Freeze Optimization Study Update for MVEIRB and Parties

Report Prepared for

Aboriginal Affairs and Northern Development Canada

Report Prepared by

SRK Consulting (Canada) Inc.

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August 2012

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Aboriginal Affairs & Northern Development Canada

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1 Introduction

The Freeze Optimization Study (FOS) is an investigation of the ground freezing method that is being proposed as part of the Giant Mine Remediation Plan. The Remediation Plan calls for freezing of the rock around underground chambers and mined-out stopes that contain arsenic trioxide dust.

The FOS is a full scale test of candidate ground freezing technologies. It is taking place at Chamber 10, one of the smallest arsenic containing chambers, located between Highway 4 and C-Shaft. Figure 1.1 shows the layout of the study area and lists the freezing methods being tested. Overall objectives of the study include:

- Demonstrating large scale ground freezing;
- Estimating parameters needed for engineering design;
- Testing implementation methods;
- Developing monitoring and data handling methods;
- Identifying constraints and opportunities related to procurement and project delivery, and
- Examining “unknown unknowns” i.e., project uncertainty and unexpected design issues.

Construction of the study area was largely completed in 2010, and ground freezing was initiated in February 2011. The construction was documented in the Interim As-Built Report and the as-built drawings (SRK, 2010), and the first year of results was documented in the Initial Findings Report (SRK 2011).

Figure 1.2 summarizes the progress of ground temperatures up to July 2012. Many of the freeze pipes have been toggled on and off for periods or converted between hybrid and passive operation as part of the testing. Nonetheless, within the first year of operations ground freezing had progressed further than anticipated, with most of the rock around Chamber 10 reaching temperatures of -10 ºC or less.

At the time of writing, the Giant Mine Remediation Plan is undergoing environmental assessment by the Mackenzie Valley Environmental Impact Review Board (MVEIRB). Parties to the assessment expressed interest in the recent findings from the FOS, and particularly how they might influence assessments of long term performance or future design and engineering choices. The remainder of this report addresses those interests. The presentation is intended to be understandable rather than exhaustive, and much of the detail is left to the accompanying figures. A more technical report is in in preparation by the engineering team, but will not be complete for several months.

2 Predictions of Long-Term Performance

One of the significant advantages of using frozen ground to manage the arsenic trioxide dust is that it is expected to be robust to extended periods of low or no maintenance over the very long term. Predictions presented in the Developer's Assessment Report were obtained from a conceptual engineering design (SRK 2006) prepared in support of the Remediation Plan. They indicated that passive thermosyphons would be able to keep the ground around the dust frozen for the long term, and that even if all of the thermosyphons were somehow to become inactive, it would take 20 years or more before the thawing reached the outer edge of the dust.

The FOS provided two types of information needed to update those predictions;

- Site specific estimates of the thermal properties of the bedrock; and
- Calibrated equations to estimate the rate of heat removal by thermosyphons.

Examples of the FOS data and modeling that were used to estimate the thermal diffusivity of the bedrock are shown in Figure 2.1. Thermal diffusivity is a combination of two fundamental physical properties, thermal conductivity and heat capacity, and it determines how quickly heating or cooling spreads through the rock. The solid lines in the Figure 2.1 plots are temperatures that were actually measured in the rock around the FOS, and the dashed lines are temperatures predicted by thermal modeling. The thermal model used temperatures measured at the pipe surface and then calculated how far the cooling would spread for various assumed values of thermal diffusivity. The plots show the "best fit" model results, which fall within a relatively narrow range of thermal diffusivity. That range was adopted for the update of the long-term predictions. It is noteworthy that these thermal diffusivities are higher than earlier estimates.

Several equations are available to estimate thermosyphon performance from air temperatures and wind speeds. Figure 2.2(a) shows three such relationships and indicates that they would result in different estimates of heat removal over the range of wind speeds common at Giant Mine. To select the most appropriate relationship for long-term predictions, each of the three equations was tested against data from the FOS. Figure 2.2(b) show that ground temperatures predicted using the 2011 equation follow a similar pattern but are consistently higher than the actual measured temperatures. In other words, that equation conservatively underestimates thermosyphon performance. The 2011 equation was therefore selected for the updated predictions.

One other input was needed, an estimate of air temperatures in the future climate. The topic of global warming was discussed in several information requests and responses filed with the MVEIRB over the past year. The last of those documents cited "multi-century" projections from the Intergovernmental Panel on Climate Change. The most cautious of those projections estimates a global average temperature increase of 6.1 ºC. The updated predictions of thermosyphon performance therefore adopted an assumption that temperatures in the Yellowknife area would increase by 6.1 ºC over the first 100 years of thermosyphon operation, and remain at that level indefinitely.

Examples of the updated predictions are shown in Figures 2.3 and 2.4. Both figures present results produced by a thermal modelled calibrated with the best fit parameters derived from FOS data. Figure 2.3 shows predicted conditions around Chamber 10 and Stope C2-12 with the thermosyphons operating. It shows that the rock immediately around the arsenic dust remains colder than -5 ºC.

These results confirm the conceptual engineering findings that the thermosyphons are able to keep the ground frozen over the long term, even under the extreme case of global warming.

Figure 2.4 shows model predictions for a hypothetical scenario where all of the thermosyphons around Chamber 12 are assumed to cease functioning in Year 100. This is a highly unlikely case: thermosyphons are proven to operate for very long periods with little or no maintenance, and of course the long-term management plan includes regular inspection, maintenance and, where needed, repair or replacement of thermosyphons. What is remarkable about the results in Figure 2.4 is that, even when the extreme global warming scenario is combined with this extreme "no maintenance" scenario, it still takes 20 years for the upper corner of the chamber to reach 0 ºC. Points deeper on the chamber walls remain below freezing for 50 years or longer. It should also be noted that Chamber 12 represents the worst case for this type of scenario. The pit wall to the north of Chamber 12 allows the heat from the ground surface to penetrate to the dust more rapidly than is the case for other stopes or chambers. These results confirm the 2006 finding that, even in the unlikely event of a complete failure of all of the thermosyphons, there would be decades of time available for detection and mitigation of the problem and re-freezing of the rock around the arsenic trioxide dust.

3 Possible Design Improvements

The conceptual designs presented in the Developer's Assessment Report are expected to undergo many rounds of review and improvement over the period leading to licensing, procurement and construction. Results available from the FOS suggest three that three types of improvements are worthy of significant consideration prior to proceeding to the selection of design details:

- Changes to the layout and timing of the initial freezing system;
- Eliminating horizontal freeze pipes below some or all of the chambers and stopes; and
- Use of "dry frozen blocks", i.e. without the introduction of new water into the dust prior to freezing.

3.1 Initial Freezing

The conceptual freezing design described in the Developer's Assessment Report included several quantities that were selected based largely on experience elsewhere. Examples include the assumed 4 m spacing between freeze pipes, the 7 m offset from the chamber or stope wall, and the active freezing brine temperature of -35 ºC. Results from the FOS have allowed many of these assumptions to be tested, and provide a basis for assessing other variants of the freezing system design.

Figure 3.1 shows examples of "tornado plots" that are used to show the influence of each design variant on the time to complete the initial freezing. The initial freezing time in this case is the time needed for a -10 ºC zone to form over at least a 10 m width around and below the chamber. Tornado plots are somewhat counter-intuitive, but they have the great advantage that results of many analyses can be displayed at the same time. In the case of Figure 3.1, the two tornado plots show the results of over thirty model runs, each examining a different design variant. For example, the red line in the first plot shows that allowing the temperature of the active freezing brine to increase from -35 to -30 ºC would increases the initial freezing time from about 220 days to about 270 days; and if the brine temperature were further increased to -25 ºC, the required initial freezing time would increase to about 330 days.

The second plot shows the effects of design variants on the time required to cool the dust within the chamber or stope to -5 ºC. The most influential parameter in this case appears to be the width of the chamber or stope. But it is important to note that all of the analyses behind this particular plot assume only two years of active freezing before the system is converted to fully passive operations. A longer active freezing period, or use of hybrid freezing, would significantly shorten the durations shown.

The tornado plots are examples only, but they illustrate some of the design parameters that are likely to be modified as the engineering process continues. Factors like brine temperature are likely to be selected on the basis of a site wide optimization, basically a comparison of brine cooling cost to overall freezing time. Factors like pipe spacing and offset, on the other hand, could be varied from one chamber or stope to another to take advantage of particular geometries.

3.2 Eliminating Horizontal Freeze Pipes

Figure 3.2 illustrates a pattern that is apparent in many of the freezing simulations carried out with the benefit of information from the FOS. The number of freeze pipes or thermosyphons needed to freeze the upper rock is much greater than is needed to cool the rock below most of the chambers and stopes. As a result, it may not be necessary to install the horizontal freezing pipes that the Developer's Assessment Report assumed would be needed beneath the dust.

The temperature contours in Figure 3.2 are for a case where only vertical thermosyphons are used to freeze the ground, and they are extended to roughly 20 m below the chamber. Despite the absence of the horizontal freeze pipes, the rock below the chamber is very effectively cooled. There are two factors that explain the difference between results like these and the earlier analyses that led to including the horizontal freezing system. The first is that the FOS results have indicated the bedrock has a higher thermal diffusivity than previously assumed, meaning that it cools much faster. The second is that the consideration of more extreme climate warming scenarios, which mean that the upper surface determines the required freeze system design, resulting in an abundance of cooling power at depth.

The results shown in Figure 3.2 are only intended to illustrate an area of current investigation. Further analysis of other chamber and stopes is needed before any conclusions about the need for horizontal freezing can be drawn.

3.3 Dry Frozen Blocks

The conceptual design presented in the Developer's Assessment Report included a step where water would be added to the dust prior to it being frozen. The water would be converted to ice and would help the dust resist any future thawing. However, analyses presented in the SRK (2006) report showed that the water had little or no effect on the time needed for the outside perimeter of the dust to begin to thaw. Its primary benefit is only in resisting a complete thawing of the dust itself.

