INDIAN AND NORTHERN AFFAIRS CANADA

POLARIS MINE DECOMMISSIONING AND RECLAMATION

JULY 24, 2009 SITE VISIT AND INSPECTION

FINAL

PROJECT NO:	0131-062-01	DISTRIBUTION:	
DATE:	March 23, 2010	INAC	2 copies
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March 23, 2010

Project No. 0131-062-01

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Dear Lou-Ann,

Re: <u>Final - Polaris Mine, July 24, 2009 Site Visit and Inspection Report</u>

Please find attached two hard copies of our above-referenced report dated March 23, 2010. The report includes a summary of the 2009 site inspection, and assessment of the water quality in Garrow Lake by Lorax. BGC Engineering Inc. has conducted a review of the data pertaining to the subsidence zone, as well as a review of the recent series of quarterly and annual reports submitted by Teck.

Should you have any questions or comments, please do not hesitate to contact me at the number listed above.

Yours truly,

BGC ENGINEERING INC.
per:

Holger Hartmaier, M. Eng., P.Eng.
Senior Geotechnical Engineer

HHH/syt

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LIMITATIONS OF REPORT

BGC Engineering Inc. (BGC) prepared this document for the account of Indian and Northern Affairs Canada. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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1.0 INTRODUCTION

The Polaris Mine site is located in Canada's high Arctic at about Latitude 75^{o} N and Longitude 97^{o} W on Little Cornwallis Island. The mine is approximately 140 km by air northwest of Resolute Bay (Figure 1).

During operations, Polaris Mine was the most northerly metal mine in the world. Operating between 1981 and 2002, the mine produced about 300,000 wet tonnes of lead and 250,000 wet tonnes zinc concentrate per year from its underground mining developments. Ore was crushed and concentrates were stored on site during the winter, then, shipped to overseas smelters during the brief summer shipping window.

Between 1981 and 2001, Polaris Mine was owned and operated by Cominco Ltd. In July 2001, Cominco merged with Teck Resources Limited to form Teck Cominco Ltd (Teck Cominco).

Mining operations ceased in 3rd Quarter, 2002 due to lack of ore. A Decommissioning and Reclamation Plan (DRP) was prepared by Cominco (Cominco Ltd., 2001) and approved by the Nunavut Water Board in April 2002. Decommissioning and reclamation of the mine site was conducted by Teck Cominco and its contractors between 2002 and 2004. Since that time, post-closure monitoring and annual inspections have been carried out as required by the current water license NWB1POL0311 which expires on December 31, 2011.

Closed mine site status was obtained from Environment Canada on July 27, 2006 confirming that Polaris Mine had no further obligations under the Metal Mining Effluent Regulations (MMER).

On June 24, 2008, Teck Cominco requested a reduction in the amount of security being held by the Crown in recognition of the reclamation work completed to date and the results of ongoing monitoring which show that all parameters are within regulatory limits. In addition, Teck Cominco has requested that the annual water quality monitoring requirements be reduced in recognition of these stabilized conditions.

On April 23, 2009, Teck Cominco Limited was renamed Teck Resources Limited (Teck).

1.1. Terms of Reference and Objectives

BGC Engineering Inc. (BGC) was requested by the Nunavut Regional Office of Indian and Northern Affairs Canada (INAC) to undertake a site inspection with INAC staff of the Polaris Mine site under the terms of Standing Offer Agreement 01-09-6007, Call-up No. 1, dated June 13, 2009 and Amendment to Call-up No.1 dated February 10, 2010.

BGC was requested by INAC to undertake the following work:

1. Complete one site inspection trip in late July 2009 with INAC staff to review progress of reclamation work and prepare a report that:
    a. considers compliance with current water license requirements,

   b. provides discussion and comment on Teck's conclusion that elevated zinc levels in the mid-depth range in Garrow Lake are due to a 'thin layer of bacteriological tissue",
   c. provides a trend analysis related to water quality monitoring results to determine if there are any or potential impacts due to mining activities to receiving waters,
   d. provides an assessment of the subsidence area, and
   e. includes any other items of concern that are subsequently identified by INAC and an evaluation of Teck's response to items noted in BGC's 2008 Site Visit Report.
2. As part of #1 above – Review the 2008 3rd quarter and annual report submitted by Teck, as well as 1st, 2nd and 3rd quarter 2009 reports and any other previous Teck reports deemed relevant to assist with # 1 above. No separate report is required from this review.

These items are part of an overall review of technical information associated with the ongoing Decommissioning and Reclamation work being completed by Teck for the Polaris Mine. This technical review will facilitate INAC's interventions to the Nunavut Water Board (NWB) and review of Crown Land Leases. In addition, this information will be used as part of the ongoing assessment of the Crown's remaining liability for the site based on reclamation work that has been confirmed/verified during the site visit.

1.2. Report Structure

Section 2 presents a summary of the 2009 site inspection observations. Appendix I contains selected, annotated photographs taken during the site inspection. INAC requested that this report include, as appendices to the site inspection, the results of the subsidence zone assessment and Lorax's review of the water chemistry trends in Garrow Lake. As such, Appendix II contains supporting data provided by Teck for BGC's review of the subsidence data, which is summarized in Section 3. Appendix III is Lorax's report on the review of the chemistry of the Garrow Lake water column sampling, which is summarized in Section 4. Section 5 provides commentary on the review of the recent quarterly and annual reports submitted by Teck.

2.0 SUMMARY OF SITE INSPECTION OBSERVATIONS

2.1. General Itinerary

The site inspection was conducted between approximately 9:00 AM and 11:30 AM on July 24, 2009. Mr. Holger Hartmaier, M. Eng., P. Eng. of BGC and Ms. Andrea Cull, Water Management Specialist, with the Nunavut Regional office of INAC in Iqaluit attended the site inspection

The site visit was facilitated by Mr. Bruce Donald, Reclamation Manager for Teck and various support staff from the camp. Weather during the site inspection was initially foggy, but improved steadily throughout the day, with generally high cloud, sunny, dry conditions. Temperatures were in the range of 13^{o} to 15^{o}C.

Concurrent with the site inspection, Teck was in the process of closing the camp and demobilizing the site staff. A weather induced one-day delay of the INAC site inspection created some scheduling conflicts with respect to the return flight. In order to meet the flight schedule, Teck proposed that the inspection start with the important areas, then, if time permitted to inspect other less critical areas. It was agreed that the following priority areas would be inspected:

- Garrow Creek water sampling and inspection at the former Garrow Lake Dam;
- The outlet of Garrow Lake at the former wavebreak structure;
- The Main portal backfill; and
- The subsidence zone.

Less critical areas, which were not considered for inspection included the following areas:

- Frustration Lake causeway and access road;
- New Quarry area;
- Operational Landfill;
- Marine foreshore;
- Little Red Dog Quarry Landfill; and
- North Portal.

Figure 2 is a plan of the Polaris Mine site, showing the major areas discussed in this report. Despite the fact that the above areas were not subject to a formal inspection, this report provides some site observations and comments based on previous inspections and documented information.

The following sections summarize the observations and recommended follow-up action items or issues (if any) noted at each of the above locations. Appendix I contains a set of selected site photos for reference to the discussion presented herein.

2.2. Priority Inspected Areas

2.2.1. Garrow Lake Dam

This area was visited first since it is the most distant site from the airstrip/camp area and INAC had to obtain a check series of water quality samples from Garrow Creek at the water licence designated final discharge point for the mine site.

Water samples were collected by Ms. Andrea Cull. The creek channel was flowing across its full width, with an average water depth in the range of 100-150 mm. Water flow was clear, with no signs of turbidity or chemical precipitates. The channel base appears stable, although sand and gravel bars within the channel below the dam have shifted, based on comparison with last year's photos. Teck had removed a piece of exposed geotextile from the channel near the former downstream toe area of the dam breach. This work involved some minor disturbance of the channel invert, resulting in the development of two small set of rapids, dropping about 60 cm in total. The channel riprap was in good condition.

2.2.2. Outlet of Garrow Lake

The natural gravel berm that has developed across the outlet of Garrow Lake has a maximum height of about 1 m across the original creek bed. Garrow Lake was mostly covered with thin ice, except for the portion bordering the shoreline. Flow from Garrow Lake takes place primarily as seepage through the gravel and through local breaches of the berm when lake levels overtop the berm. The water level in Garrow Lake is thus naturally regulated to close to its pre-mining natural water level. Teck noted that the survey just competed indicated lake level to be higher than last year, due in part to a late thaw this year before flow began at the outlet.

2.2.3. Main Portal Backfill

Teck repaired the slumped backfill slope noted by BGC in last year's inspection. The backfilled slope was bermed at the toe with additional talus material borrowed from the adjacent rock slopes. The mid-slope area of the backfill was left slightly oversteepened/undercut because the excavator could not reach far enough up the slope to grade this material. It is expected that this may result in a minor localized slough. However, the overall slope of the backfill has been flattened so that long-term stability is improved.

2.2.4. Subsidence Zone

Visual inspection of the subsidence zone showed no noticeable changes to the surface expression of the fill in this area. Teck conducted another round of surveys to obtain a record of surface topography using a differential GPS unit. Surface cracks that have been identified in previous inspections showed no indication of propagation or increase in width. These features are also being mapped and surveyed by Teck. Further detailed discussion on the review of the subsidence zone data is presented in Appendix II and is summarized below in Section 3.

2.3. Areas Not Inspected in 2009

As noted, logistical considerations prevented BGC and INAC from undertaking a complete inspection of the Polaris mine site in 2009. The areas not inspected this year were areas that, in past inspections, did not have any significant outstanding issues or concerns. The following sections provide comments regarding the current conditions, based on limited site observations and the observations documented by the annual geotechnical inspection, conducted by Teck, and reported in their annual reports.

2.3.1. Frustration Lake Causeway and Access Road

Since decommissioning, there has been relatively limited degradation of the causeway and the water surrounding the structure is clear of suspended sediment, even with wave action. In the 2008 report, BGC noted some degradation of the tundra in the form of quad tracks adjacent to the access road due to quad traffic detouring around swales filled with snowdrifts. BGC had recommended that the current water license requirement for water quality sampling of Frustration Lake and inspection of the causeway be suspended in order to avoid traffic down this road. During the 2009 inspection, Bruce Donald noted that Teck was also using Frustration Lake as their freshwater supply for the temporary camp and that it was necessary to haul water over the access road. Therefore, the road was being used more frequently than previously assumed by BGC. Since there is no alternative source of fresh water close to the camp, this situation is expected to continue as long as the camp is in operation. Teck's current plan is to use the camp for one more season in 2010, then decommission the camp during the winter of 2010-2011 by hauling everything over the ice to Resolute Bay. BGC recommended that quad traffic stay on the decommissioned footprint of the access road as much as possible to minimize further disturbance to the adjacent tundra. In 2010, the site inspection should confirm that no erosion has been initiated as a result of the detouring quad traffic.

2.3.2. New Quarry Area

Previous investigations noted the development of erosional gullies within the perimeter slopes of the New Quarry. Teck had undertaken remedial stabilization work in 2006 in two of the major gullies by flattening the side slopes and armouring the channel and slopes with riprap. These areas appeared stabilized in 2008, based on the last inspection. Other minor gullies appeared to be self-armouring with gravel sized rock fragments. Teck should continue to monitor these areas until the end of the license period and carry out any repairs in 2010 before leaving the site. BGC expects that future erosion will decrease as the slopes adjust to the new baseline gradients in the channel. The affected channels all discharge into the base of the New Quarry, so any sediment carried by the periodic stream flow is deposited as an alluvial fan, and not directly discharged as suspended sediment into a receiving body of water. The alluvial deposits on the Quarry floor also help to reduce the overall stream gradients, thereby further reducing any potential for channel erosion.

2.3.3. Operational Landfill

The main outstanding issue for BGC concerning the Operational Landfill was the thermal performance of the cover. This was being monitored by a series of thermistors. In 2006, Teck upgraded all of the thermistor installations and data loggers were added to record daily temperature readings over the course of one year. The results were not available in 2008 at the time of the inspection, but the 2007 and 2008 data were presented in the 2008 third quarter report. Based on a review of this data, BGC has the following comments:

- The warmest temperatures are reached in August each year. Therefore, the warmest part of the cycle is typically not captured by the data logger for the year that the dataloggers are downloaded. This means that the maximum depth of the active zone for the current year is not known until the following year, when access to the site is possible.
- The landfill cap is a minimum of 1.8 m thick. The shallowest thermistor bulb to remain below freezing was located at 1.25 m below ground surface, indicating that the active layer remains well within the cap material.
- It is too early to tell whether there is any particular trend in the readings. The 2006 readings were affected by disturbance after being re-installed, the 2007 readings in general were slightly cooler than the corresponding 2007 readings, but this may be due to equilibration to the ambient conditions. The 2008 readings, showed only the warming portion of the curve to July 2008. The 2009 readings, collected this year were not available for review until after Teck prepared their 2009 3rd Quarter report. These indicated satisfactory performance of the cover and continued aggradation of permafrost conditions. See Section 5.3.3 for further details and comments on this report.

2.3.4. Marine Foreshore

Since reclamation of the marine foreshore was completed, the shoreline area has been subjected to continuous, natural, coastal activity including wind and wave action and scouring by pack ice. In addition, some buried lenses of ice have melted out, leaving localized surface depressions. This has resulted in some shifting and re-shaping of the shoreline in plan and profile from those indicated on the reclamation design drawings. However, no significant active erosion is taking place that affects the long term physical stability of this reclaimed area. In the future, the shoreline area will continue to be modified in response to natural coastal geomorphological processes.

2.3.5. Little Red Dog Quarry Landfill

The only significant outstanding concern noted in previous inspections was the disposal of the pile of miscellaneous scrap metal that has been stored on the cover of the landfill. Teck has indicated that this material will be buried within the landfill before the equipment is removed from site.

Based on the ground temperatures measured by the thermistors installed through the cover and underlying waste materials to July 2008, the maximum depth of the active zone is 1.5 m, compared to a minimum cover thickness of 1.8 m. This confirms that the active zone remains within the cover. The underlying waste materials show a cooling trend since being placed between 2002 and 2004. Since 2006, the deepest thermistors have shown gradual cooling from about -5^{o}C to about -7^{o}C to -10^{o}C.

The cover appears to be performing well, with no signs of settlement or heaving noted in previous inspections.

2.3.6. North Portal

There were no concerns noted with respect to the North Portal backfill.

2.4. Conclusions Regarding 2009 Site Inspection

In general, the overall site is in good condition. The areas of physical instability identified in previous inspections have been mitigated, or are in the process of undergoing natural self-armouring. The thermal stability of the landfill materials and covers is demonstrated by the thermistor data, which indicates that permafrost has aggraded into the waste materials and the active zone is within the minimum thickness of the capping material. No additional remedial repairs are recommended.

3.0 REVIEW OF SUBSIDENCE ZONE

3.1. Introduction

This section presents an assessment of the subsidence zone, based on the background data provided by Teck (Appendix II) and the ongoing annual topographic surveys conducted by Teck during the post-closure monitoring period.

The location of the Polaris Mine subsidence zone is indicated in Figure 2. Monitoring, by mine staff, of the subsidence zone was conducted by various levels of surveys since subsidence was initiated during mining operations in 1999. Upon cessation of mining operations, the subsidence area was used as a landfill site to dispose of decommissioned mine equipment and other inert mine site materials (Reclamation Landfill). The landfilled materials were covered with a minimum cover of 1.8 m using rockfill quarried from the adjacent New Quarry. In capping this area, the intention was to restore the ground surface contours back to their pre-mining condition. Since closure in 2002, Teck has conducted annual topographical surveys of the subsidence area to monitor ground movements and to demonstrate that subsidence has ceased and that there is no long term risk to public safety or to wildlife.

Some of the figures provided in Appendix II have been reproduced by BGC as figures in the report to add further details and as reference for the discussions presented below. The reader should also refer to Appendix II for additional information, figures or details.

3.2. Subsidence Zone History

3.2.1. Background

Underground mining at Polaris commenced in 1981. Initially, mining was done using open stopes supported by intervening pillars of rock. Subsequently, the stopes were backfilled with a mixture of rockfill and water which was allowed to freeze in place under the ambient permafrost conditions. This method of support required a certain period of time for the ground to freeze, before the load-carrying capability of the backfilled stope could be mobilized. Initially, some stability problems were encountered with fill wall stability as the intervening ore pillars were mined (Golder 1994). Although this method proved successful in improving support and ore recovery, it became apparent that using cemented rockfill would provide superior backfill strength in a shorter period of time. The cemented rockfill option was more expensive than the frozen rockfill option, but the improved ground support and ore recovery justified the additional cost. Use of cemented rockfill began in 1996.

In 1990, a network of monitoring pins anchored to bedrock was established over the mining areas to help detect and measure mining induced subsidence. The monitoring pins were surveyed twice per year until the end of active operations in 2002 (Figure 3). These survey measurements were accurate enough to detect small variations in pin elevations. According to Teck, the measured subsidence at Polaris was generally smooth and uniform due to the use of backfill.

