Golder Associates

# TECHNICAL MEMORANDUM

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| **DATE** | December 20, 2011 | **PROJECT No.** | 09-1427-0006/6000/6100 |
| **TO** | Robert Girvan, Mark Cronk, Dave Bynski, and Dave Colbourne PWGSC | **AECOM DOC. No.** | 313-UG-13-MEM-0013-Rev1_20111220 |
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**INVESTIGATION, MITIGATION, AND MONITORING OF KNOWN HIGH RISK UNDERGROUND OPENINGS, GIANT MINE REMEDIATION PROJECT**

## 1.0 INTRODUCTION, STABILITY OF ARSENIC STOPES

Public Works and Government Services Canada (PWGSC) has asked Golder Associates Ltd. (Golder) to develop conceptual mitigation plans for known high risk underground items at the Giant Mine Remediation Project (GMRP).

This memo outlines a preliminary assessment of the underground work required to evaluate and execute mitigation of the known high risk underground features. It is a working discussion document and not set out as a comprehensive work plan or a proposal. It was developed for PWGSC to assist them in developing a scope and planning for the advanced remediation program and is to develop possible terms of reference (TOR) documents and scope of work documents for both drilling contractors and geotechnical engineers who would perform the work outlined.

The following high risk items associated with the underground are identified in the INAC Giant Mine Remediation Project Risk Management Report (termed the risk register), dated 2011-01-28.

**Risk 5.1.1 Bulkhead or Lower Crown Pillar Failure Leads to Large Scale Release of Arsenic Trioxide into Underground**

| Consequence | Severity | Likelihood | Risk |
|---|---|---|---|
| Community / Media / Reputation | Major | Unlikely | Moderately High |
| Consequence Costs | Critical | Unlikely | Moderately High |
| Human Health & Safety | Critical | Unlikely | Moderately High |

Note: Golder recommend that this risk be upgraded to High as described later.

**Risk 5.2.2 B208 and B212-B213-B214 Crown Pillar Collapse Leads to Release of Arsenic Trioxide Dust to Environment**

| Consequence | Severity | Likelihood | Risk |
|---|---|---|---|
| Community / Media / Reputation | Major | Possible | High |
| Environmental Impact | Minor | Possible | Moderate |
| Consequence Costs | Major | Possible | High |
| Human Health & Safety | Moderate | Possible | Moderately High |
| Legal Obligation | Moderate | Possible | Moderately High |

**Risk 5.2.3 Crown Pillar Rapidly Collapses through to Ground Surface Near the Highway or Baker Creek Resulting in a Fatality**

| Consequence | Severity | Likelihood | Risk |
|---|---|---|---|
| Human Health & Safety | Major | Possible | High |

**Risk 5.11.1 Continued Movement of Fill and Ravelling Leads to Instability of Pillar Underneath AR2 Arsenic Chambers**

| Consequence | Severity | Likelihood | Risk |
|---|---|---|---|
| Community / Media / Reputation | Moderate | Possible | Moderately High |
| Consequence Costs | Major | Possible | High |

Subsequent to development of the latest version of the project risk register, Golder reviewed and updated the previous arsenic stope and chamber stability assessments and summarised the findings in the following draft report: *Golder Associates Ltd. document 090, AECOM 313-UG-13-RPT-0004-Rev0_20110727, Review of Arsenic Stope and Chamber Stability Assessments, Aug 6, 2011.*

The conclusion in thereport generally concurred with conclusions regarding the stability of arsenic stopes and chambers outlined in previous reports which were used to develop the risk register items outlined above. Golder concluded that the likelihood of collapse of the sill pillar below arsenic Stope B2-08 was possible, and Risk 2.1.1 should be changed to High.