Information requests filed by MVEIRB reviewers and the Parties raised concerns about the wetting process. There were questions about the risk of arsenic release during the wetting step and about the added difficulty that wet dust would present to any future deliberate thawing. Responses to those requests showed that the wetting presented no insurmountable obstacles; the short term risks could be managed; and methods to deliberately thaw the dust could be developed. But it is undeniable that the presence of water in the dust does increase risks, even if they are manageable.

The FOS team therefore decided to examine the option of producing "dry frozen blocks", i.e. freezing the dust without first adding water. Figure 3.3 shows an example of some of the findings to date. It provides a comparison of how a wet frozen block and a dry frozen block would respond to an extreme climate warming and no maintenance scenario, similar to that discussed in Section 2 and Figure 2.4. The comparison shows that there is virtually no difference in the amount of time needed for the 0 ^{o}C isotherm to reach the upper corner of the wet and dry frozen blocks. In both cases, the uppermost dust is predicted to begin thawing twenty years after the thermosyphons are all assumed to stop working. The implication is that the dry frozen block is as robust to this scenario as the wet frozen block.

Again these results are presented here only to illustrate an ongoing line of analysis. The robustness of dry frozen blocks in other geometries and other scenarios also needs to be investigated before this particular design change can be concluded to be an improvement.

4 Possible Design Details

Results from the FOS are proving to be a rich source of other information that will be useful during the future selection of design details. Only a few examples are provided here.

4.1 Passive, Active or Hybrid Freezing

As indicated in Figure 1.1, the FOS is testing both active and hybrid freezing systems. Figure 4.1 shows a comparison of temperatures and heat fluxes (cooling rates) measured in the Group A active system with those measured in the Group B hybrid system. The results indicate that the active freezing system achieves colder pipe temperatures and higher rates of cooling than the hybrid system.

However, this does not mean that active freezing is preferred. Another important consideration is the conversion of the initial ground freezing system to the long term system for maintaining the frozen condition. The former can be either active, passive or hybrid, but the latter must be passive. Further analysis is needed to determine whether the faster initial freezing provided by an active system makes up for the complexity and cost of the future conversion to a passive system.

4.2 Drilling Methods

A clear conclusion is evident from the testing of various drilling methods during the FOS construction. As shown in Figure 4.2, the downhole hammer drilling method out-performed the other drilling methods on all counts.

4.3 Freeze Pipe Diameter

Freeze pipe diameter is a design detail that has a strong effect on costs. Larger pipe is more expensive than smaller pipe. More importantly, drilling larger holes can be much more expensive than drilling smaller holes.

Figure 4.3 compares the various pipe sizes tested under active, passive and hybrid operating conditions. It can be seen that pipe diameter has relatively little effect on the temperatures that are reached downhole. This was most surprising for the passive and hybrid systems, which included tests with pipe diameters ranging from 4 inches to 2.5 inches. It was expected that the smaller pipes would be less effective, but happily that has not proven to be the case.

4.4 Monitoring Instruments

A variety of instruments to measure temperature, pressure, flow rates, power use and other parameters has also been tested in the FOS. Figure 4.4 summarizes the data and observations to date. This information needs to be further analysed, but will certainly be helpful in the design of instrumentation systems, both for controlling the initial freezing and for monitoring the frozen zones over the long term.

5 Next Steps

This report is being provided to assist in the environmental assessment of the project, and is not a complete engineering product. In fact, engineering will continue for many years. Some of the major steps that remain are as follows.

- Evaluation of FOS Results. The results available to July 2012 are currently undergoing detailed review by the FOS team, and a report is expected by the end of the calendar year. Further rounds of data analysis and reporting remain under consideration.
- Trade-Off Studies. Decisions about possible design improvements, such as described in Section 3, are expected to require a form of optimization known as “trade-off studies”. These studies are a normal part of the optimization process in major projects. They consist of fulsome evaluations of significant design choices, and are generally completed so that decisions with broad implications for design can be made prior to detailed engineering.
- Environmental Assessment. Results from the current environmental assessment will be reviewed for implications related to the construction, commissioning, monitoring, and long-term adaptive management of the freezing system. Those implications will be incorporated into future phases of design.
- Detailed Design. Detailed design is likely to consist of several overlapping engineering activities, possibly in two or more phases, leading to the drawings, specifications and quantity and cost estimates needed to support Treasury Board approvals and procurement.
- Water Licensing. The state of design available by the time of Water Licensing will likely include decisions about possible design improvements, as well as overall site layouts, bulk material quantities and construction needs. It is expected that some of those factors will be further modified on the basis of recommendations coming from the licensing process.
- Procurement. Procurement needs to be kept in mind as a distinct step that could significantly influence final design. It is possible that the winning bidder will have preferences for components and/or construction methods that may require changes to the “issued for tender” designs.
- Construction, Installation and Commissioning. Significant design changes become much less likely once the project enters construction. However, minor changes will continue throughout construction, installation and commissioning. Again, these changes are a normal and healthy part of all major projects.
- Monitoring and Adaptive Management. Other members of the Giant Mine Project Team are working with the Parties on developing an environmental management system that will include monitoring and adaptive management of the freezing system over the long term. Contributions from that group will certainly inform design of the monitoring and data management system. They may also define mitigation measures that will need to be incorporated in long-term operating plans.

This report, "**Freeze Optimization Study Update for MVEIRB and Parties**", has been prepared by SRK Consulting (Canada) Inc.

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All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

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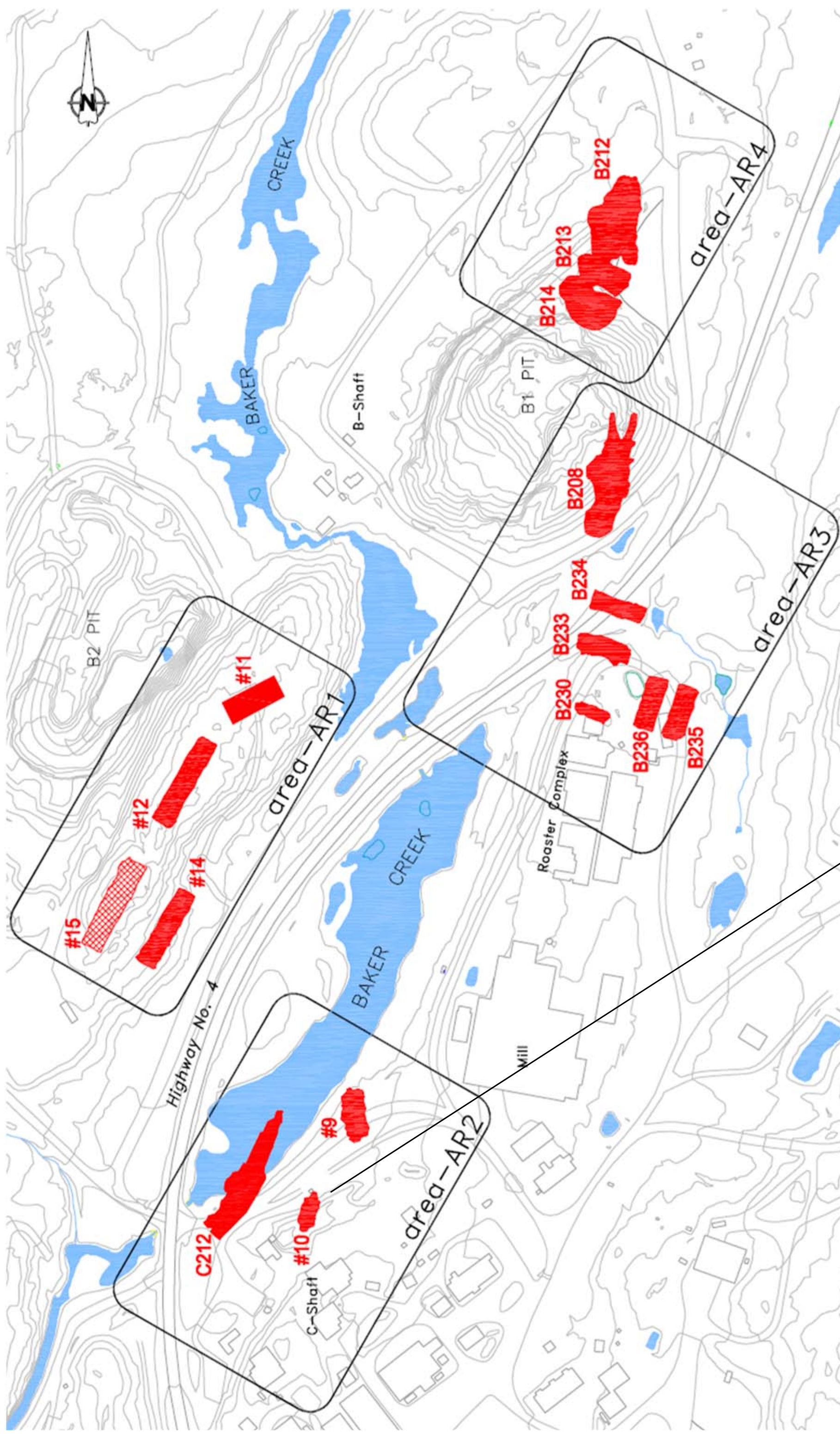
Figures