Details describing the onset and progression of the subsidence zone at Polaris are not specifically documented in the available information provided by Teck. This coupled with a lack of detailed information regarding the mine geometry and development sequence, significantly limit BGC's ability to identify and assess risks associated with ongoing or future subsidence. Only some generalized conclusions can be provided, primarily based on assessing stability by means of monitoring surface deformations and cracking.

3.2.2. Sinkhole Subsidence

Based on the report by Golder (1994), a critical episode of subsidence was initiated sometime in 1993 (or earlier) following the development of a failure during pillar mining within the Keel Zone. During this period frozen backfill was still used to support the open stopes. The failure resulted in the formation of the localized surface depression referred to as the "Sinkhole".

A key portion of the failure occurred in the 202 stope (Figure 4) (Figure 6 of Golder, 1994 report in Appendix II) as pillar extraction was underway and before backfilling could take place. A block of ore between the 820 m level and the 850 m level, bounded by steeply dipping fault structures (Figure 5) on the east and west sides, dropped a minimum of 3.5 m on the 850 level. Because the block moved as a solid mass and did not rubbilize, a void of at least 3.5 m in height developed on top of the block. Golder (1994) noted that, based on extensometer measurements in the rock above the zone of failure, a zone of separation had developed at 6-8 metres above the 850 level (Figure 4). Extensometers also indicated minor separation within the rock mass, some 40 m above the stope back (Figure 5).

The Golder (1994) sketch of the failure zone (Figure 4) indicated that the stope below the failed block extended down to the 790 m level and was partially filled with ore. Below the 790 m level, the stope was shown as being completely backfilled. Based on this geometry, the failed block, in this section, has a vertical dimension of at least 36 m and a horizontal dimension of 60-65 m. The cross-sectional dimension of the un-backfilled open stope below the block is 30 m high by 27 m wide. It is important to note that the length of the failed block in a north-south direction was not defined in the available documentation.

Golder (1994) noted that the ultimate hanging wall on the 880 m level, above the zone of block failure had not yet been cable bolted. Significant back failures had occurred in the 195 and 199 pillars to the south. Golder therefore recommended that the following activities be incorporated in the mining plan (in part):

- *"Drill test holes towards the 199 pillar to determine the north-south extent of the back failure.*
- *Cable bolt the ultimate hanging wall on the 880 Level and, dependent upon the condition of the block below 880, cable bolt downwards to secure the ground above the sliding block. It must be recognized that due to the magnitude of the movements that have occurred that cable bolting may not be successful.*

- *Ensure that the drawpoint at 700 level is kept full to minimize the impact of any potential airblast should the sliding block fail suddenly.*
- *Develop a plan to fill the void should it become necessary."*

The available documentation does not record the extent to which the above recommendations were carried out. The main concern would be the extent to which ground support was installed and the stability of the remaining unsupported stope.

The next site visit by Golder took place in November-December 1995 and was documented (Golder 1996). The report noted that ongoing mining had encountered a number of ground control problems. The following is a description of the subsidence features noted at that time (Note, figure references have been omitted for clarity - see Appendix II for further details):

- "*Subsidence induced cracking has been observed at surface over and adjacent to the Keel mining area.* (Figure 6 shows the extent of surface cracking documented by Teck to 2002. Note that this pre-dates the placement of fill within the Reclamation Landfill.)
- *Surface cracking appears to be closely associated with those areas in the Keel where there has been 100% ore extraction. No cracking has been observed over the Panhandle mining area or over partially extracted areas of the Keel. The cracks appear to be located near vertically over the mined out outline on the 820/850 level.*
- *Surface monitoring shows continuing ground movement. The maximum measured subsidence is approximately 1.25 m and is located over the 189 pillar area.*
- *Most subsidence monitors are maintaining constant velocity or decelerating.*
- *Analysis by mine staff of the monitoring data suggest an angle of draw of 40^o.*
- *Given the location of the surface cracking, the angle of cave along the east and western sides of the orebody may be about 20^o to 30^o."*

The available documentation provided no further update regarding the extent to which the support recommendations provide by Golder in 1994 were carried out. It is noteworthy that the failure of the 202 stope was a significant factor leading to the adoption of cemented rockfill (CRF) as a means of backfilling the mined out stopes. The use of CRF improved stoping control and resulted in a faster stope cycle time.

Based on the plan view drawings of the mining area provided by Teck, the north-south dimension of the Keel Zone in the vicinity of the block failure was estimated by BGC to be about 400 m. Stope heights may be as high as 120 m. Based on the outline of the underground workings shown in Figure 3, the Keel Zone stopes were oriented in an east-west direction. Presumably, the adjacent stopes were either unmined rock pillars or backfilled. In the latter case, the possibility exists that back failures could develop before the stope was completely filled and/or frozen.

In the data presented in Appendix II, Teck noted that large-scale hangingwall caves at 880 level were induced in Pillars from 190 to 212, leaving large voids that were impossible to backfill. Based on this description, the north-south extent of the failed zone causing subsidence, as shown on Figure 6 is about 215 m, extending to either side of the 202 stope. The volume of open stope represented by this zone of failure was not documented.

The extent of surface cracking associated with the development of the Sinkhole, as mapped by Teck is shown in Figure 6. Based on this data, the maximum east-west extent of surface cracking is about 300 m and the north-south extent is about 400 m.

3.2.3. Mine Subsidence Zone

It is apparent that mining was able to continue within the Keel Zone following the development of the Sinkhole. Therefore, the relatively localized surface subsidence effects related to the failure of the 202 stope were overprinted by the broader subsidence over the Keel Zone due to ongoing extraction while the mine was in operation to the 3rd quarter of 2002.

Based on monitoring pin measurements, Teck's mine engineers calculated a maximum "angle of draw" for the subsidence zone of 40^{o}. In subsidence theory, the angle of draw is used to estimate the lateral extent of subsidence associated with underground extraction of material. This angle is measured from the vertical, between the edges of the underground mine opening and the point of zero surface subsidence. A sketch of the underground mine workings showing how this value was determined by Teck was not specifically included in the documentation provided in Appendix II.

The "angle of draw" differs from the "angle of cave". The latter parameter is the angle, measured from the horizontal from the edge of the underground mine opening to the outer edge of visible cracking at the surface.

Note that the two parameters are based on completely separate sets of field data:

- The angle of draw is defined by movement. Therefore it is not a true property of the material but depends on the density of surface subsidence measurement points and the accuracy of the survey.
- The angle of cave is defined by observations of cracking. Therefore it is a function of the geological properties of the materials overlying the underground mine opening.

3.3. Analysis of Subsidence Movements

3.3.1. Subsidence Measurements Prior to Closure

To date, the only documented analysis of subsidence movements over the Keel Zone was presented in an internal Teck Cominco memorandum dated December 4, 2002, from Trevor Feduniak, Senior Mine Engineer to John Knapp, Mine Manager. The purpose of the memorandum appears to be an assessment of the subsidence over the Keel Zone to address concerns regarding the risk of subsidence induced cracking leading to an inflow of ocean water when mining the adjacent Ocean Zone. The Ocean Zone is located adjacent to the northwest end of the Keel Zone, under the shoreline of North Bay. This memorandum was originally provided to INAC in 2003 as part of a package of documentation in response to concerns regarding the long term stability of the subsidence zone at the time of closure. This information is presented in Appendix II for reference.

The “Sinkhole’ was noted to have had subsided “more than 10 metres”, based on a rough estimate by Teck. However, there is no monitoring data that records this magnitude of subsidence, or the location where this took place. The previous report by Golder (Golder, 1996), noted maximum subsidence of 1.25 m over the 189 pillar, so it is not clear if the 10 m of total subsidence occurred there, or in another section within the Sinkhole.

The following pertinent points related to the observations of subsidence over the Keel Zone were noted by Teck in the 2002 memorandum:

- Subsidence at Polaris at been measured since 1990 by surveying the elevation of monitoring posts at strategic locations.
- New pins were added over the years to provide more detail, most recently in the summer of 1999. Some attrition had occurred, pins had fallen over due to large amounts of subsidence. More commonly, pins were damaged by surface mining activity.
- Typically two sets of measurements were done per year due to the leveling instrument’s sensitivity to cold weather and wind.
- Subsidence at Polaris was defined as a drop in elevation of greater than 50 mm from the original elevation, accompanied by a downward trend over several readings. Closure accuracy, natural ground movement from freeze-thaw cycles and heavy equipment activity prevented defining mining induced subsidence more closely.
- The Keel Zone was 120 m from top to bottom and was mined without leaving posts or pillars. Hanging wall ground support in the stopes was limited to 2.4 m long Swellex bolts. Large-scale hangingwall caves at 880 level were induced in Pillars from 190 to 212, leaving large voids that were impossible to backfill. Tension cracks appeared on surface.
- There is comparatively little subsidence data on the Sinkhole area. Monitor pins were installed in ground that was likely already moving, and were destroyed or fell over quickly.

As noted by Teck, actual monitoring data over the 202 area pillar, where the documented failure took place is limited, and consists of only two points, S4 and S12. In general, subsidence rates were expected by Teck to decrease after mining ceased. Teck prepared subsidence plots showing surface displacement of the monitoring points beginning in September 1990 through to July 2002 (cessation of mining operations). These plots were included with the subsidence documentation in Appendix II. Copies of the plots have been reproduced as Figures 7, 8 and 9 for reference to this discussion. Unfortunately, there is no continuity in these plots to show how subsidence rates decelerated or stabilized after mining operations ceased.

As noted by Teck in Appendix II, subsidence movements associated with controlled mining extraction progress through a series of phases over time in a curvilinear, reverse "S"- shaped curve. Initially, as underground extraction begins in the area, the curve is flat, starting from no movement, then as extraction continues, subsidence effects become noticeable at surface and the displacement curve has a convex upward shape as movements accelerate. Constant rates of movement result in a straight line segment of the curve and increasing total subsidence. As subsidence movements slow down, the shape of the curve changes to concave upwards and the slope of the line gradually becomes flatter as movement rates decelerate. Ultimately, movement rates cease soon after extraction is completed. If further mining takes place, subsidence movements may become reactivated, following the same general movement pattern. The time frames over which these phases occur vary from mine site and depend on many factors, such as:

- number and location of working faces;
- the areal extent of the mined out extracted area;
- depth of extracted area below ground surface;
- mining advance/ extraction rate;
- time that extracted area is left unsupported;
- angle of cave and angle of draw; and
- duration of mining.

To better understand the subsidence data recorded at Polaris, BGC divided the monitoring points into three groups: (Refer for Figure 3 for monitor point locations.). Note that the graphs of subsidence data refer to the points as "S", whereas in Figure 3 they are called "SUB".

- Those points along an east-west section across the subsidence zone along Station 2150 N. This includes the following monitoring points: S3, S11, S13, S14, S15, S16, S17, and S18. This section lies more or less along the 215 pillar and is north of the 202 stope area which failed, and the zone of caving failures noted by Teck that occurred between 190 and 212 pillars.
- Those points along an east-west section at about Station 2060 N. This includes S4 and S12, which are above the 205/207 pillars and are closest to the zone of failure in 202 stope.
- Those points along a north-south section across the subsidence zone at Station 1500 E. This includes the following monitoring points: S2, S4, S5, S8, S19, S20, S22, S34, S35 and S36. This section is considered the best representation of movements across the main part of the subsidence zone and lies close to the axis connecting the north and south limits of cracking shown in Figure 6. Monitoring points at S23, S32, S33, and S37, located further to the west of this section, at the north end of the Keel Zone were considered to be affected by mining in the adjacent Ocean Zone. At the south end, it should be noted that the limit of surface cracking extends south of S5. There is no monitor which delineates the southern limit of ground movements, which

could extend at least as far as Station 1800 N. Thus the potential zone of movement extends beyond the area of post-closure surface survey monitoring by Teck.

Based on the displacement plots prepared by Teck, most of the monitoring points were still showing active movement as of July 2002. Some monitors were showing accelerated movements. BGC estimated the average rate of movements for each of the monitoring points as of July 2002. The estimate was made by drawing a visual “best fit” straight line through the data points leading up to the latest data point. The difference between the starting displacement (s_1) and the final displacement (s_2) divided by the time interval gives the average displacement rate.

Tables 1 and 2 summarize movement rates on the east west sections at 2150 N and 2060 N, respectively. The monitoring points are listed in order from west to east rather than numerically so that the movement rates can be visualized in their proper context. Similarly, Table 3 summarizes movement rates for the monitors along the north-south section along 1500 E, listed in order from south to north. For each monitor, commentary is provided as to whether the movement rate is accelerating, decelerating, constant or not moving at all. The time period and total displacement over which the rate was estimated is provided for reference. Note that monitoring of some of the stations ceased while mining was still in operation. The displacement rate for these points should therefore be assessed separately, as they would not necessarily be representative of the subsidence rates at closure.

Table 1 Average Subsidence Rates along East-West Section at 2150N at Closure.

Survey Monitor	Time Period	Duration (Days)[1]	S_1 (mm)	S_2 (mm)	Net Vertical Displacement (mm)	Displacement Rate (mm/day)	Comments
S3	Oct/98-Jul/02	1398	900	1600	700	0.501	Accelerating
S11	Aug/96-Oct/98	821	400	950	550	0.670	Accelerating[2]
S13	Apr/96-Aug/96	152	150	250	100	0.658	Accelerating[2]
S18	Jun/00-Jun/02	730	850	1000	150	0.206	Decelerating
S17	Oct/98-Jun/02	1367	300	450	150	0.110	Decelerating
S16	Oct/97-Jun/02	1732	120	250	130	0.075	Decelerating
S15	Oct/97-Jun/02	1732	35	90	55	0.032	Constant
S14	Oct/97-Jun/02	1732	15	60	45	0.026	Constant

Notes: 1. Duration assumes initial reading on first day of month and last reading at end of month.

2. Monitoring terminated while mining still in progress.

Table 2 Average Subsidence Rates along East-West Section at 2060 N at Closure.

Survey Monitor	Time Period	Duration (Days)[1]	S_1 (mm)	S_2 (mm)	Total Vertical Displacement (mm)	Displacement Rate (mm/day)	Comments
S12	Oct/00-July/02	668	1480	2350	870	1.302	Constant
S4	May/96-Aug/96	122	1170	1580	410	3.361	Accelerating[2]

Notes: 1. Duration assumes initial reading on first day of month and last reading at end of month.

2. Monitoring terminated while mining still in progress.

Table 3 Average Subsidence Rates along North South Section at 1500E at Closure.

Survey Monitor	Time Period	Duration (Days)[1]	S_1 (mm)	S_2 (mm)	Total Vertical Displacement (mm)	Displacement Rate (mm/day)	Comments
S5	Sept/99-Jul/02	1063	1480	1800	320	0.301	Accelerating
S4	May/96-Aug/96	122	1170	1580	410	3.361	Accelerating
S13	Apr/96-Aug/96	152	150	250	100	0.658	Accelerating[2]
S19	Jun/99-Oct/01	882	1000	3500	2500	2.835	Accelerating[2]
S20	Oct/01-Jul/02	303	1750	2500	750	2.475	Accelerating
S22	Oct/01-Jul/02	303	570	910	340	1.122	Accelerating
S2	May/00-Oct/00	183	110	140	30	0.164	Decelerating
S35	Oct/01-Jul/02	303	110	250	140	0.462	Accelerating
S34	Oct/01-Jul/02	303	60	150	90	0.297	Accelerating
S8	Aug/93-Jul/02	3284	0	0	0	0	No movement
S23	Oct/01-Jul/02	303	0	80	80	0.264	Accelerating
S33	Jul/97-Sept/99	821	0	0	0	0	No movement
S32	May/98-Jul/02	1551	0	0	0	0	No movement
S36	Mar/00-Jul/02	882	0	0	0	0	No movement

Notes: 1. Duration assumes initial reading on first day of month and last reading at end of month.