The arsenic chambers/stopes are currently assessed to be stable but some are in a state that suggest prudence is required due to inherent uncertainty related to the complex geometry of the mine workings, the heterogeneous nature of the rock, and time-dependant changes to the rock mass that could degrade stability. Additionally, the arsenic stopes and chambers will be subjected to changing conditions during wetting and freezing and this needs to be taken into account when assessing which areas might require mitigation. For example local rock wedges could be frost-jacked off the walls of the arsenic stopes and this could further degrade stability. B1 pit will need to be backfilled prior to freeze pipe installation and the fill will place additional loading onto the crown pillars of arsenic Stope B2-08 and B2-12/13/14.

Golder made the following recommendations to PWGSC regarding worker and public health and safety regarding the risks posed by the first three openings outlined in Table 1.1.

- Mining staff should refrain from entering non-arsenic Stope B3-06 until the situation is better understood. This includes the lack of ground support in the back and upper walls and the potential for the fill to drop since it was mined from below and arching may be present.
- Vehicle access above arsenic Stope B2-12/13/14 should be restricted until additional investigations, analysis and monitoring is carried out. Placement of appropriate signage and communication with mine staff regarding this hazard should be considered.
- Vehicle access above arsenic Stope B2-08 should be restricted until additional investigations, analysis and monitoring is carried out. Placement of appropriate signage and communication with mine staff regarding this hazard should be considered. Additionally, a fence to limit public access between Highway 4 and the area above arsenic Stope B2-08 should be put in place.

Golder' GMRP report 090 suggested specific underground openings required further investigation, monitoring, and possible mitigation (meaning prior to the start of the freeze remediation) as outlined in Table 1.1 in order of relative probability of failure.

**Table 1.1: Summary of Stability Concerns Associated with Arsenic Stopes and Chambers**

| Opening | Potential Impact of Failure | INAC Possibility or Likelihood | Comments |
|---|---|---|---|
| **Arsenic Stope B2-08 / underlying Non-arsenic Stope B3-06 Sill Pillar** | Release of arsenic dust locally into the adjacent openings. | ***Possible*** | Situation not well understood and needs additional investigation. Release of dust into B3-06 could possibly be partly contained on 3rd level. |
| **Arsenic Stope B21-12/13/14 Crown Pillar** | Impact B1 open pit and surface with release of dust to environment. | ***Possible*** | Some unconfirmed evidence of surface impact of crown pillar movement exists. Possibly some evidence of ground movement on upper arsenic drift but not confirmed. |
| **Arsenic Stope B2-08 Crown Pillar** | Impact B1 open pit and surface with release of dust to environment. | ***Possible*** | No strong evidence for movement underground or on surface noted. |
| **Arsenic Stope B2-12/13/14, Adjacent Non-arsenic Stope 2-02 Rib Pillar** | Release of arsenic dust locally underground into the adjacent openings. | ***Possible*** | The assessment of probability of failure includes the assumption that pillars shown on mine plans are stable and the stope is partially backfilled. But this has not been investigated and the situation could be worse. There is some evidence of block movement in the rib pillar in non-arsenic Stope 2-02. Release of dust into 2-02 stope could possibly be partly contained on 3rd level but it would likely move deeper into the mine. |
| **C5-09 back, Adjacent to and below Arsenic Stope C2-12 and Arsenic Chamber B9** | If failure large and sudden, could impact arsenic Chamber B9 and arsenic Stope C2-12. | ***Possible*** | Failure would likely develop slowly enough that it could be halted with backfilling prior to impacting arsenic Stope C2-12 or arsenic Chamber B9. |

The presence of inaccessible bulkheads that cannot be inspected or monitored adds uncertainty to the project as addressed in Risk 5.1.1. Risks cannot be assessed reliably. Water pressure monitoring is carried out in arsenic Stope C2-12 but the bulkheads and any leakage past them cannot be assessed.

Other possible risks associated with collapse of near surface non-arsenic stopes that could impact critical surface elements such as Bake Creek or Highway 4 are currently under analyse and further investigation. This work will provide further clarity on Risk 5.2.3.

## 2.0 MITIGATION REQUIREMENTS

The INAC guidance on mitigation and monitoring requirements states that High risk items should be a priority to mitigate within 2 years. Given that the overall remediation project schedule is not well defined and is dependent on the current environmental assessment process preparations for mitigation of high risk items must begin independently of the overall project. A preliminary list of work required to prepare the underground for the mitigation is outlined below.