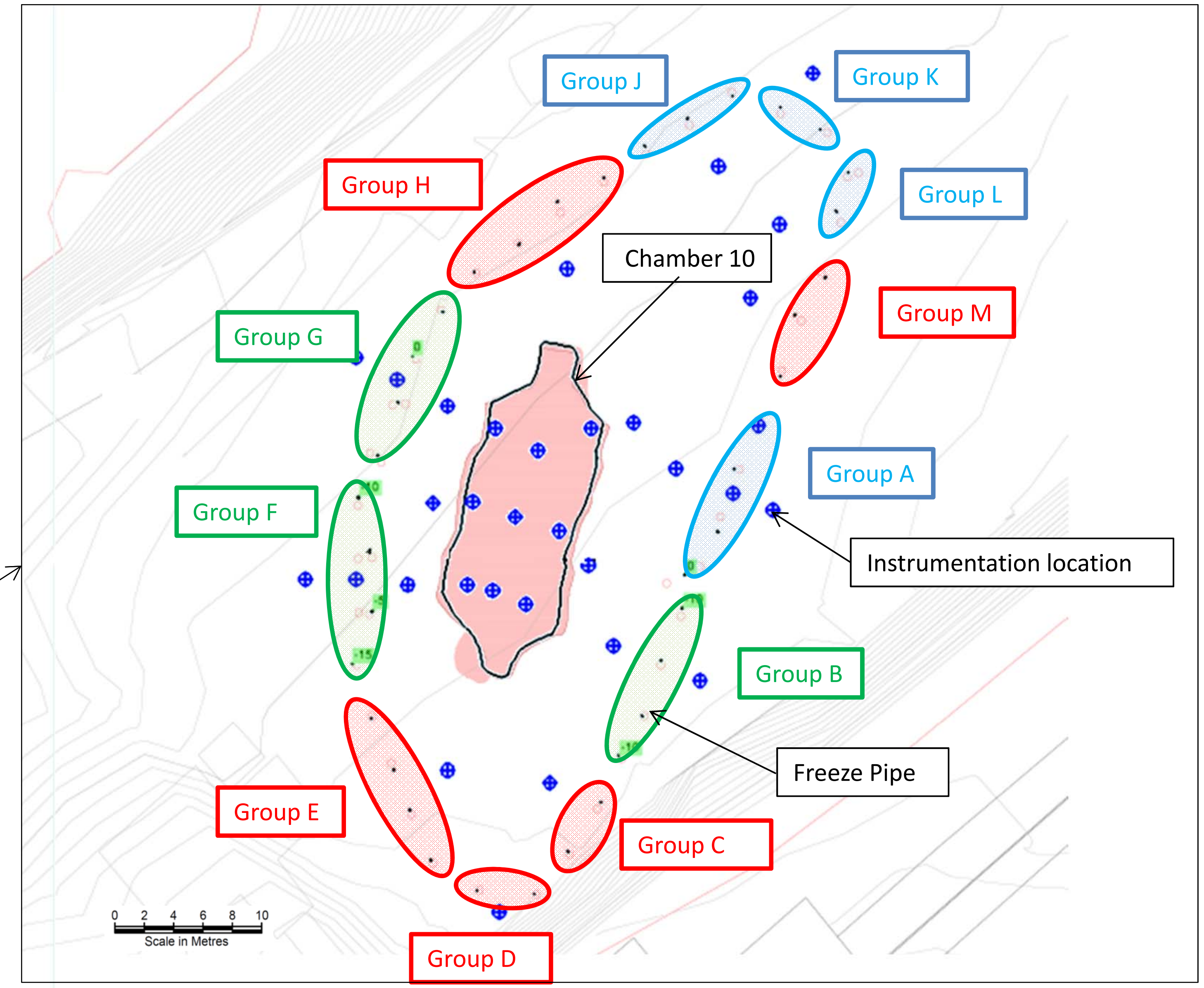


LEGEND

CHAMBER OR STOPE CONTAINING ARSENIC TRIOXIDE DUST (Vertical Projection)

EMPTY CHAMBER (Vertical Projection)

SITE PLAN



FOS STUDY AREA LAYOUT

Group	Freeze Technology	No. of Pipes	Freeze Pipe Size	Configuration
Group A	Active	4	4.5" (114 mm)	Two serial pairs connected in parallel
Group B	Hybrid Thermosyphon	4	3.0" (3.0 mm)	
Group C	Active	2	3.0" (78 mm) inside 4.5" (114 mm)	Parallel connections
Group D	Active	2	4.5" (114 mm)	Parallel connections
Group E	Active	4	4.5" (114 mm)	Parallel connections
Group F	Hybrid Thermosyphon	4	4.0" (100 mm)	
Group G	Hybrid Thermosyphon	4	2.5" (65 mm) inside 4.5" (114 mm)	
Group H	Active	4	4.5" (114 mm)	Parallel connections
Group J	Active	3	4.5" (114 mm)	All pipes connected in serial
Group K	Active	2	4.5" (114 mm)	All pipes connected in serial
Group L	Active	2	4.5" (114 mm)	All pipes connected in serial
Group M	Active	3	3.0" (78 mm) inside 4.5" (114 mm)	Parallel connections
Underground	Active	15	3.0" (78 mm)	Parallel connections

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FOS Update for MVEIRB and Parties

Study Area Layout

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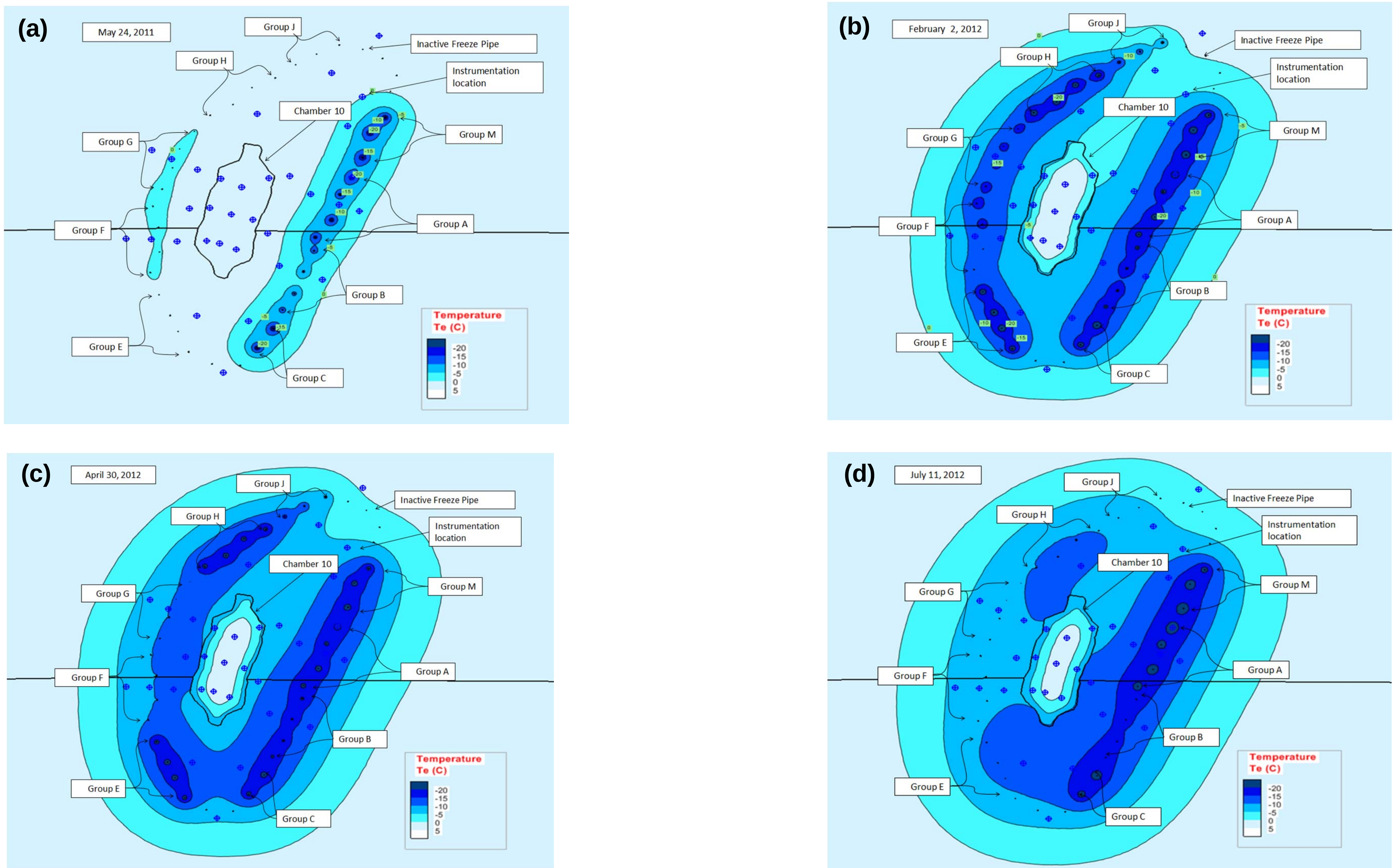
Giant Mine

Date: August 2012 | Approved: DH | Figure: 1.1



Ground temperatures around Chamber 10 at key times during the FOS. Each plot represents a horizontal section located approximately mid-height of the chamber.

(a) May 2011, just prior to conversion of Groups F and G from passive to active mode and activation of Groups E and H.
(b) February 2012, just prior to conversion of Groups F and G to passive operation
(c) April 30, 2012 just prior to deactivation of Groups E, F, and G .
(d) Conditions on the most recently completed data compilation in July 2012.

File Source: Temperature Contours: DailyPipeTempJuly2012.svm (SVHeat)

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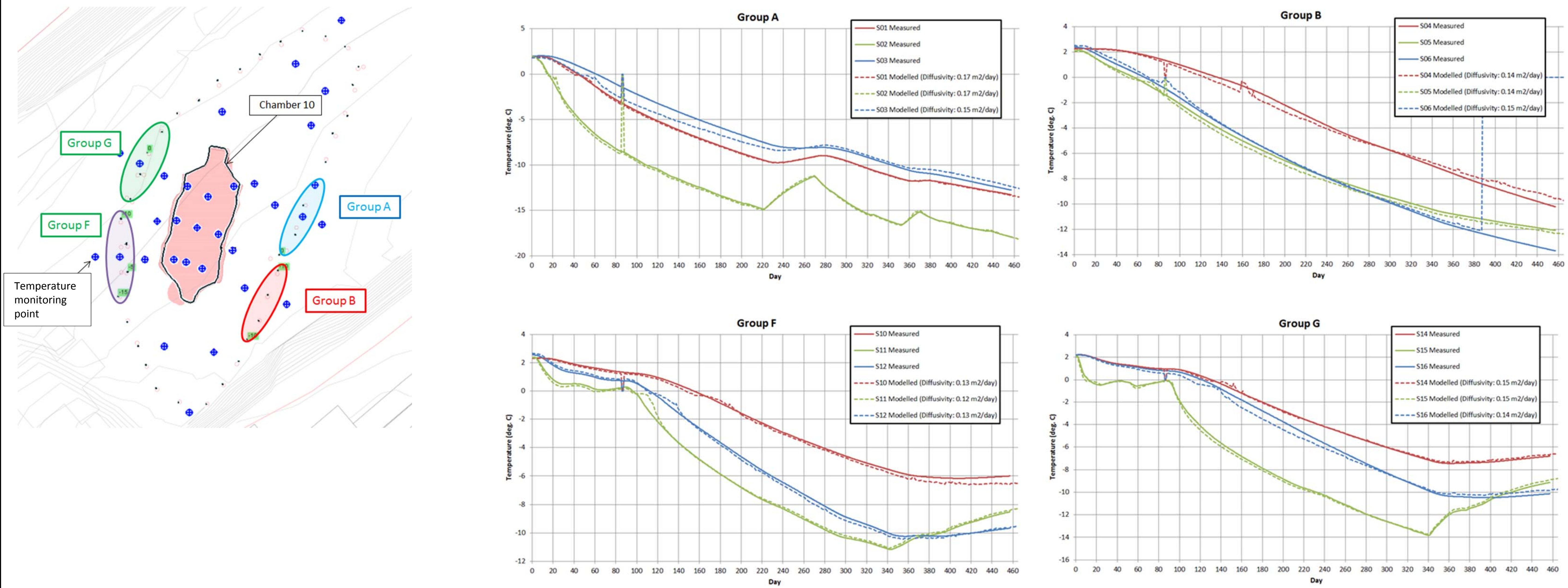
		Freeze Progress to July 2012
Job No: 1CI001.026.002 Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx	Giant Mine	Date: August 2012 · Approved: DH · Figure: **1.2**