2. Monitoring terminated while mining still in progress.

The following is a summary of the discussion of the subsidence movements as documented by Teck in December 2002. Further commentary by BGC, based on the above summary is noted for each monitoring point:

- SUB-20, started to move in 1998, and has dropped 2.50 m. Teck expected that this pin would begin decelerating in movements soon, allowing predictions to be made of the final level of subsidence in this area. This point is located very close to the northern limit of surface cracking associated with the Sinkhole area. The graph tracks subsidence from the start of movement to closure.
- SUB-22, located just to the north of SUB-20, started moving in 1999. It was down 0.91 m. Teck considered that this pin was still in the high velocity part of the expected curve. This point is located very close to the northern limit of surface cracking associated with the Sinkhole area. The graph tracks subsidence from the start of movement to closure.
- SUB-3 is located west of the Sinkhole, over the Panhandle Zone. This station had been moving at a fairly constant rate since 1994. Panhandle pillars were mined during that time. Tension cracks in this area were quite pronounced and extended throughout the cement storage pad area. These cracks were interpreted by Teck to be related to Abutment mining and were probably affected by the undercutting of A stope late in 2001. The plot shows a total movement of about 1.6 m. A slight acceleration of movements was noted since October 1998. This monitor is located very close to the west limit of surface cracking associated with the Sinkhole. The graph tracks subsidence from the start of movement to closure.
- SUB-12 is located right over top of the Abutment Pillar. This pin showed some movement before Abutment mining began in 1997, but increased in velocity afterwards. It was down 2.34 m and was expected to enter the deceleration phase in the near future. Movements have been steadily accelerating since movements began. The deceleration phase of movements had not yet taken place at closure.
- SUB-5 is at the south end of the Sinkhole. There was little mining at this end of the orebody in the previous years. The subsidence curve showed that movements underwent acceleration, rapid movements and then deceleration. The measured subsidence was 1.69 m, unchanged from the previous year. No further subsidence was expected after backfilling 185 Stope during the reclamation phase. The graph shows a total displacement of 1.8 m at closure. The rate of subsidence noted at closure represents a slight acceleration that began in September 1999, after having decelerated in 1994.
- Immediately north of the Sinkhole, the subsidence front covers the northern limit of ground movement. Beyond that the pins had just started to move. These pins are above the North Keel Zone, which had been mined differently than the Central Keel. The North Keel is 30 m high, deeper underground, and is filled entirely with CRF. The entire hanging wall was supported with 8 m or 12 m long grouted cables. Teck noted the following subsidence movements in this area:

  - *SUB-23 is located directly above 232 stope and had moved 6 cm (just past the 50 mm limit defining subsidence). This stope was completely filled with dry fill and is 80 m from the shoreline.*
  - *SUB-33, 32, 36, 37, and 8 are located north of SUB-23 and none of these stations had movements defined as subsidence (i.e. all movements were <50 mm). There was little or no extraction in this area and no signs of major acceleration. Large scale subsidence similar to the Sinkhole was not expected*. S8 indicated no subsidence related movements and was inferred by BGC to represent the northernmost limit of potential ground movements associated with the Sinkhole area. This point is located about 335 m north of the 202 stope.
- Further to the north, subsidence pins over the Ocean Zone were beginning to trend downward, however Teck didn't consider the movements to be subsidence related. The Ocean Zone was mined 30 m high, with 4 m rib pillars running north-south and 5 m posts running east-west between pillar stages. The entire hanging wall had been supported with 8 m long grouted cables. Mining of the Ocean Zone took place over 4 years, with no subsidence. No hanging wall failures occurred and all stopes were completely dry filled. No major subsidence concerns were anticipated in the Ocean Zone.
- It was anticipated that conservative mining methods used in the Ocean Zone would contain any major subsidence from mining in the southern part of the mine.
- On the east side of the Sinkhole, a series of posts runs from the end of 215 Pillar (part of the Central Keel) towards the New Quarry. The following subsidence related movements were noted along this array:
  - *SUB-18 is closest to the 215 Pillar and had subsided 1.05 m. There was a large hanging wall cave in Stage 1 of 215 Pillar (the easternmost stage). The rest of the pillar was taken in smaller stages and filled with CRF. No further hanging wall damage was incurred.* This point is located within the zone of surface cracking along the east side of the subsidence zone. The rate of subsidence at closure represents a deceleration that began in July 2000.
  - *The rest of the pins showed constant and diminishing movement as they get further from 215 Pillar, as expected. All stations experienced subsidence level movements, with SUB-14 being displaced 63 mm. Surface tension cracks have not extended further to the east.* S16, S17 and S18 lie within the zone of surface cracking on the east side of the subsidence zone. S14 and S15 lie to the east of the zone of cracking but were still undergoing constant, but small rates of movement at closure. Therefore the limit of ground movements extends to the east of S14 (*i.e.,* to the east of Station 1670 E).
- On the west side of the Sinkhole, the pins in the West Panhandle area had just moved into the classification of subsidence, with measurements ranging from 70 mm to 110 mm. The West Panhandle was filled with CRF and dry fill. Support includes

5 m wide posts and 8 m long grouted cables. Active mining was underway in this area in the previous year and Teck anticipated some further subsidence. Movements west of S3 could be related to the West Panhandle area. Nevertheless, the western limit of ground deformations at closure was not defined.

- Teck noted that they had never had surface water enter the mine workings, even with the existence of surface tension cracks and large seasonal runoff.

The extent of the subsidence limits, as measured by the surface monitoring pins during operation was a direct footprint of the orebody with the exception of the Ocean Zone, which has not experienced any subsidence. Teck attributed the stability of the Ocean Zone directly to the conservative mining extraction and extensive measures taken in ground support.

3.3.2. Conclusions Regarding Subsidence at Polaris

Based on the above summary, BGC has concluded that at the time of mine closure, the Sinkhole and surrounding subsidence area was limited to the Central Keel area, where significant ground control problems occurred during mining. These ground control problems led to the development of hanging wall voids and partially backfilled stopes that could not be subsequently stabilized. The quoted maximum subsidence of 10 m noted by Teck is not specifically recorded by monitoring data since some instruments became lost or destroyed by subsidence movements or mine traffic.

The surface tension cracks defining the perimeter of the Sinkhole are generally centered over the Central Keel area (Figure 6). According to Teck, improved mining methods limited subsidence progression to the north. To the south, no further mining was taking place and the stopes were backfilled, limiting subsidence progression to the south. On the east side, no mining was taking place east of the Central Keel stopes, so there was no potential for subsidence progression to the east. The only area where continued progression of the subsidence front was expected was to the west, due to mining activity up to closure in the Panhandle area.

Using the surface monitoring points that were still active at closure, BGC prepared a plan (Figure 10) summarizing the total subsidence displacement and movement rates for those monitoring points still active at closure, as summarized in Tables 1, 2 and 3. The maximum measured amount of subsidence was 3.5 m at S19. This monitor also had the highest rate of movement, at a constant rate of 2.84 mm/day. The closest monitor (still active at closure) to the 202 stope failure is S12, which continued to subside at a constant rate of 1.3 mm per day. It is important to note that the only monitoring points active at the time of closure that showed a decelerating tendency were S17 and S18, located within the surface cracking zone on the east side of the Sinkhole. The movement rates here were in the range of 0.1 to 0.2 mm/day.

The estimated limit of ground deformations associated with the Sinkhole, based on BGC's interpretation of the data has been added to Figure 10. In comparison, the area being monitored by ground surface surveys during the post-closure period is also indicated. Note that the post-closure surveys only go as far south as Station 2000 N and do not include the southern portion of the Keel Zone, where hanging wall failures occurred. The post-closure area being surveyed also does not cover the monitoring points that experienced significant subsidence prior to closure, such as S3 and S5. Cracking of the landfill cover placed in the Reclamation Landfill within the sinkhole area indicates that movements have continued since closure. Teck has mapped the post-closure cracking, but this information was not included in the information provided in Appendix II.

A significant piece of data lacking in the information provided to date by Teck is the delineation of the area that was left unsupported underground as a result of the ground control problems. This information is critical in determining the potential and extent of ongoing subsidence.

In 2003, Teck prepared their response to INAC's concerns regarding the risk of further subsidence of the Sinkhole in the post-closure period. This documentation is included in Appendix II for reference. This information included a summary report prepared by Trevor Feduniak, P.Eng., Senior Mine Engineer, dated September 30, 2003, which addressed the following issues raised by INAC:

- A description of the method of subsidence.
- Thermal regime and ice conditions in the overburden.
- Thermal regime and need for installation of thermistors to monitor permafrost temperatures from the surface, and the underground opening.
- Impact of surface water pond on thermal regime and permafrost stability.
- Impact of placing fill on the rate and amount of subsidence and the permafrost regime,
- Estimate of maximum extent and depth of subsidence zone.
- Assessment of physical stability and protection required.
- Recommendations for ongoing assessment and monitoring.

Teck's assessment was primarily based on its review of the subsidence monitoring pins, as summarized in the previous section.

The following sections summarize BGC's assessment of the above issues, based on a review of the information provided by Teck, supplemented by background technical data from various public domain literature sources (Gilbride *et al*. 2005, Hoek *et al*. 1995).

3.3.2.1. Subsidence Mechanisms and Assessment of Monitoring Data

Teck pointed out that the subsidence measurements at Polaris could be considered a complex result of two distinct mechanisms:

- The uniform and predictable mining induced subsidence resulting from the bending of relatively thick units of rock overlying relatively thin, but laterally extensive areas of ore extraction.

- Subsidence related to Sinkhole type caving where relatively thin rock cover exists over very high stopes, bounded by tall, slender rock pillars.

The first mechanism, which relates to the typical coal mining case, would apply to all of the active mining areas in general, assuming ore extraction is accompanied by sequential installation of backfill and support to minimize further loss of ground. This mechanism of subsidence is directly related to mining activity and typically ceases soon after mining ceases. Predictive methods are available to estimate the subsidence using empirical relationships between height and width of underground openings, depth below ground surface and length of mined area.

The second mechanism, also known as caving subsidence, is very different, and can potentially lead to continued instability even after mining ceases provided that a void exists for material to cave in to. Therefore this is the critical mechanism that needs further assessment to determine the long-term risk for the public and wildlife at the mine site.

In general, no empirical predictive capability has been developed for this type of subsidence. Recently, numerical modeling using 3D discontinuum codes to simulate progression of stress fracturing of the rock and the large-scale mass flow of the caved material have been applied to the formation of block cave mining. However, these models require a good understanding of the underground geology and individual rock mass properties of each of the rock types, such as RQD, Geological Strength Index (GSI) (Hoek *et al*. 1995), Young's Modulus, Poisson's Ratio, friction angle, cohesion and rock mass strength (Gilbride *et al*. 2005).

The Sinkhole (caving) type subsidence occurs when the roof above an open stope begins to fail, or cave into the underground opening. As the failure progresses, the rock pieces fill up the stope. Since broken rock occupies more space than intact rock, the volume of intact rock required to fill the void is less than the volume of the void. As failure progresses, upward above the stope, the area affected by the stope increases like an inverted cone. This caving process can continue until the void breaks through to the surface under the right conditions, forming a "glory hole". The failure only becomes self-stabilizing if, at some point, the volume of rock produced by the progressive failure fills the void and begins to provide support again to the overlying rock, given enough distance remains to the surface.

Teck noted that, if the overlying strata remained intact, in the case where the volume of the stope is small relative to the volume of rock overlying it, the overlying strata may continue to bend so that ongoing surface subsidence is similar to the coal mine case. Teck acknowledged that the subsidence zone represented a sinkhole type failure. However they did not provide any further opinion as to whether the failure had progressed through to the bedrock surface. The presence of surface cracking at the edges of the subsidence zone at closure and the magnitude of subsidence in excess of 10 m are indications, in BGC's opinion, that caving has likely progressed to the surface. It is also important to note that the fault structures shown in Figure 5 may significantly affect the extent and progression of caving.

The caving mechanism of subsidence is typically characterized by two zones of surface disturbance (Gilbride *et al*. 2005):

1. A primary subsidence zone, characterized by mass movement of up to several order of magnitude (metres to tens of metres), ultimately creating a "glory hole."
2. A zone of secondary subsidence, or relaxation zone, peripheral to the primary subsidence zone, characterized by only moderate ground movement (centimeters to tens of centimeters). Within this zone, subsidence is usually visually evident in the form of tension cracks, scarps, tilting, sliding and damage to vegetation.

Demarcation of the two zones is sometimes obvious on the ground and is normally taken to be the precipice of the glory hole. As noted earlier, at Polaris, monitoring during active mining was carried out by a network of survey pins anchored to bedrock and visual indications of subsidence. Figure 11 illustrates the relationships between surface subsidence effects and unsupported underground openings for the generic caving subsidence model.

Caving typically propagates upward from the extraction level through the rock mass. The cave angle (or angle of cave) is measured from the horizontal from the top of the undercut or stope to the outer edge of the zone of cracking visible at the surface. In most hardrock mines, where block caving is used, the angle of cave is quite steep, ranging from 75^{o} to vertical (Gilbride *et al*. 2005). The zone of maximum subsidence is located directly over the caving underground opening. Movement of the zone of caving rock into the stope is controlled by the progression of overstressing, leading to back failures. The failed material fills the open stope, and the depth of the subsidence zone at the surface is controlled by the gross swell factor of the caved material. The cave angle is a property of the material, being a function of intact rock strength as well as discontinuity spacing, block size and inter-particle shearing resistance.

As subsidence takes place over the caving stope, the edges of the primary subsidence zone are put into tension due to the relative differences in ground displacements creating surface tension cracks. This relaxation zone is in contrast to the rock mass near the central part of the zone of subsidence which undergoes increasing compressive load as subsidence progresses. This relaxation zone shows visually discernable signs of subsidence, such as tension cracks or step-like offset scarps. The outer edge of the zone of tension cracking transitions into a zone of minor subsidence. In this region there are no visually discernable signs of subsidence at the surface, but the ground may still be undergoing displacements related to subsidence.

The angle of draw is the angle measured from the vertical from the undercut level to the outer limit of subsidence movement. Note that this angle is not a material property, but a function of the level of detail and resolution of subsidence measurements that can be made at the surface to discern the deformation limit. Given that the stope was not enlarged by further mining, the limits of the subsidence zone would become stabilized as soon as the caving mechanism stopped progressing.

During operations, the level of detail of surface subsidence measurements made by Teck did not permit a very precise definition of the ground deformation limit. Hence, the angle of draw is poorly estimated. As noted previously, the ground deformation limits at closure extended beyond the outer perimeter of monitoring points.

Since closure, the subsidence zone was filled with landfill materials and granular cover, raising the overall ground level and obliterating all previous surface monitoring points. Ongoing, post-closure monitoring was carried out using a roving differential GPS survey system, which has the advantage of gathering more survey point measurements than was previously provided with the limited, discrete surface monitoring stations. The disadvantage of the GPS method is that the year to year survey measurements are made at random locations so it is not possible to monitor a specific location with time. Each measurement point is affected by the roughness of the rockfill cover traversed during each survey. The overall surface deformations must be determined by plotting the annual survey data and comparing each year's measurements along profiles across the subsidence zone. The limit of ground deformations must be determined by interpolation between the various data points and annual data sets.

The new baseline of post-closure ground surface elevations of the Reclamation Landfill over the subsidence zone provide the only way to monitor for any ongoing, post-closure subsidence. Teck has submitted that lack of any further subsidence or progression of the limits of ground deformation is proof that caving has stabilized.

The survey plan over the subsidence zone, and related profiles based on 2003- 2008 annual measurements by Teck are presented in Figure 12. East-west sections across the subsidence zone are plotted in Figure 12, showing the various annual profiles. Assuming that the 2003 (black line) profile represents the new post-closure baseline ground surface on the Reclamation Landfill, the profiles show that no significant subsidence has occurred in the five years after closure, compared to subsidence in the order of metres during operation. Variations, both plus and minus, up to several tens of centimeters were noted between the 2003 topography and subsequent surveys, however this variation can easily be attributed to the repeatability and resolution of the survey being carried out over a rough rockfill surface. Also, contour lines have to be interpolated between data points which vary in location from survey to survey.

BGC added the locations of the monitor points used prior to closure on the sections for reference.

If the maximum subsidence rate of 2.84 mm per day, measured at S19 at closure had continued to 2008, an additional 6.9 m of settlement would have occurred. S19 is located close to Station 2200 N and Station 1494 E. The survey sections indicate less than 0.5 m plus or minus change since 2003. Note that between 2002 and 2003 when fill was placed in this area, an unknown amount of subsidence was taking place. Therefore, the post-closure surveys confirm that subsidence movements have significantly decelerated.

The section at 2150N passes through the main east-west array of monitoring points used prior to closure. The maximum difference in ground surface occurs in the vicinity of S11. The survey profiles show a 0.5 m difference between the 2003 and 2008 surveys. This monitor was no longer active at closure, being destroyed in October 1998. At the time it was destroyed, it was moving at a rate of 0.67 mm per day. At this rate, the total subsidence over five years would be 1.2 m. The apparent subsidence measured by surface surveys is about one-half this amount. Similarly, Teck's surface surveys show less than 0.25 m difference over 5 years of post-closure monitoring at the locations of S13, S17 and S18. These comparisons at known monitoring locations confirm that the rate of post-closure subsidence is significantly reduced from rates prior to closure.

Figure 13 is a section along 2150 N prepared by Teck from the data in Appendix II. The section indicates about 15 m of overburden cover on bedrock. The top of the failed stope is about 134 m below the bedrock surface. BGC has added the locations of surface cracking at closure, based on the mapped data shown in Figure 6. As shown in Figure 13, the angle of cave, based on the extent of surface cracking related to subsidence shown by Golder (1994) varies between 40^o and 74^o. The cave angle is flatter on the west side. This may be due to the influence of mining in the adjacent Panhandle Zone. Also, there is a pronounced easterly dip to the stratigraphy which may be affecting the symmetry of the subsidence cone over the Keel Zone.

Based on the extensometer data presented by Golder (1994) (Figure 5), caving extended at least to a height of 40 m above the stope. This means that potentially, the extent of caving has migrated to within about 97 m of the bedrock surface, as illustrated in Figure 13.