- Develop an emergency response plan in the event that key pillars associated with arsenic stopes are measured or observed to be moving or de-stabilising.
- Integrate the remaining historical mine geometry information into the existing 3d model. Further collection and recording of anecdotal information regarding mine geometry and rock stability should be included in this work while personnel with underground experience are involved in the project.
- Design and execute geotechnical investigations, underground surveys, and laboratory testing on typical arsenic dust and rock core in high risk areas.
- Determine the best approach to stabilising the arsenic crown pillars.
- Develop a monitoring plan that provides information on the behaviour of the openings in question to assess worker safety and mitigation design and planning purposes.
- Re-establish or maintain critical underground mine infrastructure to areas where work is required.
- Excavate new underground development.
- Construct new arsenic drift plugs to replace existing lower arsenic drift bulkheads.
- Develop of a cemented tailings paste backfilling system.
- Backfill lower arsenic drifts.
- Tight backfill the arsenic stope and non-arsenic stope voids in question.

Additional detail on the investigations required is outlined below.

It is recommended that safe access to the inaccessible bulkheads in place in lower arsenic drifts attached to arsenic Stopes B2-12/13/14, B2-08, and C2-12 be developed and the drift plugs installed prior to any backfill being placed in the arsenic stopes.

## 3.0 INVESTIGATION

Investigations are required to further define opening geometry and rock mass geotechnical parameters to a level required to develop detailed mitigation designs and monitoring programs. Although additional investigation of the arsenic stope crown pillars could improve confidence in the assessment of the probability of failure of a specific arsenic stope pillar, it is not likely to lead to a more favourable assessment of stability.

There will be overlap between drilling required for investigation and that required for future monitoring requirements. Some boreholes required for investigation may prove suitable for monitoring and some boreholes required for monitoring will improve and expand the understanding of the geometry of the mine openings and the engineering properties of the rock mass.

A combination of geophysical survey and simple percussive surface drilling (*e.g.,* an air-track drill) surveys to delineate the overburden / bedrock contact would improve confidence in the existing stability assessment and provide valuable information for future design work. It is anticipated that a combination of radar, electrical resistivity, or light seismic (*e.g.,* sledgehammer source) geophysical techniques would prove sufficient.

Diamond drilling investigations required to develop detailed mitigation designs and to satisfy monitoring requirements are outlined in Table 2.1 and are discussed in more detail later. It may be possible to carry out some of these investigations in boreholes drilled previously (now grouted) for similar purposes. It may also be possible to carry out cavity monitoring surveys through the existing upper arsenic stope inspection hatches.

In some cases it may be optimal to drill the boreholes from underground but rehabilitation must be compete and mine services must be accessible. Additional discussion with the care and maintenance contractor is required.

Great care must be taken during investigations anywhere near an arsenic stope or chamber as the bulkhead performance criteria cannot be confirmed.

Note that most cavity monitoring survey systems are not reliable in cold weather and surveys will either need to be delayed until spring or a warm shelter built over the collars of the borehole. If there is to be a delay between drilling the boreholes and carrying out the surveys, a surface casing must be left in place and a tamper proof lockable cover installed.

HQ-3 sized (96 mm hole), triple-tube diamond drilling will be required for most of the holes. Some holes may need to be drilled very accurately, specifically to hit a small drift at depths of up to 70 m from surface. Accurate diamond drilling using a steerable bit or wedges may be suitable to small targets at depth but down-the-hole hammer (dthh) drilling techniques such as those employed during drilling of vertical freeze holes for the freeze optimisation study (FOS) may be required in some cases. Detailed and accurate hole surveys will be required to tie any cavity monitoring surveys into the 3d model.

Eventually, large diameter backfill delivery holes will be required and these will also form part of the investigation.