Results of the thermal model calibration for temperature sensors located near Groups A, B, F and G with comparisons to the measured ground temperatures. For each sensor, the bedrock thermal diffusivity that provided the best match is noted.

The thermal diffusivity is the ratio of thermal conductivity to heat capacity. The higher the thermal diffusivity, the faster heat is transferred through the material. The bedrock diffusivity is generally higher than anticipated at the start of the study.

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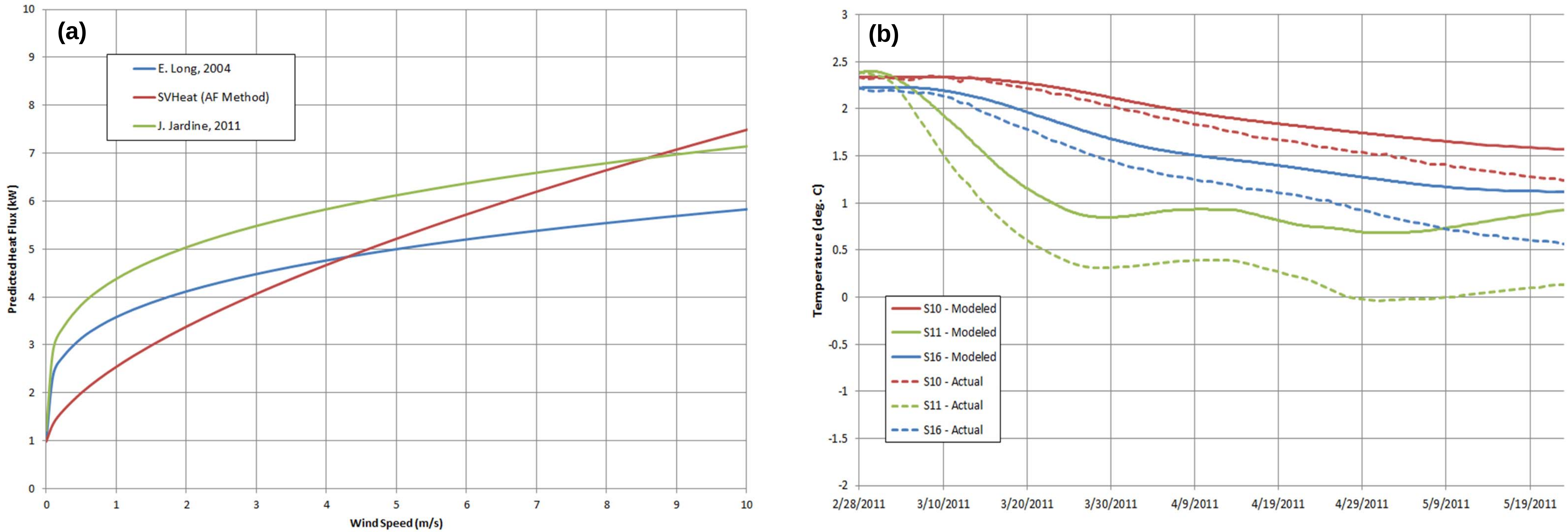
		Bedrock Thermal Property Calibration
Job No: 1CI001.026.002 Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx	Giant Mine	Date: August 2012 / Approved: DH / Figure: 2.1



Example results from calibration of the thermosyphon performance equations:

(a) Heat flux rates (heat extraction) as a function of wind speeds for different equations found in literature and supplied by the thermosyphon manufacturer. The plot assumes air and ground temperatures of -10 °C and 0 °C, respectively.

(b) Comparison of predicted to actual temperatures. Actual temperatures are from sensors located near hybrid thermosyphon Group F during a period of passive operation. Predicted temperatures were obtained using the J. Jardine (2011) equation. The predicted temperatures are higher than the actual temperatures indicating that the passive thermosyphon performance is better than predicted. The 2011 equation conservatively underestimates thermosyphon heat removal by about 10%.

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		Passive Thermosyphon Performance
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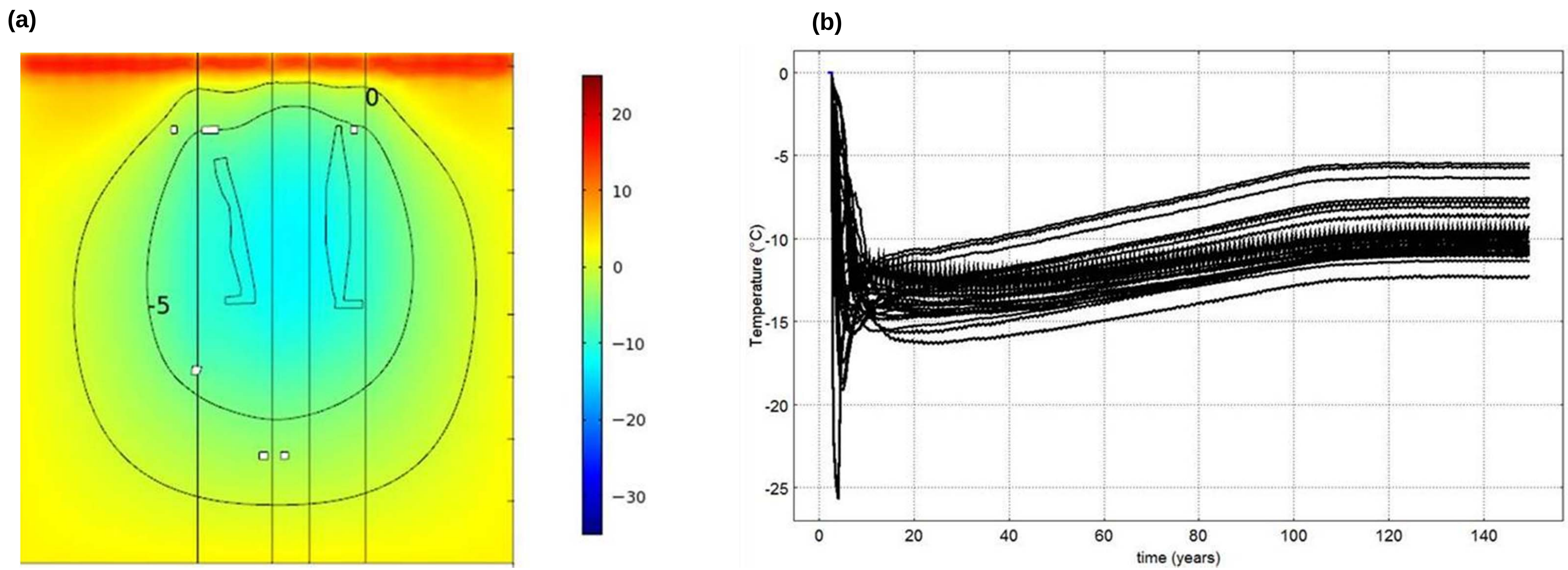

Long-term predictions using parameter estimates updated with FOS results. Both plots show results from simulations of Chamber 10 and Stope C212, and assume five years of active freezing followed by a worst case mean annual temperature increase of 6.1 ^{o}C over 100 years:

(a) Temperature contours at Chamber C10 and C212,, showing that the thermosyphons maintain frozen conditions around the dust over the long term.

(b) Temperatures at various points along the chamber and stope walls. All temperatures remain below -5 °C.

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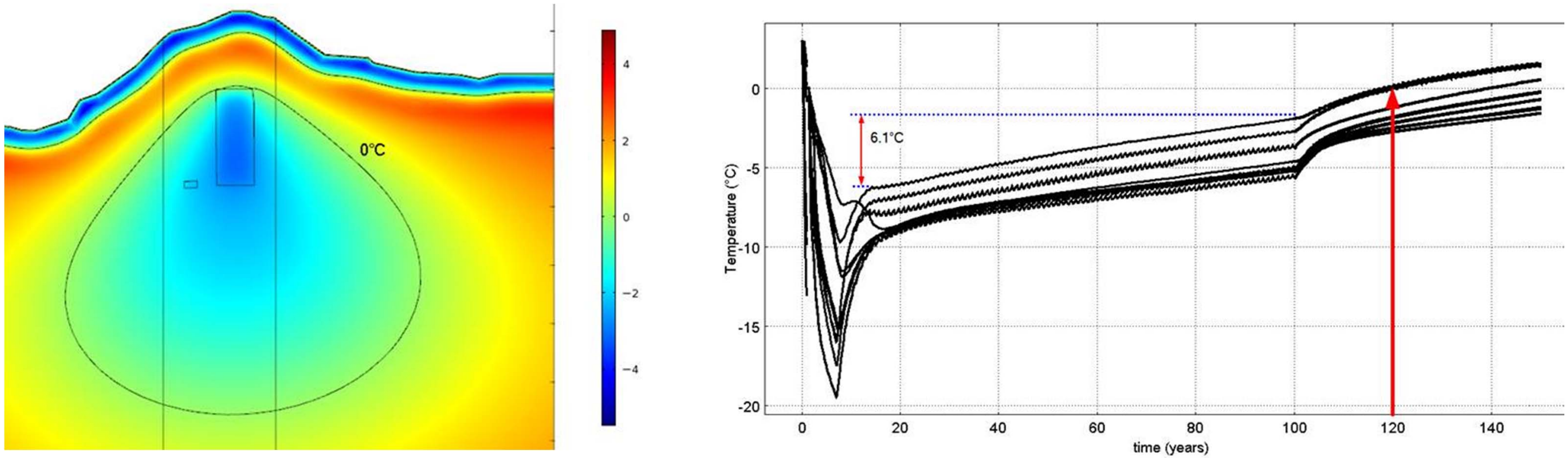
Job No: 1CI001.026.002 Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx	Giant Mine	Date: August 2012 · Approved: DH · Figure: **2.3**

(a) (b)



Updated prediction of thawing around Chamber 12 in the hypothetical scenario where all thermosyphons cease operating in Year 100. The predictions also assume extreme climate warming of 6.1 ^{o}C over 100 years:

(a) Temperature contours 20 years after the thermosyphons stop operating, showing the 0^{o}C isotherm just touching the upper corners of the chamber. The plot also shows how heat enters the ground through the pit wall on the left. Chambers and stopes below more level ground show much slower warming.