The host rock for the Keel Zone, as shown in Figure 13 is the Thumb Mountain Formation. If caving has progressed to the extent predicted above, the rock unit potentially forming the back of the caving stope is the overlying Irene Bay Formation. The uppermost rock unit in this section is the Cape Phillips Formation. The following is a description of these units (Teck 2001):

- Thumb Mountain Formation:
  - Ordivician limestone, Lower Member deposited in a shallow water tidal flat environment and Upper Member formed on a shallow water shelf environment.
  - Rock weathers into material characterized as well drained gravel.
  - Lower Member is exposed on west side of peninsula by Crozier Strait, between the shoreline and the accommodation complex area, comprising a fine-grained and micritic limestone.
  - The Upper Member is exposed in Little Red Dog Quarry.
- Irene Bay Formation:
  - Poorly exposed, recessive weathering unit.
  - Exposed in southeast wall of the Old Quarry, where it lies in contact with the

basal units of the Cape Phillips Formation.
  - Consists of interbedded green mudstone (shale), argillaceous gray-green limestone and massive gray limestone.
- Cape Phillips Formation:
  - Black, bituminous carbonate mudstone.
  - Exposed in New Quarry.
  - Orange weathering patches extend along frost shattered fractures.

The available documentation provides no further details on the engineering properties and rock mass behavior of these units. Based on the above descriptions, it is BGC's opinion that caving would progress, given the potentially large open stope volumes in the Keel Zone at the time failures were initiated, unless a thick, massive bed of intact, strong rock exists within the stratigraphic section. The vertical fault structures shown in Figure 5 may localize caving or result in large block movements, such as the one that initially occurred during mining operations.

As no subsurface investigations were conducted to assess the initial extent of the void during mining operations or the present, post-closure condition, it cannot be determined, from the available data, which of the following potential conditions now exist within the subsidence zone:

- The failed stopes are completely filled with caved material and no unsupported voids exist, resulting in long term stable conditions (the condition being assumed by Teck).
- Caving has only partially filled the void in the stope, leaving a potentially unstable roof, that may continue to subside unpredictably in the future.
- Caving has progressed to the point where the stope has become filled with caved rock, but a meta-stable equilibrium has been created around a void that has migrated above the stope, within the subsidence zone.

In the first case, there is no potential for long term risk associated with further subsidence. In the latter two cases, the potential exists for long term risk for future subsidence that could occur unpredictably.

The 1995 report by Golder gave no further comment on the potential subsidence mechanism, as there "*is little precedent which can be used to assess further subsidence…*".Golder suggested that more or less sole reliance will be on the information being gathered by mine staff and mine derived relationships, assisted, for example, by numerical modeling.

3.3.2.2. Ground Thermal Regime

The site is located within the continuous permafrost zone. Ground temperatures were measured underground during mining operations and ranged from -5°C near the outer edges on the ocean side of the orebody to -12°C to -15°C in the deep interior. The base of the permafrost is estimated to be about 428 m below ground surface (NRC 1995) on Little Cornwallis Island.

Teck has also carried out temperature monitoring of surface and near surface ground temperatures during operations and post-closure. These measurements have indicated that large quantities of fill placed at the surface freeze within a short period of time, with a relatively shallow active layer, less than 1.5 m deep.

Climate change effects may influence the near-surface thermal regime, but are not expected to be significant with respect to the thermal regime deep underground. Teck has indicated that the permafrost regime has a beneficial "healing" effect within the subsidence zone. During the summer months, water can infiltrate the cracks and rock mass undergoing subsidence. Due to the high thermal mass of the frozen overburden and bedrock, this water will freeze before it can penetrate to the underground mine opening. This freezing action will seal off further infiltration and existing voids and cracks will become ice-filled in a self-healing process, adding to the strength of the materials in the subsidence zone.

BGC accepts that the healing by freezing mechanism improves the strength of the subsidence zone. However, its benefit can only be realized if subsidence movements have stabilized and stopped. Otherwise, ongoing subsidence induced movements will eventually overstress the rock-ice bonds, leading to loss of this healing effect.

The presence of ponded water within the surface depression created by the subsidence zone noted in the annual inspections by Teck and BGC is positive indication of the sealing effect by ice within the rockfill cover over the subsidence zone. The depth of the pond is too shallow to have any detrimental effects on the underlying ground thermal regime, as it freezes to the bottom every winter. The presence of the pond since closure may be considered an indicator that the fill placed into the subsidence zone is not undergoing any deformation that would lead to cracking of the ice filling the voids between the rockfill. The pond also provides a reservoir of water that would infiltrate any voids that were created.

3.3.2.3. Effects of Fill Placement Into Subsidence Zone

Teck estimated that 10-15 m of fill were added to the subsidence zone to bring the ground surface back up to pre-mining levels. This backfill placement was done as part of the construction of the Reclamation Landfill. The impact of this fill on subsidence rates was considered by Teck to be minor, based on the fact that there was about 150 m of existing rock cover over the stope.

No subsidence data was measured during the time that fill was placed, so it is not possible to assess if there was any ongoing movements until the new baseline was established post-closure, after the Reclamation Landfill was completed.

3.3.2.4. Extent and Depth of Subsidence Zone and Assessment of Long Term Stability

As noted in the previous sections, the actual extent of the underground area subject to caving was never clearly established by Teck. However, based on the surface subsidence expression, the area of concern has been clearly delimited by monitoring of surface movements. Based on the mechanism of caving described in Section 3.3.2.1, BGC's opinion is that Teck has not yet conclusively demonstrated that long term stability of the subsidence zone has been achieved. Nevertheless, the following are what BGC would consider to be positive indicators that support the conclusion that the risk of future subsidence that would be a hazard to the public or wildlife is low:

- Five years of surface surveys by Teck indicating no significant or consistent ongoing subsidence movements or increase in the area of ground subject to deformations.
- Prior to fill placing, Teck estimated that there was 10-20 m of soil overlying the bedrock. During the period of active subsidence and post-closure, this area was traversed by heavy mobile equipment, placing fill and recontouring the area, without incident or signs of sudden slumping or collapse.
- As the rate of subsidence has slowed, there is a tendency for the ground to become frozen and healed, regaining some strength of the materials within the subsidence zone.
- The presence of the pond within the subsidence zone depression since closure indicates and ensures that the rockfill beneath remains sealed by ice.
- Annual visual inspection shows no signs of localized movement or any significant and consistent propagation of surface cracking.
- The site is remote and not frequently visited by the public.

3.3.3. Conclusions Regarding Review of Subsidence Zone Data

Five years of post-closure surveys over the subsidence zone by Teck indicates that there has been no significant ongoing subsidence. The subsidence area continues to remain stable at the surface and does not present a safety hazard to the public or wildlife at this time. This assessment is based entirely on the ongoing annual visual and surveyed monitoring observations. It does not take into account the potential subsurface conditions that have progressively developed since the original stope failure during mining operations in the 1990's.

In BGC's opinion, the mechanism of subsidence of concern for long term stability is caving subsidence, which is hard to predict and may not, under certain conditions, achieve a stable, equilibrium condition once mining has ceased. Due to the lack of information regarding the actual extent of the underground openings undergoing caving, there is a possibility that the current state of stability may reflect a meta-stable condition. Because there is no empirical method or modeling basis to assess the relationship between the total amount of surface subsidence that has been measured and the geometry of the area undergoing caving, the lack of ongoing surface deformations is no guarantee that the ground won't subside again in the future. For example, a bridge of frozen material spanning a void at depth may have developed. Alternatively, caving may have progressed to the point where a thick, massive, strong bed of rock spans across a void caused by partial filling of the stope below. In either case, there exists a risk, albeit low, that caving or collapse of this meta-stable bridge, may result in renewed subsidence, or sudden slumping. Long term stability of the subsidence zone would only be assured if the failed stope has become filled with bulked caved material and no voids, composed of bridged material have developed.

In BGC's opinion, the risk that future subsidence would create a hazard to the public or wildlife is low, but cannot be entirely eliminated on the basis of the data provided by Teck to date. Despite the mitigating factors that may reduce the potential for further subsidence, the subsidence zone represents the only significant area of potential post-closure physical instability at the site. The Decommissioning and Restoration Plan (Cominco 2001) prepared by Teck describes the subsidence zone, but does not specifically address its stability or reclamation. To mitigate these concerns, and improve the level of comfort for regulators administering the Polaris mine site, BGC offers the following recommendations to Teck:

- Provide a complete set of copies of the Golder reports from which the extracts presented in Appendix II were obtained, as well as any other relevant data concerning historical mining operations and the mining sequence in the Keel Zone to better understand the actual timeline and failure sequence.
- If available mining records document in more detail the volume and extent of the unsupported underground openings associated with the subsidence, confirm the potential volume of voids and amount of material required to fill them to the point that they become stabilized. The potential long term risk is substantially reduced if it can be shown that the potential void volume is small, compared to the overall volume of the material in the subsidence zone.
- Using historical mine records, confirm the extent of ground support installed.
- Re-assess stability and subsidence using an updated version of cave and draw angles based on best estimate of the shape and extent of the unstable underground openings.
- Based on above information, develop a numerical model simulation to simulate caving and subsidence to show if the collapse progression becomes self- arresting and stable in the long-term, or if the potential exists for short-term meta-stable bridges and voids, subject to collapse and subsidence in the future. This will require input on rock mass properties and geological conditions around the orebody using historical mine records.
- If the above recommendations prove to be inconclusive, consider a program of site investigations to assess the subsurface conditions within the subsidence zone. Site investigations could include geophysical methods such as seismic and drilling to check for the presence of voids, or to confirm that the voids are filled with ice. This would require a costly remobilization of personnel and equipment to the site and would only be warranted as a last resort if there was a real concern for public safety.

4.0 GARROW LAKE WATER QUALITY REVIEW

4.1. Introduction

In the 2007 4th quarter report, Teck provided an explanation for the locally high concentration (approximately 1 mg/l) of zinc at a depth of about 10 m in the Garrow Lake water column. The explanation of “a thin layer of bacteriological tissue” was unsubstantiated by actual data. INAC has expressed a need to review this issue further as it is the only outstanding water quality anomaly. Although concentrations appear to have decreased since mining ceased in 2002, the anomalous concentration is close to the maximum authorized concentration in a grab sample according to the federal Metal Mining Effluent Regulations (MMER).

BGC sub-contracted this portion of the review to Lorax Environmental (Lorax), who reviewed the available sampling data and trends to provide an opinion on the possible causes and assess if there is any risk of future impacts to receiving waters. The complete review prepared by Lorax is included in Appendix III of this report. The following sections provide a summary of the major findings and conclusions noted by Lorax.

4.2. Key Findings

Lorax presented a detailed discussion on the geochemistry of the Garrow Lake water column, based on the information provided by Teck in the 3rd quarter 2008 report. The following is a summary of the key findings:

- Vertical profiles of T-Zn (total zinc) in Garrow Lake show a fair degree of uniformity both temporally and spatially.
- For all sampling episodes, T-Zn profiles show pronounced maxima at depths of about 10 m. The peaks occur at the upper boundary of the pycnocline that separates saline bottom waters from relatively fresh surface waters.
- For Zn to be associated with bacteriological tissue implies:
    1. T-Zn must be associated with particulate (bacterial) phases in the horizons of maximum concentration. This aspect could be effectively examined through collection of both dissolved and total Zn profiles to determine the relative proportions of dissolved and particulate phases. The vast proportion of bacteria will be effectively screened by filtration through a 0.1 or 0.2 micron membrane, and therefore the absence of particulate phases would preclude the notion of bacterial assimilation.
    2. Dissolved Zn must be removed from solution and concentrated by bacteria either as complexes sorbed to bacterial membranes or through active cellular uptake. Although possible, it is unlikely such mechanisms could concentrate Zn to the levels observed.
- Garrow Lake is naturally meromictic (permanently stratified), relatively saline and dense bottom waters are overlain by more dilute and less dense surface waters.

- The physical structure of the water column is clearly illustrated by the profiles of conductivity and temperature.
- The impact of Zn-rich effluents to the lake during active tailings discharge represents a source of dissolved Zn to the water column.
- It may be assumed that effluents were likely denser than pre-mining lake surface waters and probably less dense than the natural saline bottom waters of the lake.
- The T-Zn peaks in Garrow Lake may represent a relict signature from the period of tailings discharge.
- For this to be the case, the peaks in T-Zn represent the dissolved phases and the dissolved Zn levels in the tailings discharge were at least greater than the highest T-Zn values ever recorded in the water column.
- The maximum recorded value in the water column is 1.6 mg/l (March 2002). This value should be checked against historical records to verify that dissolved Zn levels in tailings discharges were greater than this value.
- Profiling for both total and filterable fractions could be used to verify the importance of dissolved Zn species.
- Above the 10 m horizon, T-Zn concentrations have remained relatively invariant since 2004 with mean values in surface waters (upper 5 m of water column) at the central site ranging from 0.17 to 0.25 mg/l.
- The relatively constant values in the surface imply that the mixolimnon has approached a pseudo-steady state condition.
- Within a given year, the lowest values in the lake surface have been measured in August which is consistent with the period of maximum fresh water input.
- T-Zn values in the lower water column have exhibited pronounced decrease during closure period. Between 2002- 2005 T-Zn levels below 15 m at the central station have decreased from 0.5 mg/l to <0.05 mg/l.
- The profiles of dissolved oxygen (DO), Fe, Mn and sulphide are indicative of reducing conditions in the water column below the pycnolcline. Free sulphide, in the presence of dissolved HS results in Zn precipitates from solution as secondary sulphide phases (ZnS, *i.e.,* sphalerite). ZnS is highly insoluble and will form before other competing sulphide phases such as FeS.
- The formation of ZnS is the leading hypothesis to explain the depletion of Zn in the bottom of Garrow Lake.
- In the zone at the upper boundary of the pycnocline where conditions are only mildly suboxic, sulphate reduction and therefore Zn removal is not predicted to occur. Therefore the relict Zn signature from historic effluent inputs in this region could persist over yearly time scales.

4.3. Conclusions and Recommendations

Lorax concluded that the Zn maxima in the water column of Garrow Lake are likely due to dissolved Zn fractions that represent a relict signature of Zn inputs associated with historic tailings discharges, rather than being associated with bacterial tissues.

Lorax recommended several low-cost measures that can be added to the monitoring program to support or negate the arguments presented in their report:

1. Collect measurements of both total and dissolved trace metals in the water column for one survey. A filter size of 0.1 or 0.2 microns should be used to filter out bacteria.
2. Add sulphate to the analyte list.
3. Collect measurements of dissolved sulphide (if not already being done) and use appropriate preservation methods.
4. Minimize the potential for oxidation artifacts during the collection of water samples through the use of a peristaltic pump and in line filtration.
5. Compare maximum T-Zn levels in Garrow Lake with those of historic effluent discharges to aid in assessing whether the Zn peaks in the water column represent a relict signature of historic tailings deposition.

Based on the assessment by Lorax, the Zn in the Garrow Lake water column is being naturally attenuated through the precipitation of sulfide minerals. Lorax recommended that the addition of dissolved measurements should be added to one sampling campaign only to assess the merits of using this component in subsequent surveys.

On a long-term basis, the water column data shows the stability of the meromictic nature of Garrow Lake. The anomalously high Zn concentration at the 10 m depth zone in the water column should not be a concern for future discharge water quality; given that lake discharge involves the uppermost portion of the water column which is diluted by freshwater inflow on a seasonal basis. To date the effluent from Garrow Lake has met all water quality parameters specified in the water licence. If the hypothesis proposed by Lorax proves to be correct, then the high Zn concentrations at 10 m depth should gradually attenuate to compliant levels, as the Zn precipitates as insoluble sulphide in the lower water column.

5.0 REVIEW OF 2008 AND 2009 QUARTERLY AND ANNUAL REPORTS

5.1. 2008 3rd Quarter

This report was submitted by Teck to the Nunavut Water Board and INAC on November 26, 2008. In a typical year, most of the annual monitoring requirements are carried out in the third quarter as the site is snow free in July and August. Teck reported that the site was occupied by five to six people between July 13 to July 19, conducting the annual geotechnical inspection, surveying, retrieving thermistor data and collecting miscellaneous samples. On August 24, the annual INAC inspection was carried out. On August 29, staff from AECOM Canada Ltd. (AECOM) conducted the Garrow Lake minimum ice thickness sampling event. By mid-September the site was snow covered and Garrow Lake was frozen, ending water sampling for the year.

The report includes the following items that were sampled or inspected in the 3rd quarter:

- Water quality samples of effluent discharge from Garrow Lake taken weekly during periods of flow.
- Surveyed the water elevation at Garrow Lake during mid-July.
- In late August (minimum ice conditions), the water chemistry of the water column of Garrow Lake was sampled at two locations.
- Wind speeds at Resolute Bay were reviewed during open water periods of Garrow Lake when the site was not occupied.
- Surface water quality samples of Frustration Lake and of the surface water observed at Little Red Dog Landfill were taken as required by the Decommissioning and Reclamation Plan approvals.
- Three soil samples of the former Concentrate Storage Building area were collected.
- The annual geotechnical inspection of the site by a professional geotechnical engineer contracted by Teck.
- Retrieval of daily temperature data from eight landfill thermistor strings that monitor the temperature conditions within the two landfills.
- The annual topographic surveys of the subsidence zone and marine foreshore were completed.

BGC noted the following key findings documented by Teck:

- Water quality monitoring of the effluent from Garrow Lake found that all water quality parameters were compliant with the limits in the Water License.
- The August 15 samples for LC_{50} acute toxicity arrived at the laboratory after the specified holding times due to delays in shipping and so results were not included in the reports. The other three samples passed with no acute lethality.