Investigation of some potentially high risks associated with near surface non-arsenic stopes are not outlined in this memo. These could be included to optimise future drilling investigations and to possibly create enough work that a drilling contractor would be attracted to work on the project.

An increase in water pressure due to drilling near a bulkhead could cause some leakage and this should be avoided. Boreholes drilled from underground and anywhere near an arsenic stope and chamber will need to be drilled using a blowout preventer / isolation system to protect the drilling crews from exposure to arsenic dust.

A detailed drilling plan and collar location map has not been developed for this memo as additional effort is required do so including receipt of some direction from PWGSC as to which drilling priorities outlined in Table 3.1 will be targeted. Additionally, discussions with the care and maintenance contractor are required to assess the feasibility of underground drilling.

**Table 3.1: Summary of Anticipated Minimum Investigative Diamond Drilling or Down-the-Hole Hammer Drilling Requirements for Known High Risks Associated with Arsenic Stopes**

| Area or Arsenic Stope or Chamber Requiring Drilling Investigation | Borehole Required for Investigation, Mitigation Design, or Monitoring | Borehole Camera or Cavity Monitoring Survey? | Drilled from Underground or Surface? | Approximate Number of Boreholes Required | Approximate Length of Drilling (m) | Drilling Priority | Will Boreholes Provide Additional Geotechnical Information, and How? | Can the Borehole be used for Monitoring? How? | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Arsenic Stope B2-08 / Underlying Non-arsenic Stope B3-06 Sill Pillar** | All | Camera and C-als for those drilled into void. | Likely underground, but only if rehabilitation and services completed. | 2 into sill pillar, 2 into eastern portion of B3-06 void. **Total 4** | 30 m each if underground, **Total ~120 m** | 1 | Core recovered and logged, possible borehole televiewer work. | 1) Successive c-als surveys to assess if the back of the stope or the position of the top of the dust is changing (compare to 2005 work).<br>2) Possible conduit for borehole extensometers including simple tell-tales or more sophisticated approaches. | Two boreholes required to intersect the void on top of the backfill in the eastern, no-accessible portion of non-arsenic Stope B3-06 for void delineation and monitoring purposes. |
| **Arsenic Stope B21-12/13/14 Crown Pillar** | All | Camera and C-als for holes drilled into void. | Likely surface. Underground would be possible but safe access is currently limited. | 4 into crown, 1 into pillar between stope and pit wall. **Total 5** | 30 m each from surface. **Total ~150 m** | 1 | Core recovered and logged, possible borehole televiewer work. | 1) Successive c-als surveys to assess if the back of the stope or the position of the top of the dust is changing (compare to 2005 work).<br>2) Possible conduit for borehole extensometers including simple tell-tales or more sophisticated approaches. | Some of the boreholes drilled into the chambers for investigative purposes in 2005, which were subsequently grouted, could be re-drilled for this purpose.<br>One borehole should be drilled into the pillar between the arsenic stope and the open pit if safe to do so. |
| **Arsenic Stope B2-08 Crown Pillar** | All | Camera and C-als for holes drilled into void. | Likely surface. Underground would be possible but safe access is currently limited. | 2 into crown, 1 into pillar between stope and pit wall. **Total 3** | 30 m each from surface. **Total ~90 m** | 1 | Core recovered and logged, possible borehole televiewer work. | 1) Successive c-als surveys to assess if the back of the stope or the position of the top of the dust is changing (compare to 2005 work).<br>2) Possible conduit for borehole extensometers including simple tell-tales or more sophisticated approaches. | Some of the boreholes drilled into the chambers for investigative purposes in 2005, which were subsequently grouted, could be re-drilled for this purpose.<br>One borehole should be drilled into the pillar between the arsenic stope and the open pit if safe to do so. |
| **Arsenic Stope B2-12/13/14, Adjacent Non-arsenic Stope 2-02 Rib Pillar** | All | Camera and C-als for holes drilled into void. | Likely surface. | 1 into crown of 2--02, 1 into pillar at north end of B2-12. **Total 2** | 70 m each from surface. **Total ~140 m** | 2 | Core recovered and logged, possible borehole televiewer work. | Possible conduit for borehole extensometers in pillar. | The drill hole into the pillar between arsenic Stope B2-12 and non arsenic Stope B2-02 will need to be accurate and might need to be drilled with a dthh drill? |
| **C5-09 Back, Adjacent to and Below Arsenic Stope C2-12 and Arsenic Chamber B9** | All | Camera and C-als for holes drilled into northern portion of void. | Safe u/g access possible | 2 into sill pillar for geotech. and 2 into northern portion of void **Total 4** | 30 m each, from underground **Total ~120 m** | 2 | Core recovered and logged, possible borehole televiewer work. | 1) Successive c-als surveys to assess if the back of the stope or the position of the top of the dust is changing (compare to 2005 work).<br>2) Possible conduit for borehole extensometers including simple tell-tales or more sophisticated approaches. | The southern portion of the void above non arsenic Stope C5-09 is mostly accessible underground and can be surveyed using c-als at any time. |
| **Inaccessible Bulkheads Connected to Arsenic Stope B2-12/13/13** | Investigation and design. | Camera and C-als for holes drilled into void. | Likely best from underground but more risk in doing so. | 2 inaccessible bulkhead holes required. **Total 2** | 50 m each u/g, 70-80 m from surface **Total ~160 m** | 2 | Core recovered and logged, possible borehole televiewer work. | If required, not foreseen. | These holes need to be accurately drilled, so we may need to use a down the hole (dthh) rig if we drill from surface. Risk of drilling into arsenic and a plan to complete (grout) these holes and re-drill will be required. |
| **Inaccessible Bulkheads Connected to Arsenic Stope B2-08** | Investigation and design. | Camera and C-als for holes drilled into void. | Likely best from underground but more risk in doing so. | 2 inaccessible bulkhead holes required. **Total 2** | 20 m each u/g, 70m each from surface **Total ~140 m** | 2 | Core recovered and logged, possible borehole televiewer work. | If required, not foreseen. | These holes need to be accurately drilled, so we may need to use a down the hole (dthh) rig if we drill from surface. Risk of drilling into arsenic and a plan to complete (grout) these holes and re-drill will be required. |
| **Inaccessible Bulkheads Connected to Arsenic Stope C2-12** | Investigation and design. | Camera and C-als for holes drilled into void. | Likely best from underground but more risk in doing so. | 2 or 3 inaccessible bulkhead holes required. **Total 3** | 30m each u/g, 70m from surface **Total ~210 m** | 2 | Core recovered and logged, possible borehole televiewer work. | If required, not foreseen. | These holes need to be accurately drilled, so we may need to use a down the hole (dthh) rig if we drill from surface. Risk of drilling into arsenic and a plan to complete (grout) these holes and re-drill will be required. Inaccessible bulkhead #54 can be accessed by rehabilitating the 1st level raise access. |