(b) Temperatures at various points on the chamber wall. Note that deeper parts of the chamber remain frozen for past then end of the simulation period.

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FOS Update for MVEIRB and Parties

Updated Prediction of Thawing in Long-Term Worst Case

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Giant Mine

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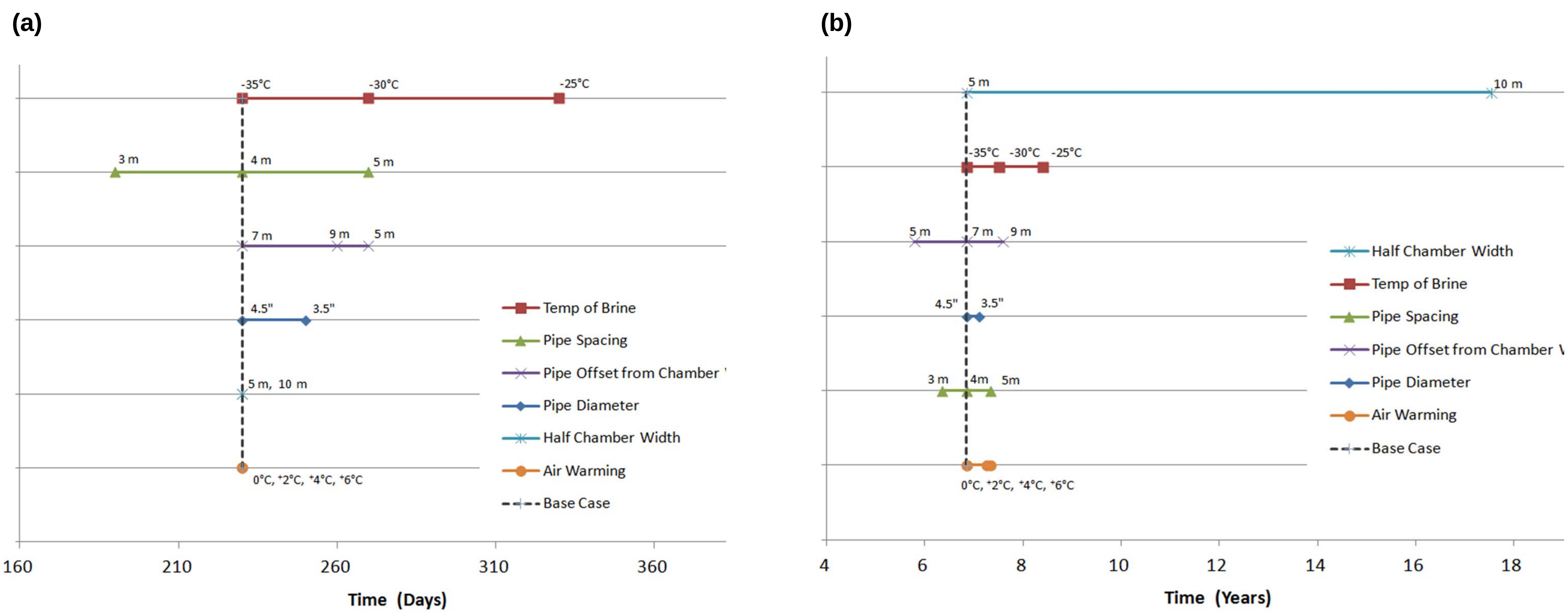
Figure: 2.4



Sensitivity of initial freezing times to design choices. Both plots assume two years of active freezing followed by conversion to passive thermosyphons. The plots are "tornado diagrams" showing the effect of various design parameters on:

(a) Time to achieve a complete frozen wall, -10 ^{o}C or colder over a width of 10 m, all around the sides and bottom of a chamber or stope,

(b) Time for the dust within the frozen zone to reach -5 ^{o}C or colder.

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FOS Update for MVEIRB and Parties

Possible Design Improvements - Initial Freezing

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Giant Mine

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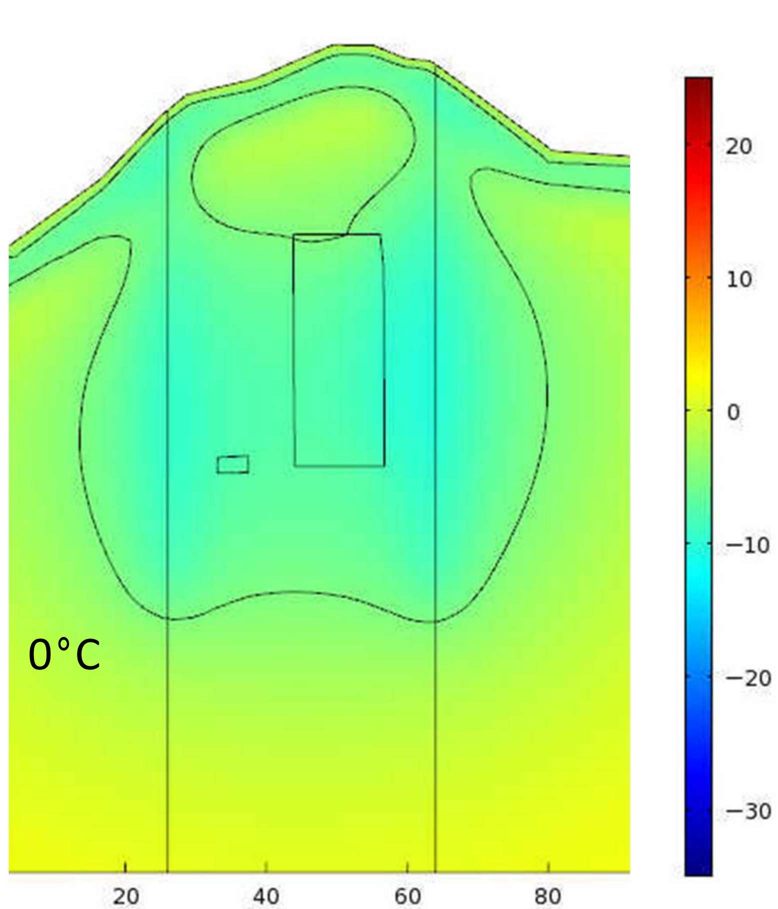
(a)



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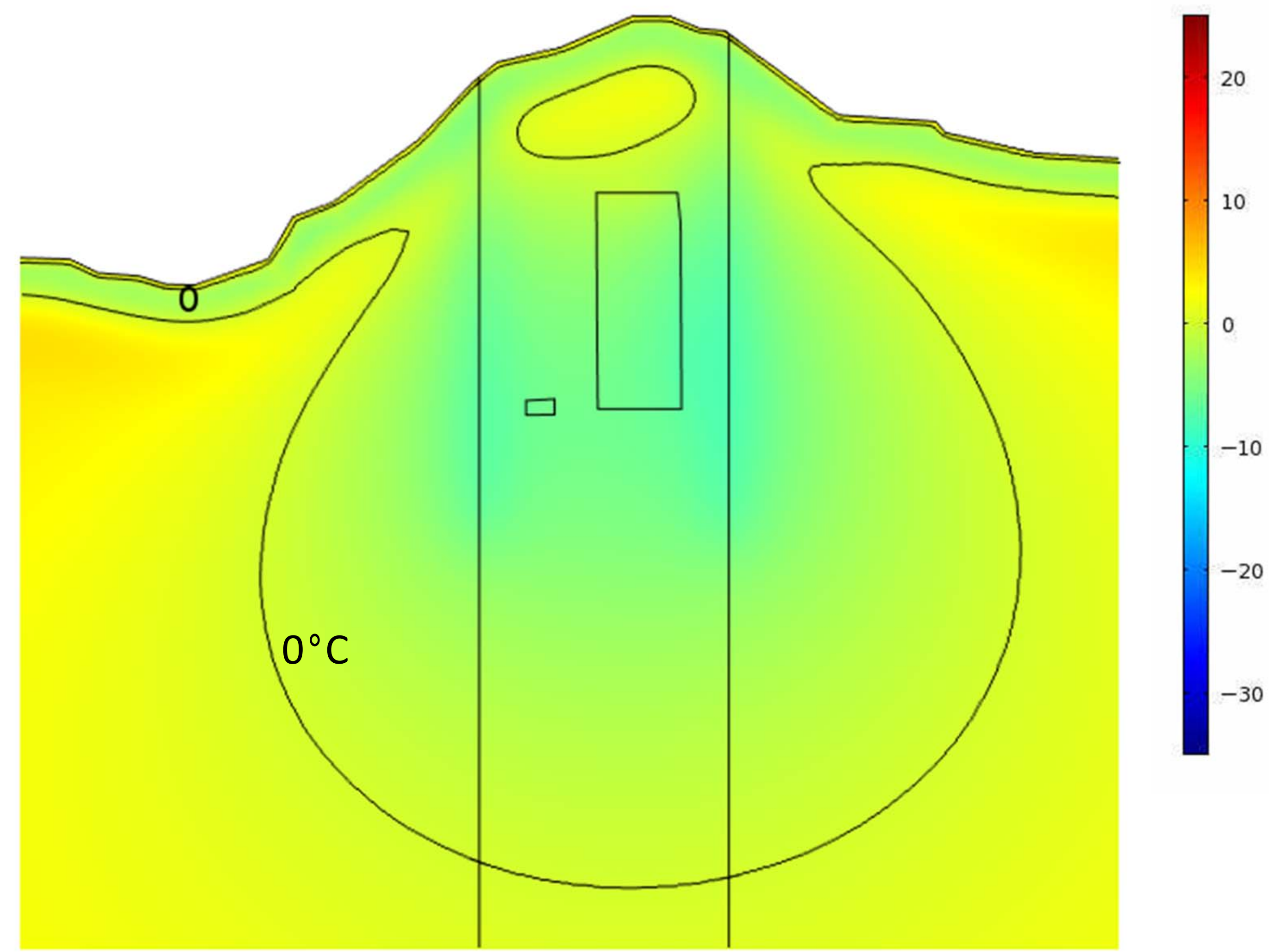