- Garrow Lake water column sampling test results were consistent with previous years, demonstrating stability of the meromictic nature of the lake. There is a decreasing trend in Zn concentrations over time at depth and at surface.
- Teck's sampling continues to show that the Zn concentration at Station 262-3 and 262-3A are identical and they have argued that there is no need to collect data from both stations.
- Sampling of surface waters at the Little Red Dog Quarry indicated lead concentrations of <0.0025 mg/l and zinc concentrations of 0.0269 mg/l, indicating no concern about uptake of metals.
- Frustration Lake TSS sampling (July 19, 2008) indicated a concentration of 3.5.mg/l confirming that the jetty remains stable, with no evidence of significant erosion since 2007.
- The 2007 survey over the subsidence zone was not completed due to equipment failure. The 2008 survey was successfully completed and showed no evidence of significant movement since surveys began five years ago.
- A map of the surface cracks currently exposed on the ground surface was not provided by Teck. A map of the surface cracks was made by Teck that documented the progression of cracking between 1995 and 2002 (Figure 6). Post-closure mapping of the cracks should be documented to assess the progression of subsidence-related cracking in the cover materials placed over the Reclamation Landfill, which now occupies the subsidence zone area. This evidence is key to supporting the post-closure survey data that subsidence movements have stabilized.
- Surveys of the marine foreshore area indicated that ice action and melt-out of ice lenses buried under the beach is altering the beach profile. However there was little evidence of any significant erosion of the shoreline.
- The annual geotechnical inspection was carried out by a registered professional geotechnical engineer with AECOM. No significant concerns were noted. The slump at the main portal noted by BGC in 2008 was not observed at the time of the geotechnical inspection due to snow cover. The area was repaired in 2009, as recommended by BGC in the 2008 INAC inspection report (BGC 2008).
- As noted above, BGC recommends that the geotechnical inspection report include some discussion regarding the post-closure crack mapping in the subsidence zone area.
- Continued monitoring of the gulley erosion and slopes around the New Quarry was recommended by AECOM to confirm that they have become self-stabilizing and do not progress into slope instability.
- Teck reported the following elevations of Garrow Lake: (Elevations measured in 2005-2007 were based on local benchmark datum. In 2008, surveys were changed to GPS based measurements. Pre-dam level of Garrow Lake was el. 1005.70 m).
    - 2005/June 27- el. 1005.11 m.

  - o 2005/August 24 - el. 1005.07 m.
  - o 2006/June 29 - el. 1005.50 m.
  - o 2006/August 20 - el. 1005.31 m
  - o 2007/July 31 - el. 1005.41 m.
  - o 2008/July 19 - el.1005.78 (measured by GPS).
  - o 2008/August 29 - couldn't measure water level due to big waves.
- Teck reported that Garrow Lake was ice-free before the middle of August 2008 and remained ice-free at the time of the August 29 sampling event. Two wind events on August 5-6 and August 28-29 were recorded at Resolute Bay. The August 29 sampling showed no unusual conditions of lake chemistry or salinity to indicate unusual mixing or lake instability.
- Ground temperature measurements in the Operational Landfill indicated 1.25.m of thaw within the 1.8 m thick cap confirming that the cover is working as designed. Thermistors at depths of 3 m or deeper have remained constant.
- Ground temperatures in the Little Red Dog Quarry landfill indicated an active zone of 1.5 m. Thermistors deeper than 3 m were still showing a cooling trend since materials were placed in 2002-2004.
- Soil samples from the former Concentrate Storage Shed area showed that lead, zinc and pH values were all below the approved remedial targets for the site.

5.2. 2008 4th Quarter and Annual Report

This combined report was prepared by Teck and issued to the NWB and INAC on February 12, 2009. No activities or sampling was carried out at the site during the 4th quarter of 2008 as the site is snow covered and there are no effluent discharges. All monitoring is done during the 3rd quarter, except for the sampling of Garrow Lake carried out in the 2nd quarter. The following is a summary of the closure and reclamation work undertaken during 2008:

- Camp opened on July 13, with a small crew of 5-6 people, which remained on site until July 19 to complete the annual inspection.
- Clean up of site litter, while crews were on site.
- Completed subsidence surveys, which showed no identifiable movement from previous years.
- Wind speeds were monitored at Resolute Bay. Two high wind events were noted on August 5-6 and August 28-29. Detailed sampling was routinely performed on Garrow Lake on August 29 and no impact from the high winds was detected.
- The waters discharging from Garrow Lake into Garrow Creek were fully compliant with the Water Licence during the year.
- Garrow Lake stratigraphy continues to be both physically and chemically stable based on the May and August sampling events.

- The annual geotechnical inspection was completed by an independent professional geotechnical engineer. In the 2007 inspection, a section of exposed geotextile was noted in the channel downstream of the toe of the decommissioned dam, which was removed in the 3rd quarter of 2008. There were no active areas of erosion identified. A minor slope failure in the Main Portal area was noted by INAC and was repaired in 2009.

Teck reported that the reclamation and monitoring costs for 2008 were $261,000.00. Total reclamation costs to date were $69,513,587.00. Teck's forecasted expenditure to 2011 was $1,224,000.00, based on the following annual breakdown:

- 2009 - $300,500.00
- 2010 - $440,000.00
- 2011 - $483,000.00

Teck requested that the reclamation security be reduced to $1.6 million. Although the MMER requirements no longer apply, Teck argues that the water license and DRP still include the same intense water quality monitoring program. As a result, the annual costs are higher than originally budgeted. Teck has requested that INAC and the NWB rationalize the water quality monitoring program, in view of the consistently compliant post-closure sampling results, so that annual monitoring costs can be minimized.

Teck prepared a Post-Demolition and Site Reclamation Spill Contingency Plan, dated December 2008, which was included in the report. Teck reported that all chemicals have been removed from site and all residuals have been cleaned up and removed during decommissioning. Current on-site storage includes two 5,700 L storage tanks and one 5,000 L double walled tank containing diesel in the bermed area south of the camp. Gasoline is stored in 205 L steel drums in a sea container near the camp. Approximately ten 205 L drums containing lubricating, hydraulic/transmission oil, grease and engine oil are stored on pallets and are replenished from Resolute Bay as required. Teck reported that there are five drums, or about 1,000 L of Jet B fuel stored on pallets at the airstrip.

MSDS sheets were provided for the following materials stored on site:

- automatic transmission fluid;
- diesel- Arctic;
- ethylene glycol;
- gasoline- generic;
- grease;
- hydraulic oil;
- Jet B fuel;
- lead acid batteries;
- lubricating oil;

- motor oil;
- oxygen;
- propane;
- Varsol®; and
- windshield washer fluid.

The following equipment was listed by Teck to be on site as of December 2008:

- six Honda quads;
- one Cat D6 dozer;
- one Skidozer all terrain/snow vehicle;
- one CAT 345BL excavator; and
- one Ford 8 yd. dump truck.

This equipment would be available in the event of an on-land spill and can be supplemented with additional contractor's equipment from Resolute Bay (depending on size and availability of airplanes). Teck also reported that there was a substantial supply of spill response kits stored in a sea container adjacent to the camp near the fuel and lubricant storage areas.

5.3. 2009 Quarterly Reports

The 2009 1st and 2nd Quarter report was submitted to INAC and the NWB on September 23, 2009. The 2009 3rd Quarter report was submitted to INAC and the NWB on January 12, 2010.

5.3.1. 1st Quarter

During the 1st Quarter of 2009, the Polaris Mine site remained unoccupied by personnel as no monitoring events or reclamation activities occurred during the quarter. Although the water license requires a mid-winter sampling of Garrow Lake stratigraphy for water quality parameters, this sampling event has historically not been carried out as the site is not safely accessible at that time. Charter aircraft will not fly to the site due to the dark conditions without the site having runway lighting and visual confirmation from the ground of landing conditions.

There was no discharge from Garrow Lake and thus there was no effluent discharge to monitor.

5.3.2. 2nd Quarter

In early June, the monitoring of the water column of Garrow Lake was carried out to capture the Maximum Ice Thickness conditions as required by the Water License. Teck reported that ice conditions were abnormally thick in 2008, with the ice being approximately 3-3.5 m thick. The sample analysis from ALS Laboratories continues to confirm that the stratigraphy of the lake is intact and stable and that zinc concentrations in the water column are low. There was no effluent flow during the quarter, so Teck had no effluent data to report. Landfill temperature data from the dataloggers connected to the thermistors was not collected during the quarter as there was only one day where anyone was on site.

5.3.3. 3rd Quarter

The key annual monitoring requirements for the Polaris Mine were undertaken during this period. The site was snow free during July and August. The temporary camp was open from July 19 to 24, with five to seven people on site to conduct the geotechnical inspection, surveying, planning for site abandonment, retrieving thermistor data and collecting other miscellaneous samples. Water quality monitoring was continued weekly by Teck using trained local residents flown in from Resolute Bay. An AECOM representative travelled to the site on August 16 to conduct the Garrow Lake minimum ice thickness sampling event. By mid-September the site was snow covered and Garrow Creek was frozen ending the water sampling for the winter.

Teck reported the following activities in the 3rd quarter:

- Water quality samples of effluent discharge from Garrow Lake were taken during periods of flow. All water quality results were compliant with the parameters specified in the Water License.
- Surveyed the water elevation of Garrow Lake during mid-July. The reading taken on July 24, 2009 indicated a lake elevation of 1006.09 (based on an arbitrary datum). The pre-dam lake elevation at the end of the discharge season was reported to be 1005.7. In comparison, the previous reading in 2008 (July 19) was 1005.97.
- In late August (minimum ice conditions), the water chemistry of the water column of Garrow Lake was sampled from two different sampling sites. No unusual results were noted and the chemistry continues to show the surface waters to contain zinc concentrations below 0.3 mg/l and at depth the zinc concentrations are below 0.02 mg/l. These results are consistent with previous years.
- Wind speeds at Resolute Bay were reviewed during open water periods for Garrow Lake when the site was not occupied. There were no wind speeds exceeding the criterion of 50 km/hour sustained over more than one hourly measurement, while the lake was ice free.
- Surface water TSS samples were taken from Frustration Lake. The laboratory report for the Sample taken on July 24, 2009 indicated a TSS of 24.4 mg/l. This measurement was inconsistent with the Teck’s visual observations at the time. Note that BGC/INAC did not have the opportunity to inspect this area in 2009 and therefore are unable to provide further comments.
- The surface water observed at Little Red Dog Landfill was sampled for zinc content. The results were:
    - Lead was <0.05 mg/l (total).
    - Zinc was 0.017 mg/l (total).

- Three soil samples from the former Concentrate Storage Building area were collected. The concentrations for lead and zinc were both substantially below the approved site remedial targets.
- The annual geotechnical inspection of the site by a professional geotechnical engineer was conducted. No areas of concern were noted.
- The daily temperature data for the past 12 months from the eight landfill thermistor data loggers in the two landfills was retrieved. In the Operational Landfill, the deepest active zone in the 1.8 m thick cover extended to a depth of 1.25 m. Temperatures at depth remained fairly constant over the past three years. In Little Red Dog Quarry, the deepest thermistor to warm up to near freezing in the 1.8 m thick cover was located 1.5 m below ground surface.
- The annual topographic surveys of the subsidence zone and the marine foreshore were completed. A topographic map of the subsidence zone was included in Appendix 6 of the Quarterly Report. Comparison of cross-sections based on data collected in 2005, 2008 and 2009 showed no evidence of any significant movement in this area. A crack survey was conducted in 2009 over the subsidence area in conjunction with the topographic survey. Further commentary on this information is provided below. The marine foreshore is continually being reworked by ice action, but there is little evidence of any significant erosion of the shoreline occurring.

With respect to the subsidence survey and crack mapping data presented by Teck, BGC has the following comments:

- A copy of the crack mapping survey from the 3rd Quarter report is presented in Figure 14 for reference.
- It would be useful to show the areal limits of the fill placed in the Reclamation Landfill after closure. This would assist in interpretation of the significance of the topographic data and crack mapping with respect to ongoing subsidence. For example, some settlement and perhaps cracking of the recently placed fill should be expected, but this has no relationship to subsidence induced surface ground movements. However, if the cracking can be correlated with cracking mapped prior to closure, then cracking of the cover may be an indicator of ongoing, post-closure subsidence related ground movements.
- Teck noted that identification of cracks in 2009 was not as consistent as in 2005. It was not known if this was due to the crack being missed in 2009, or if it in fact disappeared due to wind/rain/erosional effects at the ground surface.
- In 2010, the crack survey will be repeated to address the above discrepancies and uncertainties.
- BGC recommends that the 2010 INAC and Teck's annual geotechnical inspection be carried out together and in conjunction with the crack survey, preferably at the start of the season. This would permit all parties to undertake a joint inspection of the site, identify any outstanding issues and agree on any final remedial measures that could be carried out before the camp and equipment are demobilized.

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1. Summary

This report has summarized the results of the 2009 site inspection conducted by BGC on behalf of INAC. BGC conducted a review of the available data provided by Teck (see Appendix II) regarding the future risk to the safety of the public and wildlife in the subsidence zone. In addition, as part of this annual inspection and review of the DRP, INAC requested an assessment of the chemistry of the water column in Garrow Lake to comment on the anomalous concentration of zinc at the pycnocline. A review of the available data provided by Teck in their 2008 quarterly reports was conducted by Lorax and is included in Appendix III. BGC reviewed and provided comments on the 2008 3rd Quarter, 2008 4th Quarter and 2008 Annual, and the 2009 1st and 2nd Quarter reports prepared by Teck and submitted to the Nunavut Water Board and INAC.

6.2. Conclusions and Recommendations

With regard to the 2009 site inspection, there was no significant outstanding issue regarding the areas examined. The site appears physically stable and the ground thermal regime in the Operational Landfill and LRD Quarry covers seem to be indicating that they are performing according to design. The slump in the Main Portal Backfill noted by BGC in 2008 was repaired by Teck in 2009. In 2010, Teck will decommission the temporary camp and demobilize the construction equipment from the site. BGC recommends that Teck schedule the annual geotechnical inspection and the INAC inspection as a joint inspection in 2010 at the beginning of the season so that any outstanding mitigation work can be identified and addressed before demobilizing from the site. The annual topographic survey and crack mapping of the subsidence zone should take place during the joint inspection, so that all parties have the opportunity to inspect, document and discuss any unresolved issues related to the subsidence zone.

BGC's assessment of the subsidence data was limited by the lack of data describing the actual dimensions of the unsupported underground openings associated with the subsidence zone. At closure, several of the then active monitoring pins were still showing accelerating subsidence related settlements. Post-closure monitoring since 2002 by Teck indicates no significant subsidence has occurred. The area presently being surveyed by Teck does not cover the southern portion of the Keel Zone where the original hanging wall failures occurred. This includes the monitoring points that experienced significant subsidence prior to closure such as S3 and S5.

In BGC's opinion, the mechanism of subsidence is due to caving of unsupported rock into the open stope. This type of subsidence is difficult to analyze and predict using conventional empirical relationships. Long term stability of the subsidence zone would be possible if the caved material completely filled the underground openings by bulking. There is a potential however that caving has progressed to the point that a meta-stable void remains within the zone of subsidence. Therefore, there is an unknown long term risk of future subsidence. The lack of significant post-closure subsidence movements, alone provides no assurance that long term stability has been achieved. The risk to public safety is considered low on the basis of numerous mitigating factors. BGC has recommended some further desktop assessment using available historical mine records to try to verify the volume of the open stope affected by the caving subsidence. This would provide regulators with a higher level of assurance that the caving subsidence that has occurred to date has indeed reached a stable equilibrium by bulk filling of the unstable underground openings. As a last resort, additional subsurface investigations could be conducted, if the above desktop study was inconclusive and there was a legitimate outstanding concern for safety of the public and wildlife.

The assessment, by Lorax, of the water quality with respect to the zinc anomaly in the Garrow Lake water column by indicated that bacteriological tissue is likely not responsible for the high concentrations measured by Teck. Instead it is more likely that the zinc peaks are due to dissolved fractions that reflect a relict signature of zinc inputs associated with historical tailings discharge. The formation (precipitation) of ZnS (sphalerite) is the leading hypothesis to explain the depletion of Zn in the bottom of Garrow Lake. Lorax recommended several low-cost measures that could be added to the monitoring program to support or negate the arguments presented in their report.

Documentation provided in the 2008 and 2009 Quarterly and 2008 Annual reports addresses the requirements of the Water License. In general, the site is physically stable, permafrost is aggrading within the landfills, landfill covers are performing according to design and all water quality parameters are within the limits of the Water License.

7.0 CLOSURE

We trust this draft report meets with your requirements. Should you have any questions or require further information, please do not hesitate to contact the undersigned, at your convenience.