| Area or Arsenic Stope or Chamber Requiring Drilling Investigation | Borehole Required for Investigation, Mitigation Design, or Monitoring | Borehole Camera or Cavity Monitoring Survey? | Drilled from Underground or Surface? | Approximate Number of Boreholes Required | Approximate Length of Drilling (m) | Drilling Priority | Will Boreholes Provide Additional Geotechnical Information, and How? | Can the Borehole be used for Monitoring? How? | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Investigate Lower Arsenic Drifts to Assess Dust Position for Arsenic Stope B2-12/13/14** | All | Camera and C-als for holes drilled into void. | Safest from surface given target is possibly saturated arsenic dust. | 3 boreholes required. **Total 3** | 70-80 m each, from surface **Total ~240 m** | 3 | None required. | If required, not foreseen. | These holes need to be very accurately drilled, so we may need to use a down the hole (dthh) rig if we drill from surface. We will drill into arsenic and surface holes are safer although underground are shorter. |
| **Investigate Lower Arsenic Drifts to Assess Dust Position for Arsenic Stope B2-08** | All | Camera and C-als for holes drilled into void. | Safest from surface given target is possibly saturated arsenic dust. | 3 boreholes required. **Total 3** | 70 m each, from surface **Total ~210 m** | 3 | None required. | If required, not foreseen. | These holes need to be very accurately drilled, so we may need to use a down the hole (dthh) rig if we drill from surface. We will drill into arsenic and surface holes are safer although underground are shorter. |
| **Investigation of Rock Mass Ahead of Required New Development** | All | Camera and C-als for holes drilled into void. | Safest from surface given target is possibly saturated arsenic dust. | Up to 10 boreholes required **Total 10** | 30-50 m each, from underground **Total ~500 m** | 4 | Core recovered and logged, chemical work required for PAG analysis. | If required, not foreseen. | May not be required given that rock mass is generally uniform and of high quality. However excavation into shear zone areas and possible faults may require some drilling investigation. |