Example showing the development of a large frozen zone below a chamber, even without the use of horizontal freeze pipes. The case shown assumes passive freezing only, and with only vertical freeze pipes installed from surface:

(a) After five years of passive freezing

(b) After 100 years of passive freezing

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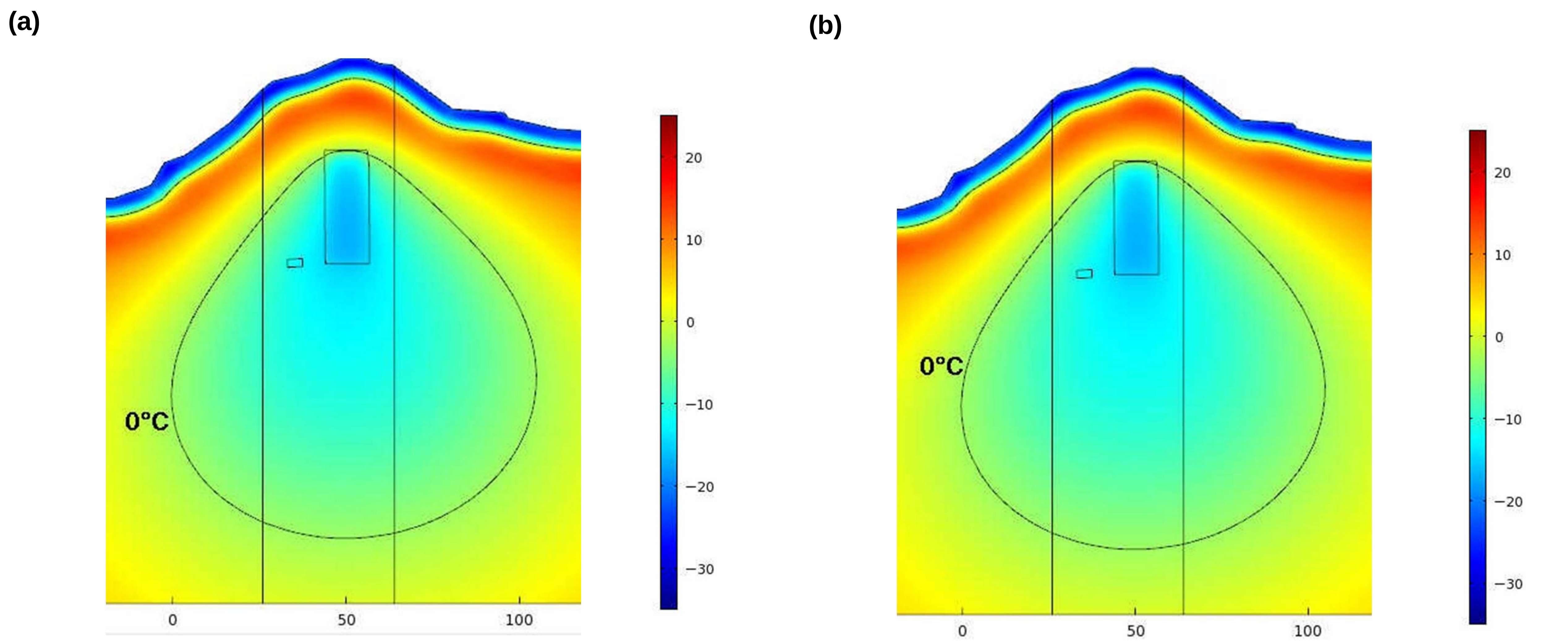
		Possible Design Improvements – No Horizontal Freeze Pipes
Job No: 1CI001.026.002 Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx	Giant Mine	Date: August 2012 · Approved: DH · Figure: **3.2**



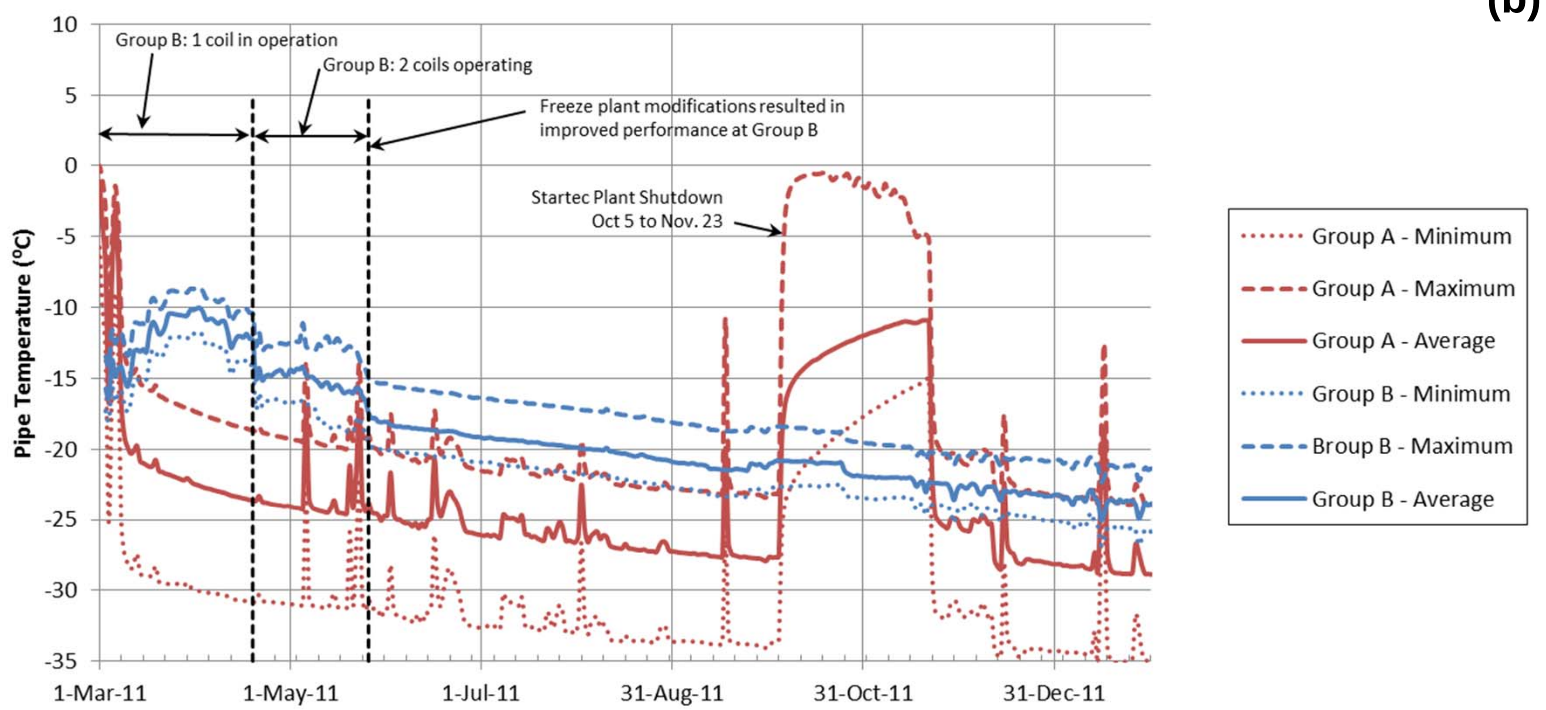
Comparison of progress of thawing under extreme climate warming of 6.1 ^{o}C , and after twenty years with all thermosyphons out of operation:

(a) Wet frozen block, i.e. with water added to the dust prior to freezing as described in the DAR,

