potential environmental risk.

### 6.1 PHYSICAL MONITORING

It is expected that the Waste Rock Storage Area and open pit will be geotechnically stable based on the conservative design basis and parameters that will be adopted. It is the responsibility of the pit supervisors to visit all working areas every shift to check for working area hazards. Therefore, dumps and pit walls are inspected every shift and any hazardous conditions are reported.

### 6.2 TEMPERATURE MONITORING

Once the waste rock dump has sufficiently developed, ground temperature cables (GTCs) will be installed at locations within the dump footprint to monitor cooling within the dump and to measure seasonal variation in active zone thickness. The focus of the temperature monitoring will be on confirming active zone thicknesses and geometries across waste rock materials distributed throughout the waste rock dump. GTCs are typically installed in nests, with individual GTCs installed at different depths and measured several times annually to capture seasonal variation in active zone thickness. This approach has been effectively used at the Ekati Mine over the last decade.

### 6.3 ENVIRONMENTAL MONITORING

#### 6.3.1 INSTRUMENTED TEST PILES

A program of carefully designed field test pads and laboratory columns should be considered as soon as waste rock becomes available, prior to or at the commencement of mining activiites. This program can assist in simulating and predicting drainage chemistry from the proposed waste rock stockpile and provide a relationship between kinetic test work and actual scaled up field conditions. In the absence of available waste rock to conduct a field test pad program, it is recommended that during the summer of 2012, field reconnaissance work be conducted to identify any suitable exposures of hanging wall and foot wall waste rock that could be mined on a small scale for the purpose of test pad construction and operation during 2013.

#### 6.3.2 WASTE ROCK GEOCHEMISTRY

The technique for the identification and segregation of PAG and non-PAG waste rock will be refined based on the results of the 2012-2014 characterization program. It is likely that the identication will be based on a combination of analytical techniques that rely on both field visual observations, and on-site sulphur analyses of blasthole cuttings and of samples of blasted rock. For the purpose of validation of field results, an adequate percentage of samples will be sent to an external independent laboratory for standard ABA parameters.

The main objectives of geochemical monitoring will be to confirm the general geochemical characteristics of the waste rock prior to deposition in the waste rock pile. Initially, individual blast patterns or blasted rock piles will be differentiated on the basis of PAG vs. non-PAG, or some range therein. Once the individual blasts are identified, then the waste rock from those blasts can be managed appropriately in accordance with the waste rock management plan for the operation. Operational experience at other mining operations such as Diavik, Ekati, and Voiseys Bay provides evidence that this type of operational sampling and monitoring can provide adequate characterization of waste rock. As confidence builds during the iniitial confirmatory phase of operational geochemical sampling, it is anticipated that the frequency and intensitiy of sampling can be adjusted accordingly.

#### 6.3.3 SEEPAGE AND PIT WATER MONITORING

Based on topographic and natural drainage considerations, preliminary locations for seepage monitoring will be established around the toe of the dump. Prior to construction of the waste rock dump, multi-year baseline samples will be collected at these locations interprteted to be near the toe of the dump and to represent natural drainage pathways. Actual locations will be selected based on field reconnaissance during construction. Samples will be collected at a minimum twice annually (mid-summer and late summer). A comprehensive seepage monitoring protocol and training program will be established to ensure consistant and high quality results are obtained from the program.

Similarly a pit sump monitoring program will also be implemented to monitor flows pumped from the open pit sump and to analyze for effluent quality parameters.

#### 6.3.4 AQUATIC EFFECTS MONITORING

An extensive aquatic effects monitoring program (AEMP) has been developed that is designed to detect any changes to the aquatic environment downstream of the Deposit No. 1 waste rock storage area and open pit sump discharge outfall.

# SECTION 7.0 - SUMMARY OF PROPOSED GEOCHEMICAL CHARACTERIZATION PROGRAM

## 7.1 IMPLEMENTATION SCHEDULE

The implementation schedule for the waste rock geological and geochemical characterization program (the Program) as described in Sections 3.0, 4.0, and 5.0 is presented in Table 7-1. The proposed verification and operational monitoring program described in Section 6.0 for the post 2014 period will be modified based on the results obtained from the 2012-2014 Program.

## 7.2 DATA MANAGEMENT AND REPORTING

Report updates for the Program will be provided in March of each year as part of annual reporting requirements. The reports will present the latest results for the previous calendar year including collected waste rock geology and geochemistry data, data interpretation, updates of the waste rock and pit water quality modeling, and the results of related work studies that are described in Sections 3.0, 4.0, and 5.0, herein.