Respectfully submitted,

BGC ENGINEERING INC.
per:

Holger Hartmaier, M.Eng., P.Eng.
Senior Geological Engineer
Direct Line (403) 250.5185 ext.113

Reviewed by:

J. Roland Tosney, M.Sc., P.Eng.
Senior Mining Geotechnical Engineer

REFERENCES

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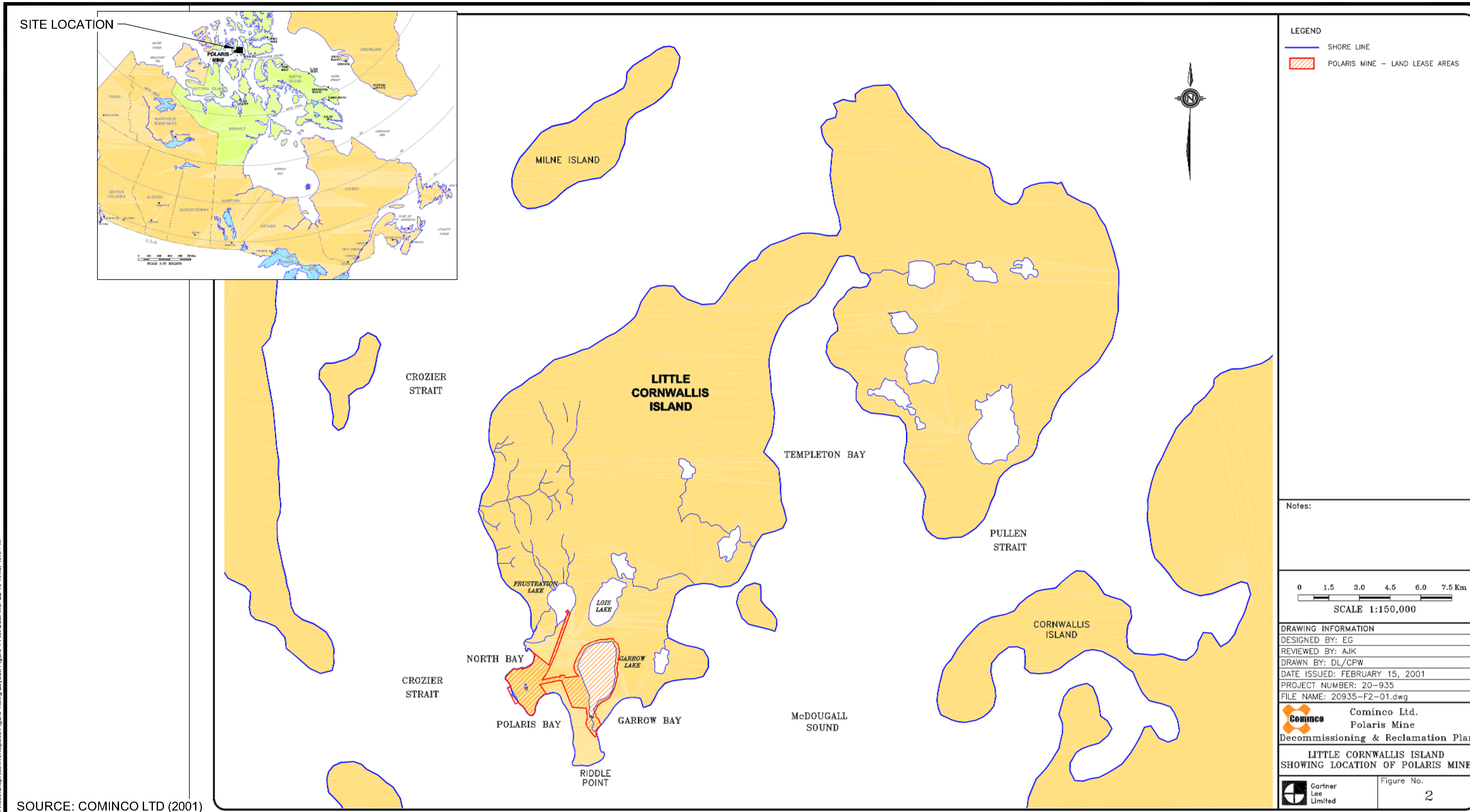
Teck Cominco Ltd., (2009), Polaris Mine Post-Reclamation Monitoring Report, 2008 4th Quarter and 2008 Annual Report, submitted to Nunavut Water Board and Indian and Northern Affairs Canada, February 12, 2009.

FIGURES



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SCALE:	AS SHOWN
DATE:	MAR 2010
DRAWN:	JL
DESIGNED:	HHH
CHECKED:	HHH
APPROVED:	HHH

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
POLARIS MINE - SITE LOCATION PLAN

PROJECT No.:	Figure No.	REV.:
0131-062-01	1	0

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010

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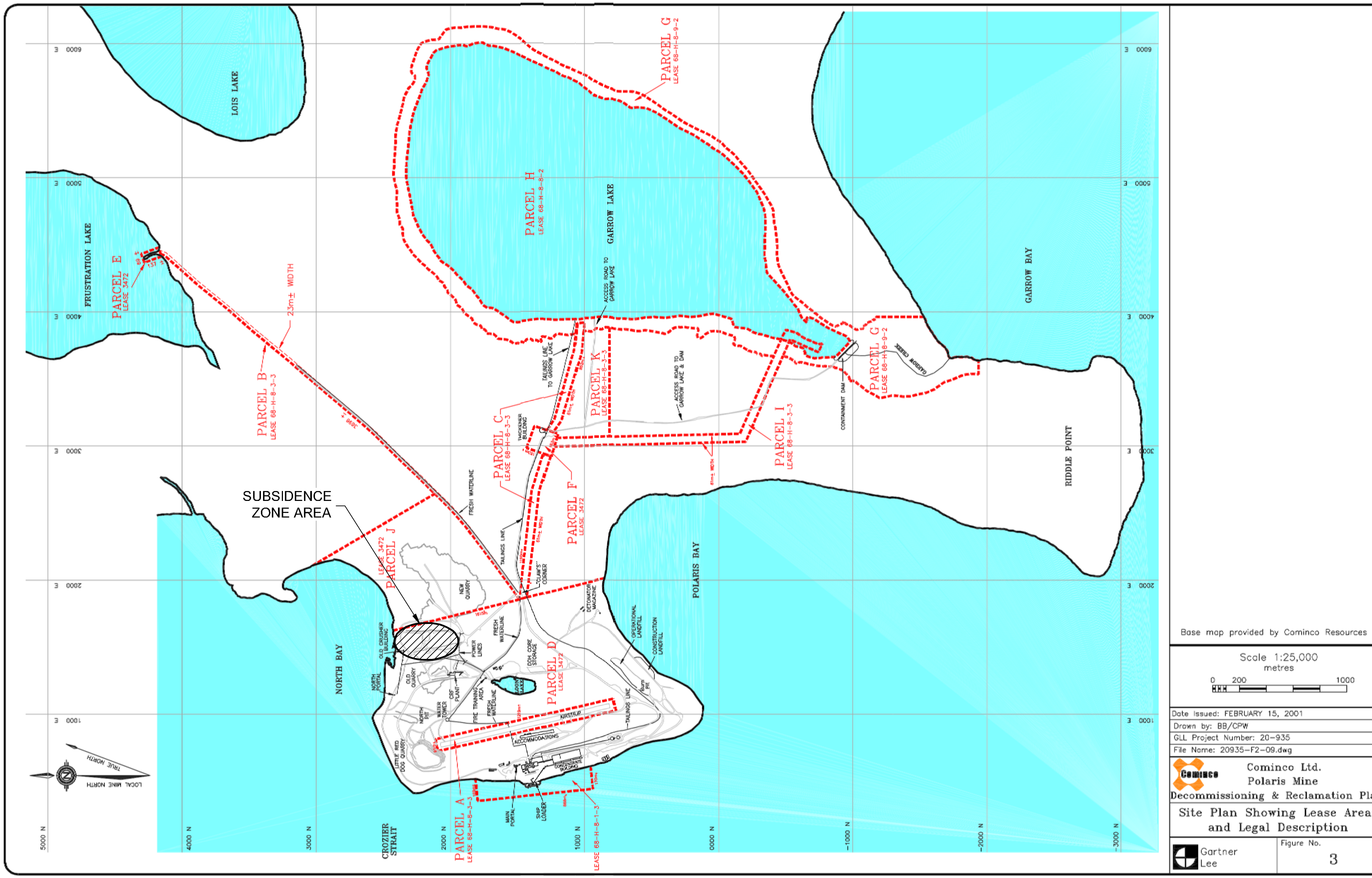

SOURCE: COMINCO LTD, 2001

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
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CLIENT: Affaires indiennes et du Nord Canada / Indian and Northern Affairs Canada

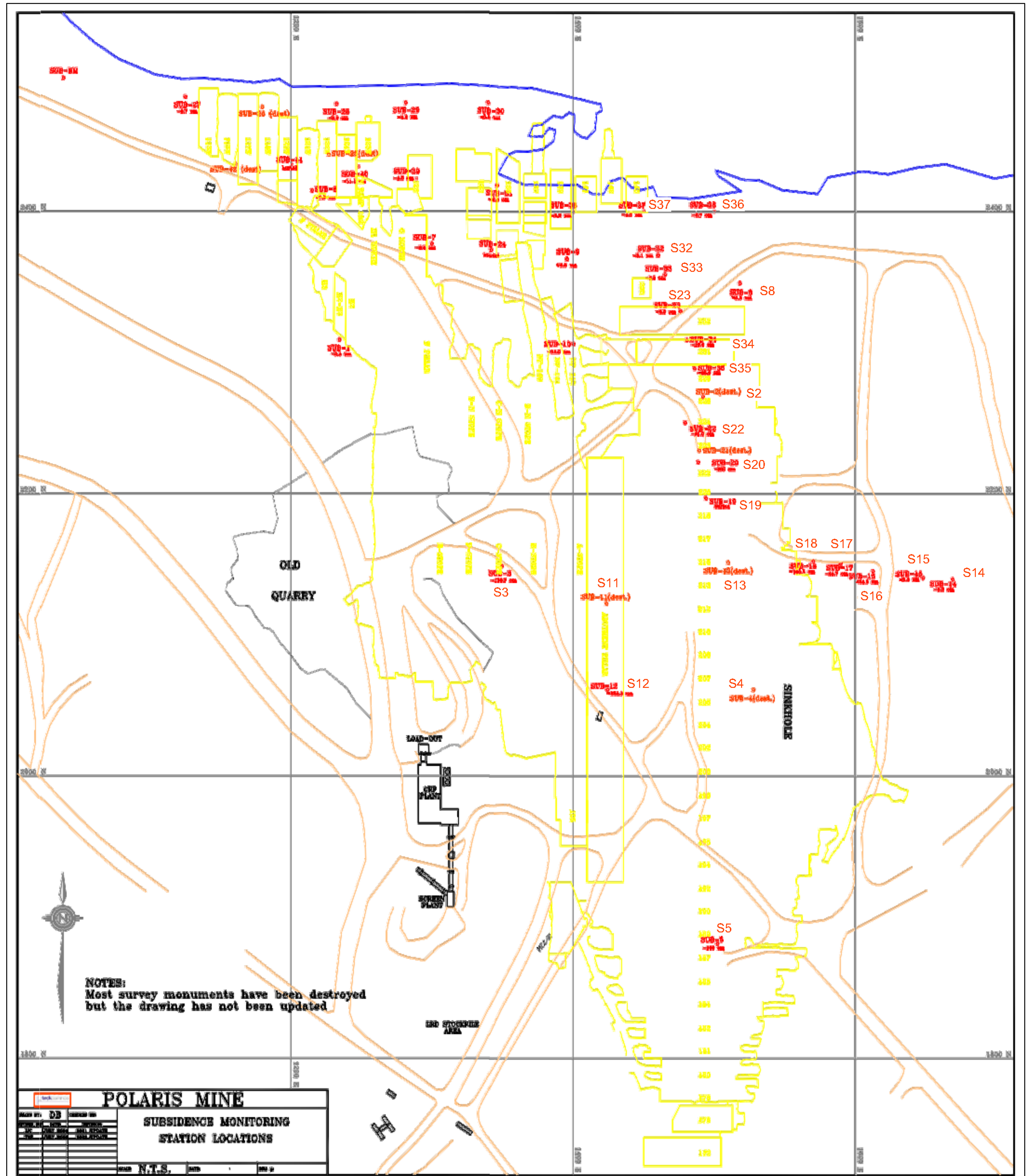
PROJECT: INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE: POLARIS MINE - SITE PLAN

PROJECT No.:	Figure No.	REV.:
0131-062-01	2	0

K:\Projects\0131 DIAND\062 Polaris Mine 2009 Services\Graphics\Workspace\Figure 2.dwg Layout: 2 Plot Date Mar 22 10 Time: 4:21 PM

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010



SOURCE: TECK COMINCO, 2003.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAR 2010
DRAWN:	JL
DESIGNED:	HHH
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AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
SUBSIDENCE ZONE - LOCATION OF MONITORING PINS PRIOR TO CLOSURE

PROJECT No.:	Figure No.	REV.:
0131-062-01	3	0

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010

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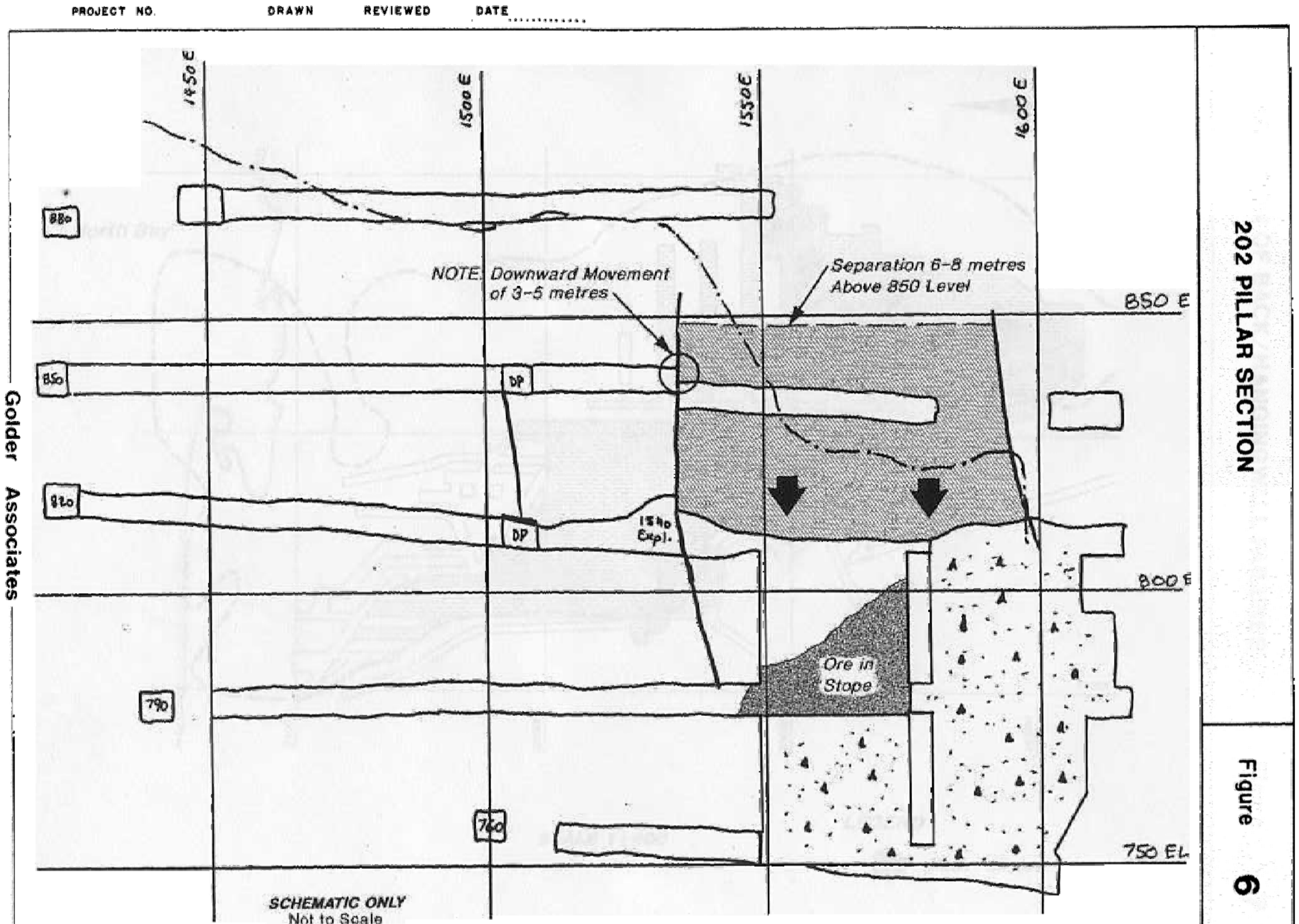

SOURCE: GOLDER, 1994.