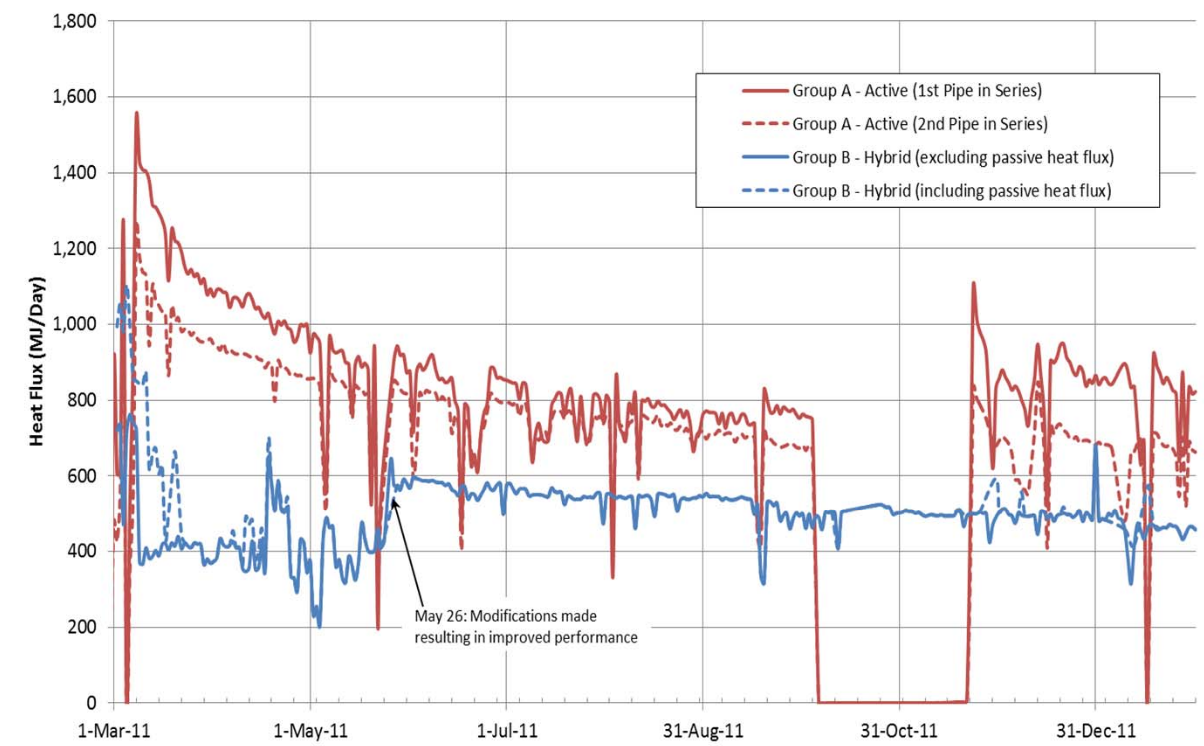
(b) Dry frozen block, i.e. without water addition.

srk consulting	Aboriginal Affairs and Northern Development Canada	FOS Update for MVEIRB and Parties **Possible Design Improvements - Dry Frozen Blocks**
Job No: 1CI001.026.002 Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx	Giant Mine	Date: August 2012 · Approved: DH · Figure: 3.3

(a)



(b)



Comparison of Group A (active freezing) and Group B (hybrid freezing) for the first year of the FOS:

(a) Pipe temperatures . Group A has a larger range of pipe temperatures as the pipes are connected in series of two (the coolant is warmer as it passes through the second freeze pipe resulting in warmer pipe temperatures). Adjustments made to the hybrid freeze plant on May 26, 2012 resulted in improved performance. But pipe temperatures for the active freeze group are generally 5 to 10 °C colder than those of the hybrid freeze group.

(b) Heat fluxes (cooling rates). The active freezing heat flux was typically 40% higher compared to hybrid freezing when both technologies were operated optimally. The first and second pipes in a series are plotted to show the range of values. The effect of passive heat flux can be seen March 2011 when air temperatures were cold and ground temperatures were still warm.

File Source: Figures.FreezeTechComparison.1CI001.026.rev02.xlsx

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Comparison of Freeze Technologies

Job No: 1CI001.026.002
Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx

Giant Mine

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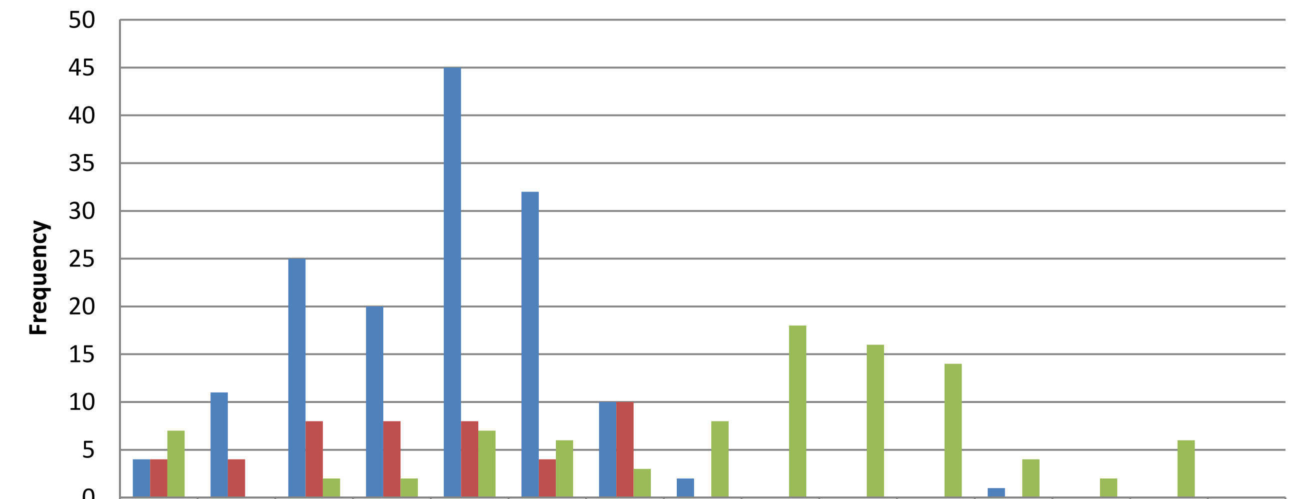
(a)

Drilling Method	Symbol	Number of Holes	Average Deviation (m)
Downhole Hammer Drill	DHH	47	0.6
Diamond Drill	DDH	11	0.8
Mud Rotary Drill	MR	8	1.8
Steerable Mud Rotary Drill	MR	23	0.8

(b)



	0 to 5m	5.1 to 10m	10.1 to 15m	15.1 to 20m	20.1 to 25m	25.1 to 30m	30.1 to 35m	35.1 to 40m	40.1 to 45m	45.1 to 50m	50.1 to 55m	55.1 to 60m	60.1 to 65m	65.1 to 70m	>70m
MR	4	11	25	20	45	32	10	2	0	0	0	1	0	0	0
DDH	4	4	8	8	8	4	10	0	0	0	0	0	0	0	0
DHH	7	0	2	2	7	6	3	8	18	16	14	4	2	6	0

Comparison of the three types of drill rigs that were used during the construction of the FOS,
Downhole Hammer Drill (DHH), Diamond Drill (DD), and Mud Rotary Drill (MR):

(a) Drilling accuracy. A steerable drilling attachment was added to the mud rotary drill after completing eight holes to improve performance. The downhole hammer drill was found to be the most accurate with an average deviation of 0.6 m compared to 0.8 m for both the diamond drill and mud rotary drill with the steering attachment.

(a) Productivity. The downhole hammer was the most efficient drill with an average of over 40 m drilled per shift, compared to about 20 m per shift for both the diamond and mud rotary drills.

File Source: FOS_AsBuilt_Report_1CS009.012_DEH_20100825_FNL.docx

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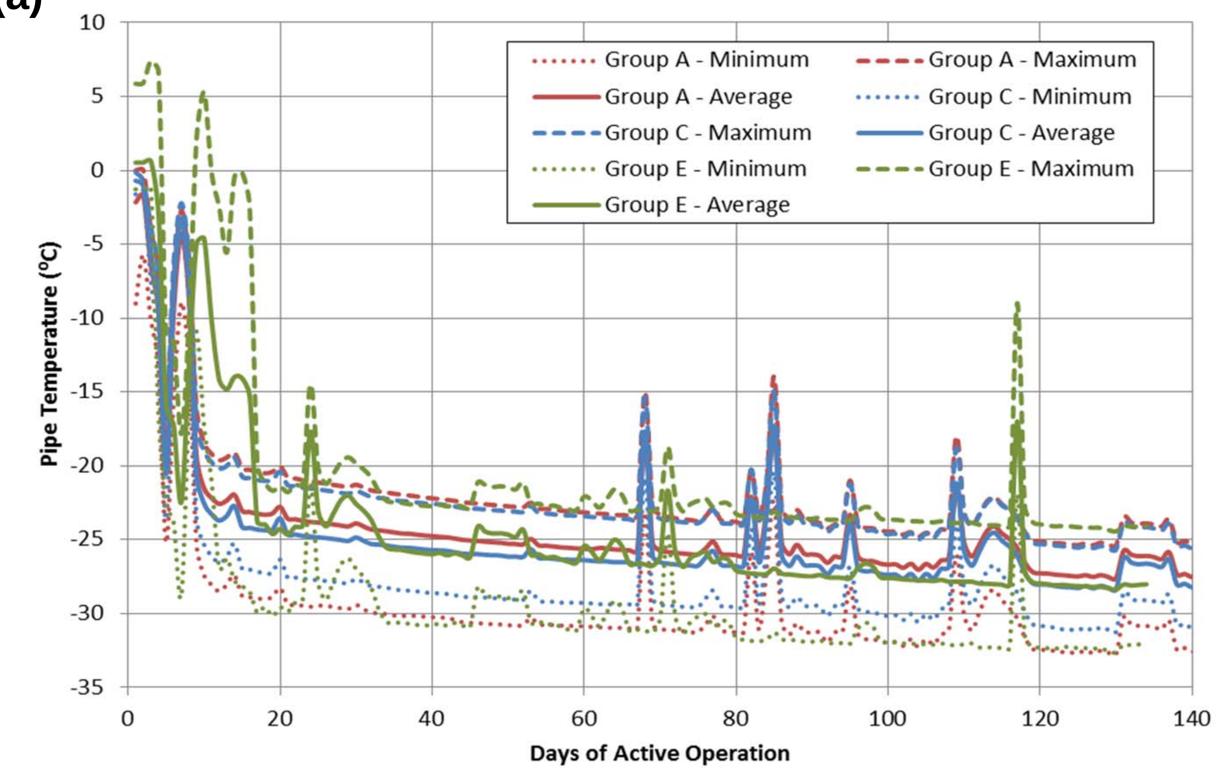
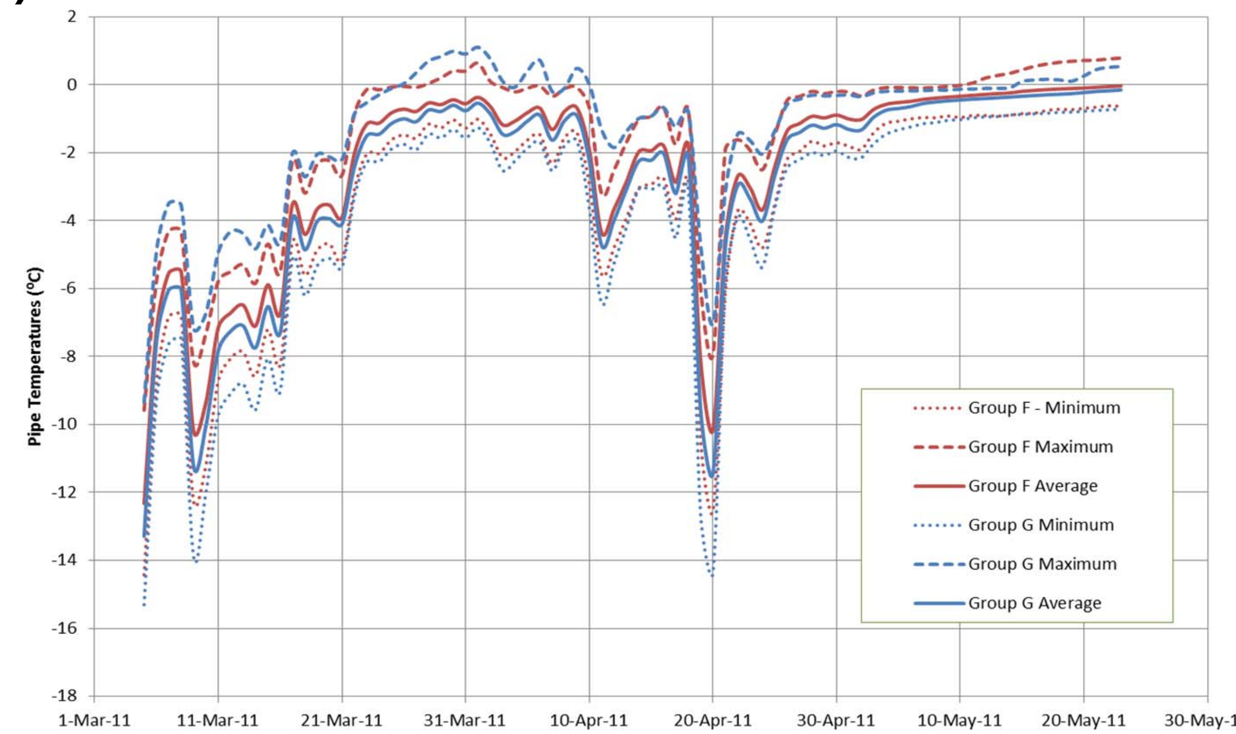
Job No: 1CI001.026.002 Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx	Giant Mine	Date: August 2012 / Approved: DH / Figure: 4.2