The drilling totals outlined in Table 3.1 are summarised in Table 3.2 and 3.3.

**Table 3.2: Preliminary Summary of Drilling**

| Drilling Priority | Standard Surface Diamond Drilling, Total Number of Holes | Standard Underground Diamond Drilling, Total Number of Holes | Very Accurate Surface Diamond Drilling or Down the Hole Hammer Drilling, Total Number of Holes |
|---|---|---|---|
| **1** | 4 | 8 | |
| **2** | 2 | 4 | 7 |
| **3** | | | 6 |
| **4** | 10 | | |

Note there is no contingency in the drilling estimates provided above.

**Table 3.3: Preliminary Summary of Drilling Lengths**

| Drilling Priority | Standard Surface Diamond Drilling, Total (m) | Standard Underground Diamond Drilling, Total (m) | Very Accurate Surface Diamond Drilling or Down the Hole Hammer Drilling, Total (m) |
|---|---|---|---|
| **1** | 120 | 240 | |
| **2** | 120 | 140 | 510 |
| **3** | | | 450 |
| **4** | 500 | | |

Note there is no contingency in the drilling estimates provided above.

## 4.0 SURVEY AND LABORATORY TESTING

Detailed geotechnical mapping of all the future drift plug locations will be required for design.

The following surveys will need to be carried out:

- A ground support rehabilitation survey of the existing underground openings.
- Underground surveying tied to the Giant mine grid is required to improve the accuracy of the mine geometry information and to improve the 3d mine model. Some remote surveying, using a remote controlled rover and 3d laser scanning may be carried out in lieu of ground support rehabilitation and conventional man-entry surveying.
- Underground ventilation surveying.

The following laboratory testing needs to be carried out:

- Additional paste backfill tailings work including additional tests on tailings from the central tailings pond, flow-loop testing, determination of cement contents required to limit liquefaction, and tests on alternative binder material to cement (*e.g.,* kiln dust).
- Some intact rock strength laboratory testing is required for both underground and surface rock mechanics studies.

More detail on the tailings recover plan for backfilling is required, including assessment of dust reduction and human health factors associated with moving tailings and dusting.

# 5.0 MITIGATION DESIGN

An emergency mitigation response plan in the event that a problem is identified should be developed. In many cases the likely course of action is to be able to quickly backfill an area with cementitious backfill to support and stabilize it quickly although doing so may add cost and schedule to the overall remediation. Ideally, the mitigation carried out supports the remediation but emergency response should take priority.

The 3d mine geometry model in the vicinity of the arsenic stopes and chambers needs to be improved to support future detailed mitigation design. This task should be expedited as the valuable anecdotal knowledge present in current staff members should be leveraged while the opportunity still exists. The primary task is to digitise critical 2-d engineered level plans and incorporate them into the 3d model which at present is primarily based on 2-d vertical geological cross-sections. Any known errors and omissions in the mine geometry information needs to be taken into account in the design of the investigation, monitoring system, and the mitigation itself. 2d engineering drawings required for execution of the mitigation will be developed with the updated 3d mine model.