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SCALE: AS SHOWN
DATE: MAR 2010
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Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
202 PILLAR SECTION - BLOCK FAILURE

PROJECT No.: 0131-062-01
Figure No.: 4
REV.: 0

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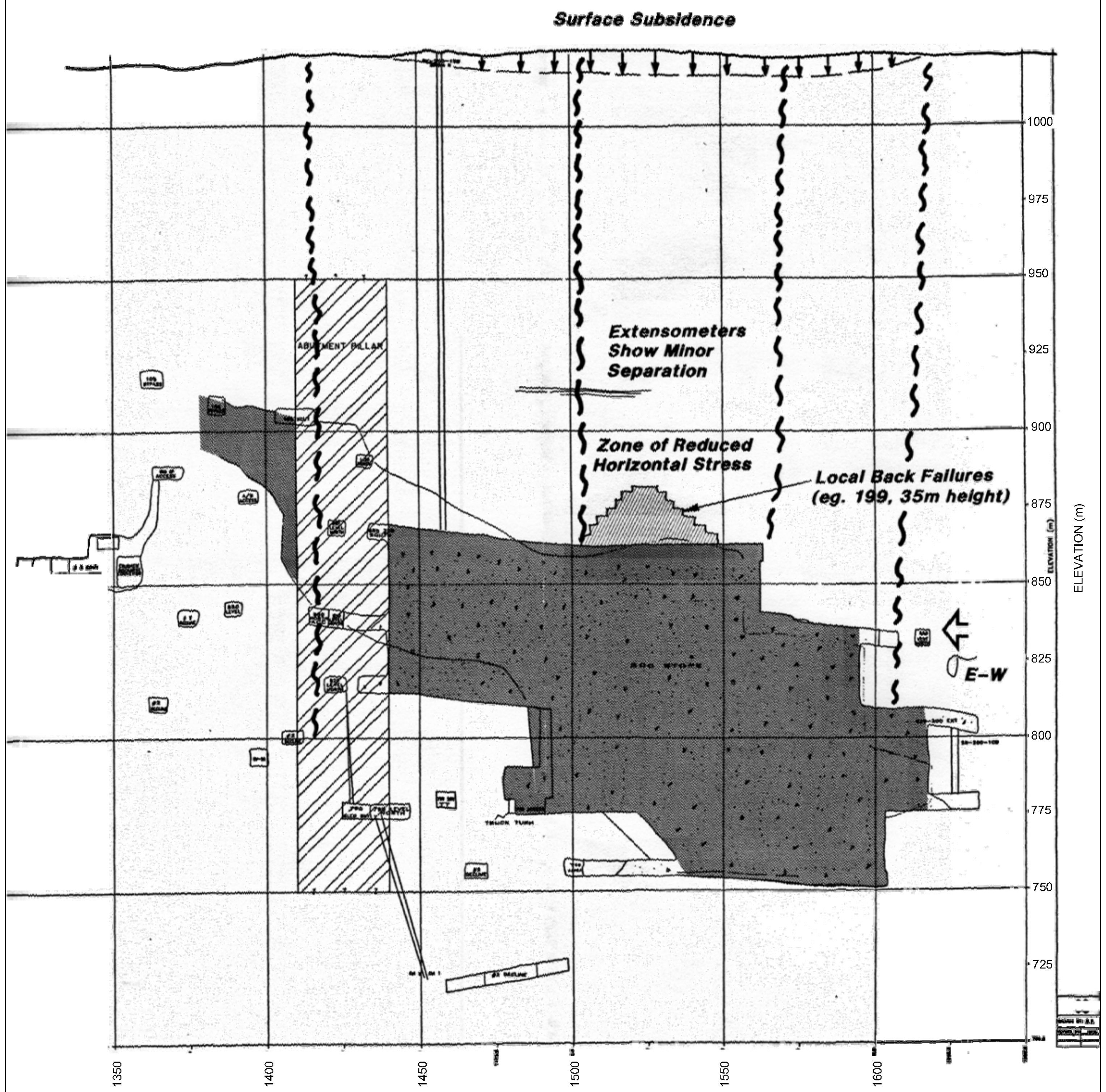
HANGINGWALL MODEL



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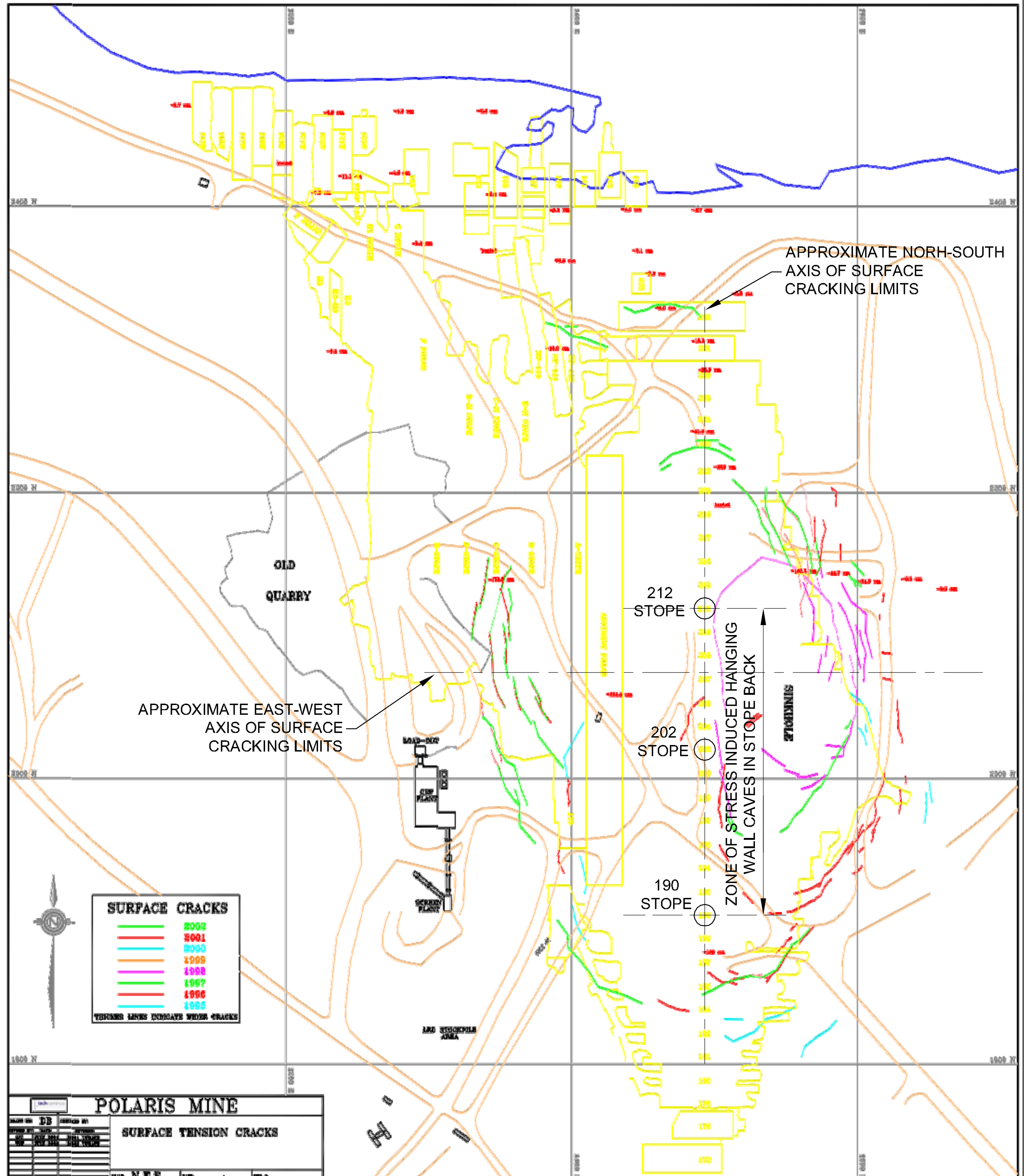
CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
SECTION SHOWING INFERRED
FAULT STRUCTURES IN KEEL ZONE STOPES

PROJECT No.:	Figure No.	REV.:
0131-062-01	5	0

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010



SOURCE: TECK COMINCO, 2003, MODIFIED BY BGC, 2009.

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CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
MAP OF SURFACE TENSION CRACKS AT CLOSURE

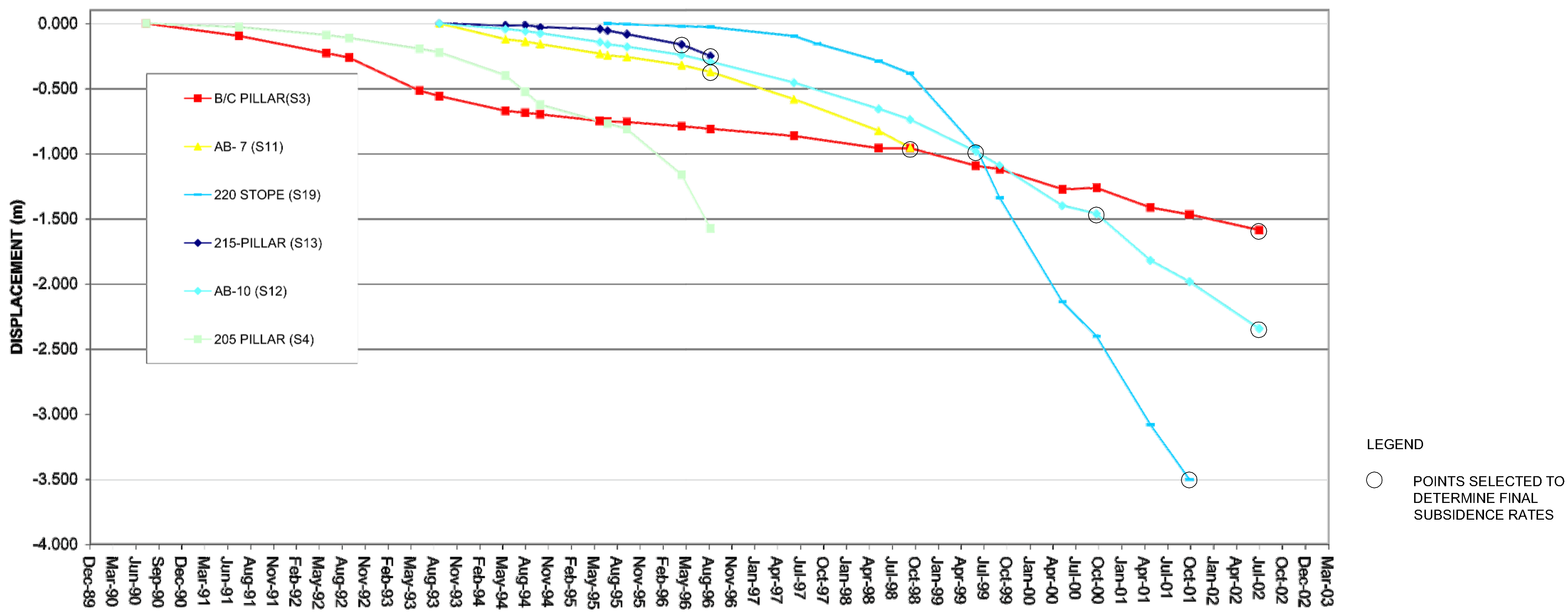
PROJECT No.:	Figure No.	REV.:
0131-062-01	6	0

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010

K:\Projects\0131 DIAND\062 Polaris Mine 2009 Services\Graphics\Workspace\Figure 6.dwg Layout: 6 Plot Date Mar 23 '10 Time: 1:26 PM

SUBSIDENCE DISPLACEMENT
WEST OF SINKHOLE AREA
AT 2150 N SECTION

teckcominco



SOURCE: TECK COMINCO, 2003, MODIFIED BY BGC, 2009.

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SCALE:	AS SHOWN
DATE:	MAR 2010
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APPROVED:	HHH

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Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
SUBSIDENCE PLOTS PRIOR TO CLOSURE
SECTION 2150 N WEST PORTION

PROJECT No.:	Figure No.	REV.:
0131-062-01	7	0

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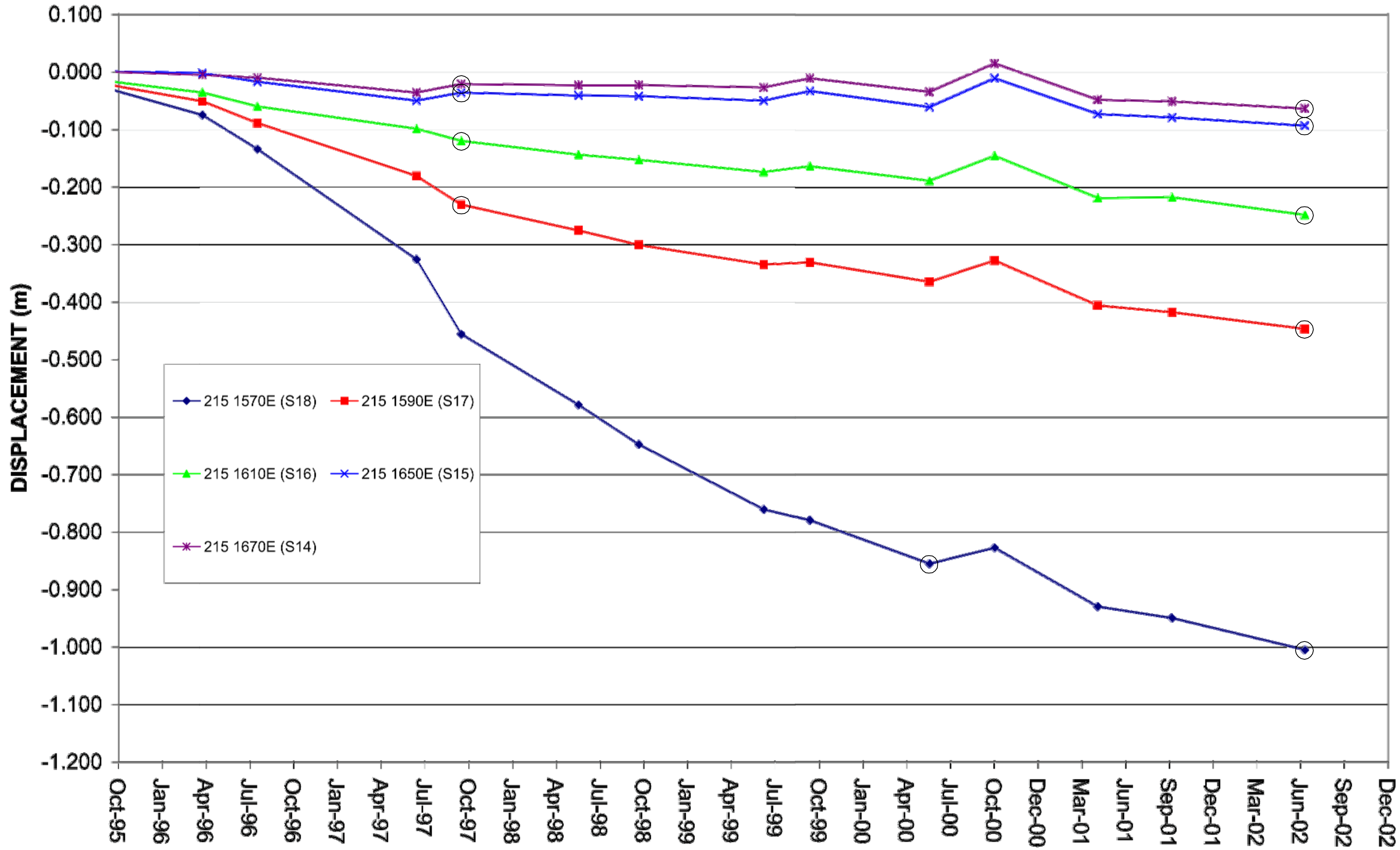
DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010

SUBSIDENCE DISPLACEMENT
EAST OF SINKHOLE AREA
AT 2150 N SECTION



LEGEND

○ POINTS SELECTED TO DETERMINE FINAL SUBSIDENCE RATES

SOURCE: TECK COMINCO, 2003, MODIFIED BY BGC, 2009.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
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APPROVED:	HHH

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Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
SUBSIDENCE PLOTS PRIOR TO CLOSURE
SECTION 2150 N EAST PORTION