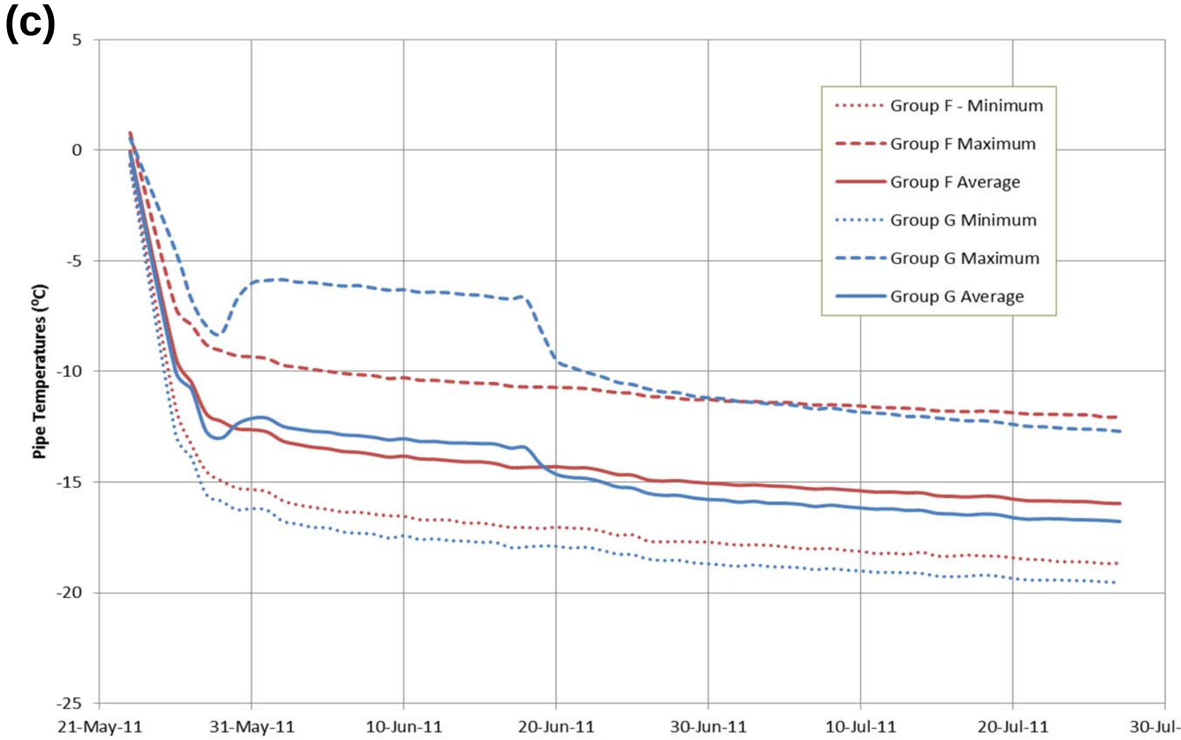
(a)



(b)



(c)



Effect of freeze pipe diameter for:

(a) Active freezing, comparing temperatures of 4-inch diameter Groups A and E with 3-inch diameter pipes at Group C

(b) Passive operation of hybrid thermosyphons, comparing 4-inch diameter pipes at Group F with 2.5-inch diameter pipes at Group G

(c) Active operation of hybrid thermosyphons, sizes as in (b).

Each graph plots the average, maximum and minimum pipe temperatures recorded by all pipe temperature sensors.

File Sources: Fig_PipeSize.1CI001.026.rev00.pm.xlsx
FiguresSection8.4.FOS.1CI001.026.rev00.xlsx

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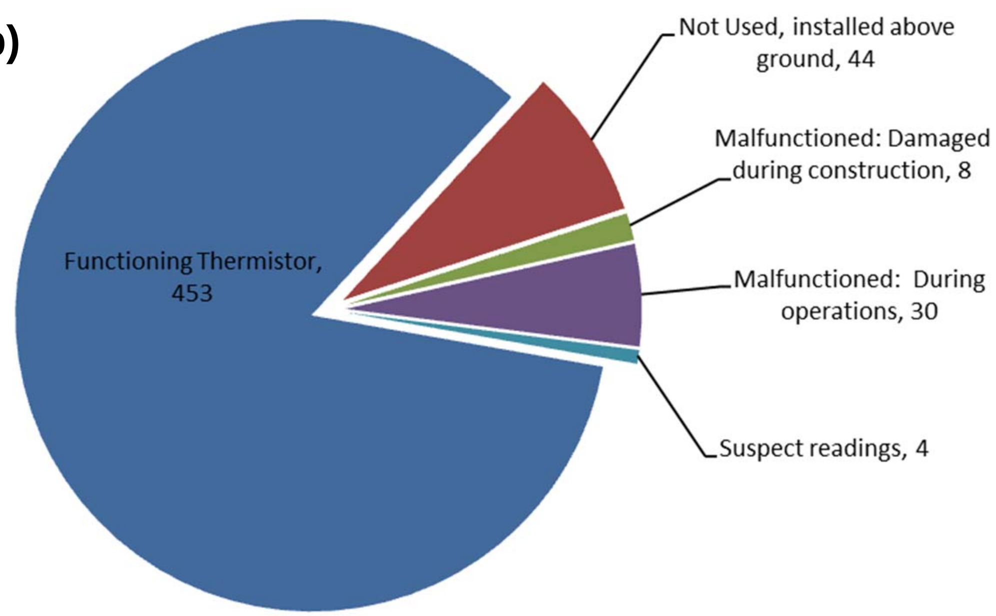
		Comparison of Freeze Pipe Diameters
Job No: 1CI001.026.002 Filename: FOSUpdateMVEIRB.Fig.1CI001.026.rev0.pm.pptx	Giant Mine	Date: August 2012 / Approved: DH / Figure: **4.3**

(a)

Instrument Type	Quantity Used in Study	Description	Instrumentation Issues
Vibrating wire piezometers	20	The piezometers measure water levels inside of Chamber 10. There is currently no pooled water detected by the piezometers.	None.
Flow meters – Active system	41	The flow meters measure the flow rate of Dynalene coolant through each freeze pipe, distribution loop, and total flow through the freeze plant. The flow rates are required for heat flux calculations.	None.
Flow meters – Hybrid thermosyphons	24	For each hybrid thermosyphon, two mass flow meters are installed to measure flow rates. The flow rates are required for heat flux calculations.	The mass flow meters have malfunctioned on three occasions providing erroneous readings. On each occasion, the unit was replaced with a spare and repaired off-site.
Resistance temperature sensors (RTDs)	128	The RTDs are used to measure pipe/fluid temperatures on surface. 6 are installed on each thermosyphon, 2 on each active freeze pipe, and 4 at the active freeze plant. The temperatures are required for heat flux calculations.	Since the start of the study, 1 sensor has malfunctioned.
Thermistor temperature sensors	539	Thermistors are used to measure underground temperatures and are grouted inside boreholes and along freeze pipes throughout the study. The thermistors are used to monitor freeze progress and calibrate material properties.	See (B).
Power meters	3	Power meters are present at both freeze plants to monitor power consumption and calculate plant efficiency. There are two meters at the active freeze plant, and one meter at the hybrid freeze plant.	One of the power meters at the active freeze plant malfunctioned due to a power surge originating from off-site.
Weather Station	1	A weather station is on site that monitors: air temperature, relative humidity, wind speed and wind direction. The data is required for calculation of passive heat flux from the thermosyphons.	None.

(b)



The FOS contains a large amount of instrumentation to monitor the freeze progress and support calculations of heat extraction rates and efficiencies.

(a) Summary of the instrument types and issues since the start of the study.

(b) Assessment of the thermistor sensors used to measure temperatures underground. Since the start of ground freezing 6% of the functioning thermistors have failed.

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Monitoring Instrumentation

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