The existing underground mine workings near the arsenic stopes and chambers will need to be rehabilitated to allow safe access for underground drilling investigations, monitoring, and future mitigation construction efforts. A ground support rehabilitation survey will be required. This detailed survey may lead to the recommendation of abandoning unsafe development and the excavation of bypasses around them. Such bypasses have been recommended by Golder but others may be required.

Re-establishment or maintenance of critical underground mine infrastructure to areas where work is required and designs for all of it will need to be developed, including:

- Power supply.
- Ventilation system.
- Mine water and compressed air supply.
- Ground support systems.
- Mine communication system.
- Refuge chambers and lunch rooms.
- Secondary egress and ventilation raises will need to be developed, likely through rehabilitation of existing openings to surface.

Detailed designs for the paste backfill system, new underground development openings, drift plugs, lower arsenic drift backfill, and the stope void backfill will be required.

It is not anticipated that extensive investigation of the path of future new development openings is required for geotechnical purposes, unless the openings are planned near shear or fault zones. Some investigation may be required to determine the level of potentially acid generating (PAG) material may be encountered as it may need to be preferentially used as fill or stored underground whereas non-PAG rock will be used for surface fills which are at a premium on the site.

The investigation of the currently inaccessible bulkhead areas will help determine if it is possible to develop safe access to them and whether remote plug designs are required. Details on the new development required to reach the inaccessible bulkheads including: which existing development to start from; what direction to approach from; and whether any backfilling of currently unstable openings that will be subsequently be developed through, are required. Design of the drift plugs will require detailed 3d surveys and geotechnical assessment of the rock walls. The design of the large diameter concrete delivery holes to optimal locations to support the plug design work is required.

There are still some information gaps regarding detailed design criteria for drift plug design due to a lack of a wetting and freezing plan. These include the potential range of fluid or slurry pressure that could be imparted on them during wetting of the dust. Additionally, the potential for frost pressure to impact the plugs has not been assessed determined due to the lack of a freezing plan. Specifically the freeze hole geometry is not yet known and the direction of freezing, and the impact of freezing-induced pressures on drift plugs or rock pillars cannot be assessed. Both wetting and freezing are required to complete plug design and assess risks.

Determination of the optimal method to stabilise the arsenic stope crown pillars requires additional discussion and work. Current design thinking suggests that tight backfilling the void in the arsenic stopes in question with a lightly cemented backfill would limit propagation of any crown pillar failure should it occur. Because a wetting and freezing plan has not yet been established additional discussion on suitable crown pillar support is required. Several key items that have not been resolved include: a wetting plan; a freezing plan; a minimum dust and void backfill water content criteria; and an assessment of dust consolidation parameters for both loading and wetting. Questions and challenges resulting from these gaps include:

- Simply pouring a relatively dense cemented paste backfill into the void may compress the dust and reduce the void space in it and in the backfill below. Some criteria is required for freeze block longevity in the event of cooling loss.
- The dust may consolidate during wetting and the additional exposure of stope walls could induce some stability of unknown extent.
- The dust may consolidate during initial wetting and any backfill previously placed on top of the dry dust could fall with it and/or hangingwall and footwall stability could be compromised. The backfill may need to be engineered to remain stable if a void opens up below it.
- Water in the fractures of the rock surrounding the chambers and in the pore space of the dust and the backfill will expand during freezing. Depending on the direction of the freeze front and the amount of void left in the chamber available for expansion, some damage to rock pillars and drift plugs could result. This needs to be further assessed.

The following work is recommended in the short term risk mitigation phase to better understand the dust behaviour, including.

- Assessment of the in-situ water content, void-ratio, and density of the dust in the arsenic stopes in question.
- Bench scale laboratory tests on the behaviour of the dust during wetting, specifically consolidation potential, liquefaction potential, and assessment of properties such as static and dynamic slurry density.
- Development of a wetting / freezing plan. This needs to include the position of the freeze holes and the direction of the propagation of the freeze front. This information is required to assess the potential for frost jacking and damage to the drift plugs and in the rock pillars around the arsenic stopes and chambers.