**Table 7-1. Geochemical Characterization Program - Implementation Schedule 2012 to 2014**

| | | Refer to Report Section | Description | Q1-2012 | Q2-2012 | Q3-2112 | Q4-2012 | Q1-2013 | Q2-2013 | Q3-2113 | Q4-2013 | Q1-2014 | Q2-2114 | Q3-2014 | Q4-2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1.0** | **DRILLING PROGRAM** | | | | | | | | | | | | | | |
| **1.01** | **Execute Drilling Program** | 3.2.2, 3.3 | 2,000 - 3,000 m drill program utilizting rotary core rig focussed on footwall and hanging wall of the deposit. | | | | | | | | | | | | |
| **1.02** | **Core Logging** | 3.3 | Log and sample core in accordance to established methods. | | | | | | | | | | | | |
| **1.03** | **Field Scale Geological Interpretation** | 3.3 | Utilizing new information obtained from from drill logs, revise geological maps and cross-sections of the footwall and hanging wall of the deposit. | | | | | | | | | | | | |
| **2.0** | **PREDICTIVE GEOCHEMICAL SAMPLING AND TESTING PROGRAMS** | | | | | | | | | | | | | | |
| **2.01** | **Sampling** | 4.1, 4.5 | Systematic sampling of 2012 drill core of footwall and hanging wall based on established methods. | | | | | | | | | | | | |
| **2.02** | **Static Testing** | 4.2, 4.5 | Static testing of select 2012 drill cores using established analytical methodologies. | | | | | | | | | | | | |
| **2.03** | **Mineralogy** | 4.3, 4.5 | Detailed mineralogical characterization by R-XRD, optical microscopy, and SEM. | | | | | | | | | | | | |
| **2.04** | **PAG Segregation** | 4.5 | Ongoing synthesis of available data to assess importance and ability to segregate PAG materials | | | | | | | | | | | | |
| **2.05** | **Kinetic Testing - ongoing work** | 4.4 | Continuation of kinetic test initiated in May 2011. | | | | | | | | | | | | |
| **2.06** | **Kinetic Testing - from 2012 drill core** | 4.4, 4.5 | Continued expansion of laboratory kinetic test work program, | | | | | | | | | | | | |
| | | | Upgrade and ongoing sampling of lystimeters, monitoring wells, and seepage. | | | | | | | | | | | | |
| | | | Assess feasibility of field waste rock test piles. | | | | | | | | | | | | |
| | | | If feasible, construct and sample test piles. | | | | | | | | | | | | |
| **3.0** | **WATER QUALITY PREDICTIONS - WASTE ROCK AND PIT** | | | | | | | | | | | | | | |
| **3.01** | **Hydrology** | 5.4 | Collect additional hydrological data. | | | | | | | | | | | | |
| **3.02** | **Source Terms** | 5.4 | Better quantify source terms for pit and waste rock models | | | | | | | | | | | | |
| **3.03** | **Proportion of PAG** | 5.4 | Better quantify proportion of PAG in waste rock pile and pit walls. | | | | | | | | | | | | |
| **3.04** | **ARD On-Set Time** | 5.4 | Improve understanding of ARD on-set times. | | | | | | | | | | | | |
| **3.05** | **Surface Areas and Permafrost** | 5.4 | Improve understanding of surface area scaling values, active zone thickness, and water infiltration into waste rock pile. Conduct thermal modeling of waste rock pile. | | | | | | | | | | | | |
| **3.06** | **Mineralogy** | 5.4 | Incorporate processes of metal sorption and solid phase precipitation behaviour. | | | | | | | | | | | | |
| **4.0** | **Reporting Updates** | | | | | | | | | | | | | | |
| **4.01** | **Interim Waste Rock Geochemiscal Charcterization Report** | 7.2 | Annual report updates that present latest results of geochemical characterization program including waste rock geochemistry, waste rock and pit water quality modeling modeling, and related studies. Reports to be provided March 31 of each year. | | | | | | | | | | | | |
| **4.02** | **Waste Rock Water Quality Modeling Report** | 7.2 | | | | | | | | | | | | | |
| **4.03** | **Open Pit Water Quality Modeling Report** | 7.2 | | | | | | | | | | | | | |

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