Foam concrete backfill as previously proposed by SRK may prove to be a suitable interim solution to mitigate these stopes while key questions regarding wetting, freezing, and dust behaviour are being answered. Some form of ground support such as cable bolting, or excavation of the overburden from above the rock crowns could ultimately prove part of the solution.

## 6.0 MONITORING

An updated monitoring plan that provides information on the behaviour of the openings in question for safety and mitigation design and planning purposes is required. Significant monitoring will be required during the mitigation construction phase when worker exposure will be highest. Additional monitoring may be required to help constrain the behaviour of the rock mass surrounding an arsenic chamber during wetting and freezing of the first few chambers and although this is not within the scope of addressing short and immediate high risks it might be expedient to install it early. The monitoring plan requires clear and concise triggers and trigger responses for operators.

Monitoring cannot be used as a definitive tool to assess if and when mitigation is required because failure could occur with little warning. Golder had previously recommended a crude monitoring program in the fall of 2010 for the areas above arsenic Stope B2-12/13/14 and arsenic Stope B2-08 to assist with interpretation of the nature of surface cracking observed near B1 pit. Prisms mounted on tripods were placed on surface and the prisms are currently being surveyed manually twice a week. The data is added to a spreadsheet and forwarded on to interested parties typically within 1 to 2 days. The current monitoring system is subjected to freeze thaw effects and possible ice lens melting during the break-up period (early spring and late fall) the reliability of the system as an indicator of crown pillar stability is currently limited. This system needs to be improved.

Monitoring in addition to the current system is recommended to determine if the crown pillar is deforming, the extent of the deformation, and the movement mechanisms involved. This monitoring will be used to help plan the mitigation work and for assessment of both worker and public safety but as noted above it will not provide a fail-safe warning of impending failure. Such monitoring could include:

- A simple visual monitoring program of rock mass conditions in the accessible underground near the arsenic stopes and chambers should be systematically and routinely carried out. Good quality digital photographs should be collected.
- Measurement of deformation in rock pillars. The use of simple “tell-tales” installed in boreholes that intersect the top of the arsenic stopes in question. These consist of a measuring tape secured to the breakthrough of the borehole and the top of the arsenic stope and the distance between that breakthrough and a surface casing or top of the bedrock surface is recorded. Decreasing measurements indicate ravelling of the crown pillar that could lead to de-stabilisation. More sophisticated multi-point borehole extensometers (MPBX) or time-domain reflectrometry (TDR) cables grouted into boreholes drilled through the arsenic stope crowns would give more detailed information. These can be connected to a data logging and visualisation system to allow assessment of strains in key pillars surrounding the arsenic stopes.
- Periodic cavity monitoring surveys. These need to be carried out from key positions either in inspection hatches or boreholes that intersect the void above the dust in arsenic stopes in question. Different surveys can be compared in detail to assess if sagging, wedge detachment, or ravelling is occurring from the back and/or if the dust is settling. Dust settlement could destabilise the stope hangingwall and/or footwall and ravelling of either could eventually impact crown pillar stability.
- A more sophisticated surface prism monitoring system. Tighter surface survey control and more frequent surveying will be required during the mitigation construction phase. It may be efficient to eventually employ a survey robot placed in a controlled environment surface hut to automatically monitor prisms.

Additionally, monitoring of the level of backfill in non-arsenic stopes under or adjacent to the arsenic stopes in question should be developed, including:

- Re-establish monitoring of fill level and vibrations in non arsenic Stope C5-09 (*e.g.,* a monitoring program was initiated but to Golder's knowledge has not been maintained).
- Develop monitoring of fill level and vibrations in non-arsenic Stope B3-06 stope.
- Develop monitoring of fill level and vibrations in non-arsenic Stope 2-02.

## 7.0 CLOSURE

We trust this memo provides a summary of all the underground work required for the mitigation of high risk items and particularly the priority of drilling required to support the design and any monitoring required. Please don't hesitate to contact the undersigned if you have any questions.

**GOLDER ASSOCIATES LTD.**

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