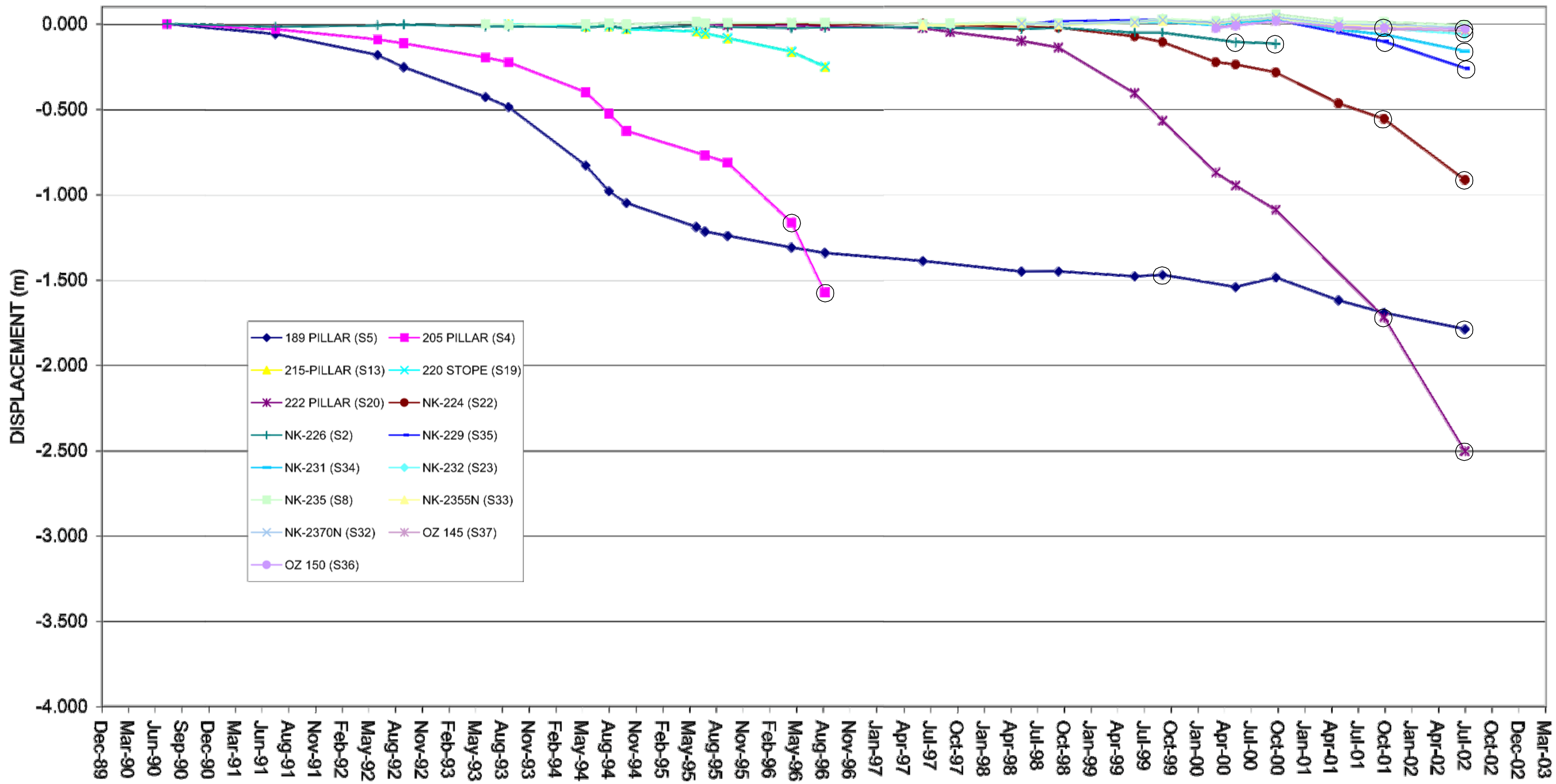
PROJECT No.:	Figure No.	REV.:
0131-062-01	8	0

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010

K:\Projects\0131 DIAND\062 Polaris Mine 2009 Services\Graphics\Workspace\Figure 8.dwg Layout: 8 Plot Date Mar 23 10 Time: 1:31 PM

SUBSIDENCE DISPLACEMENT
NORTH - SOUTH THROUGH SINKHOLE AREA
AT 1500 E SECTION

teckcominco



LEGEND

○ POINTS SELECTED TO DETERMINE FINAL SUBSIDENCE RATES

SOURCE: TECK COMINCO, 2003, MODIFIED BY BGC, 2009.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAR 2010
DRAWN:	JL
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INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
SUBSIDENCE PLOTS PRIOR TO CLOSURE
SECTION 1500 E

PROJECT No.:	Figure No.	REV.:
0131-062-01	9	0

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010

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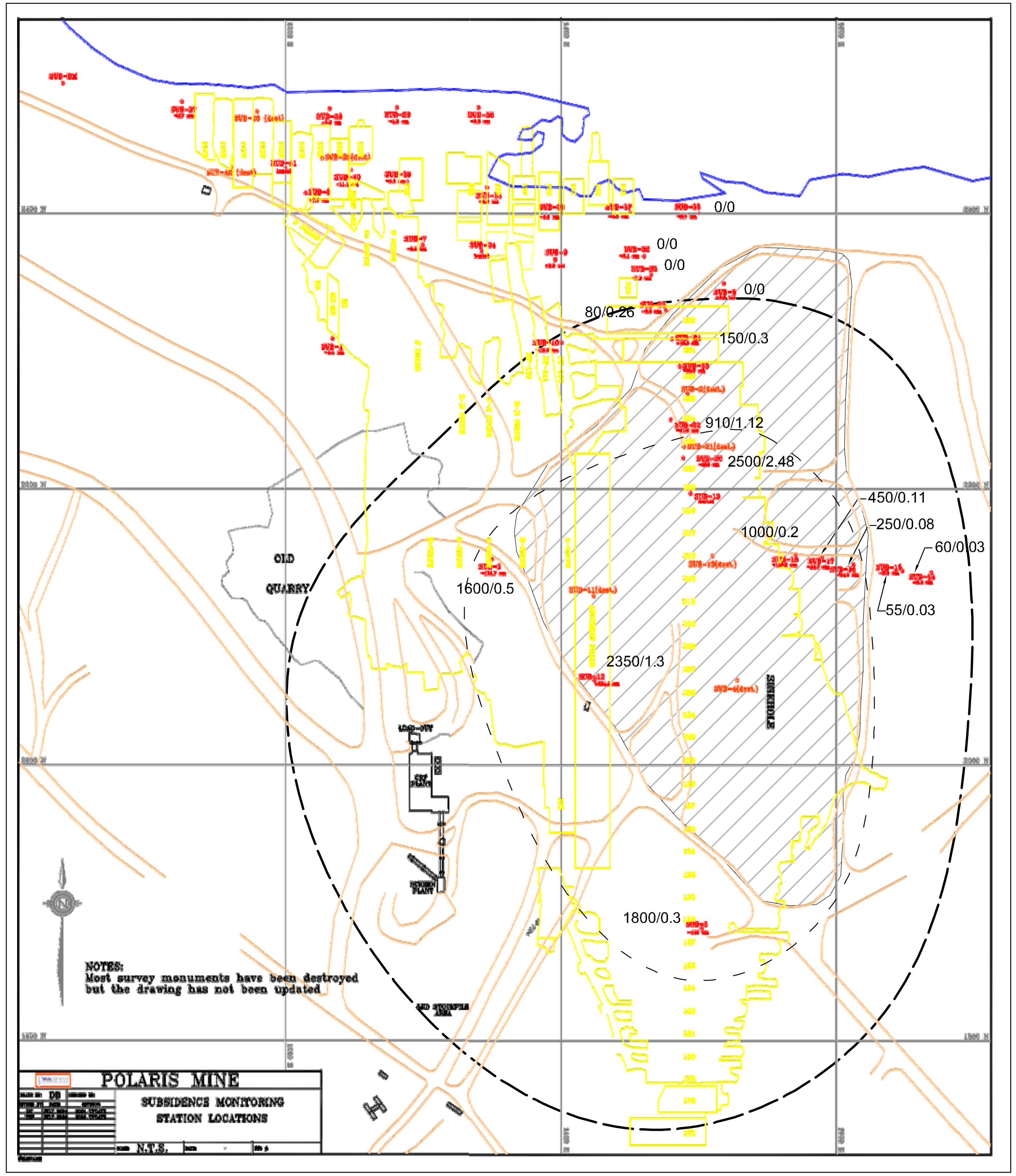

SOURCE: TECK COMINCO, 2003, MODIFIED BY BGC, 2009.

LEGEND:

450/0.11	TOTAL SUBSIDENCE mm/RATE OF SUBSIDENCE mm/DAY AT CLOSURE (JULY, 2002)
— — —	OUTER LIMIT OF VISUAL CRACKING AT SURFACE AT CLOSURE (JULY, 2002)
—— ——	ESTIMATED LIMIT OF SUBSIDENCE DEFORMATIONS ASSOCIATED WITH SINKHOLE
(hatched)	AREA BEING MONITORED BY TECK WITH ANNUAL GROUND SURFACE SURVEYS

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAR 2010
DRAWN:	JL
DESIGNED:	HHH
CHECKED:	HHH
APPROVED:	HHH

PROFESSIONAL SEAL:

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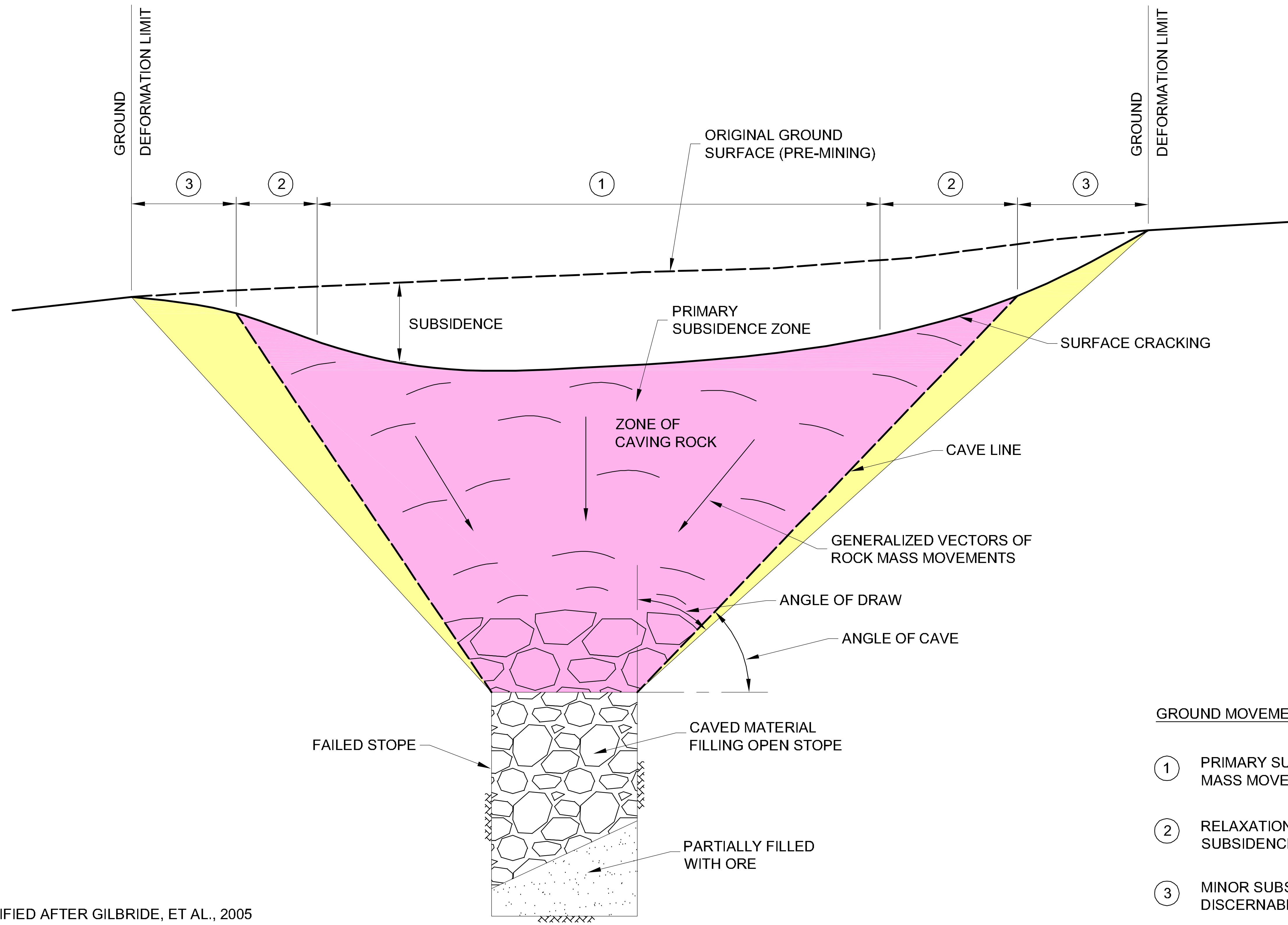
CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
SUMMARY DATA RELATED TO SINKHOLE SUBSIDENCE

PROJECT No.:	Figure No.	REV.:
0131-062-01	10	0

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010



GROUND MOVEMENT ZONES

1. PRIMARY SUBSIDENCE ZONE, DISCONTINUOUS MASS MOVEMENT.
2. RELAXATION ZONE, VISUALLY DISCERNABLE SUBSIDENCE EFFECTS, SURFACE CRACKING.
3. MINOR SUBSIDENCE WITHOUT VISUALLY DISCERNABLE SUBSIDENCE EFFECTS.

SOURCE: MODIFIED AFTER GILBRIDE, ET AL., 2005

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	NTS
DATE:	MAR 2010
DRAWN:	JL
DESIGNED:	HHH
CHECKED:	HHH
APPROVED:	HHH

PROFESSIONAL SEAL:

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

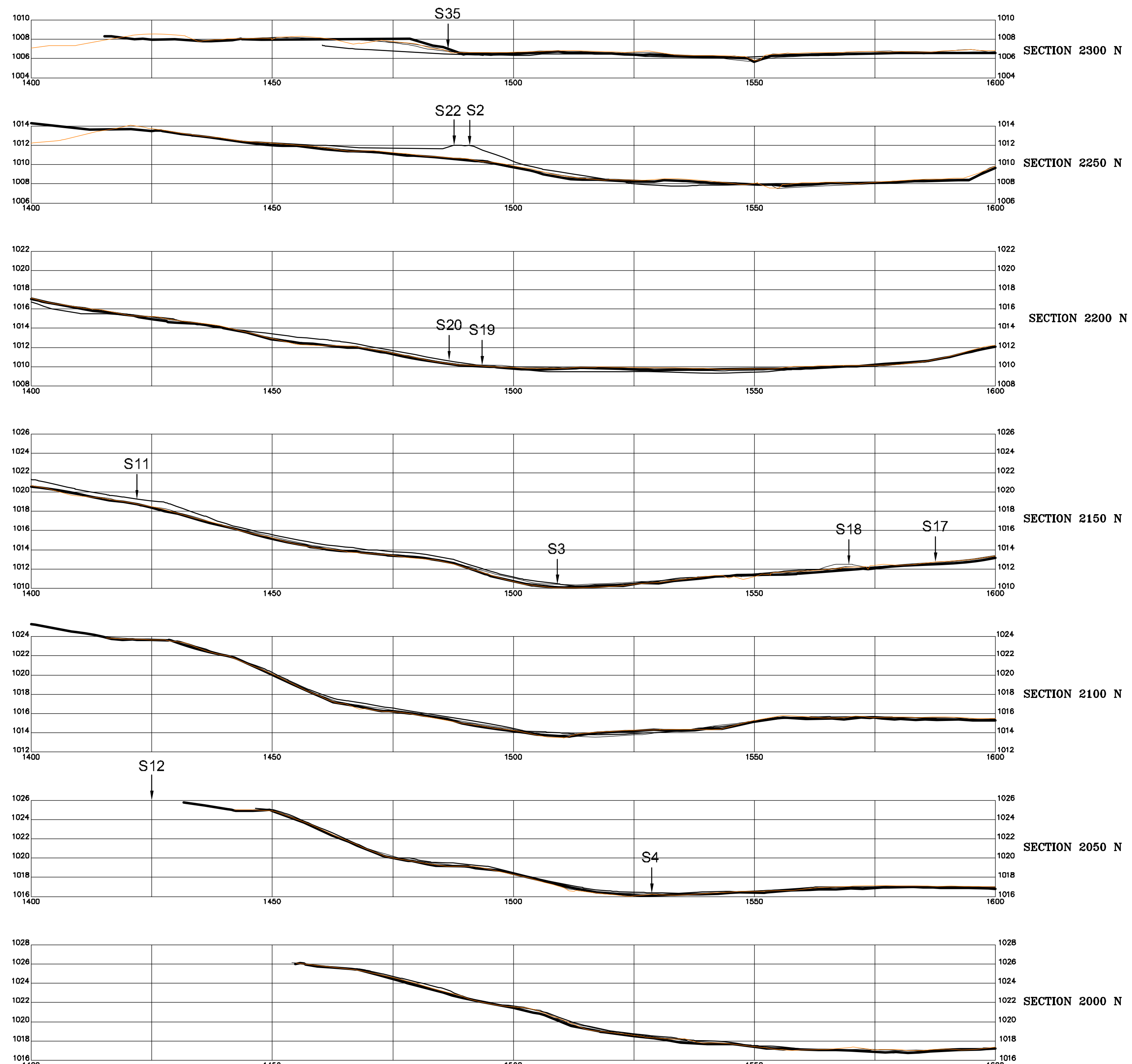
PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

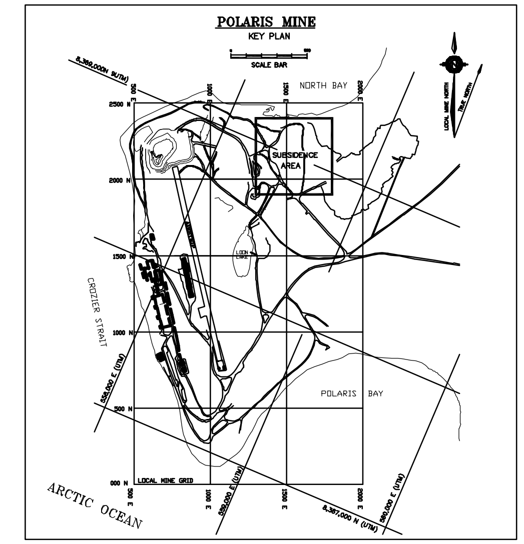
TITLE:
CAVING SUBSIDENCE MODEL

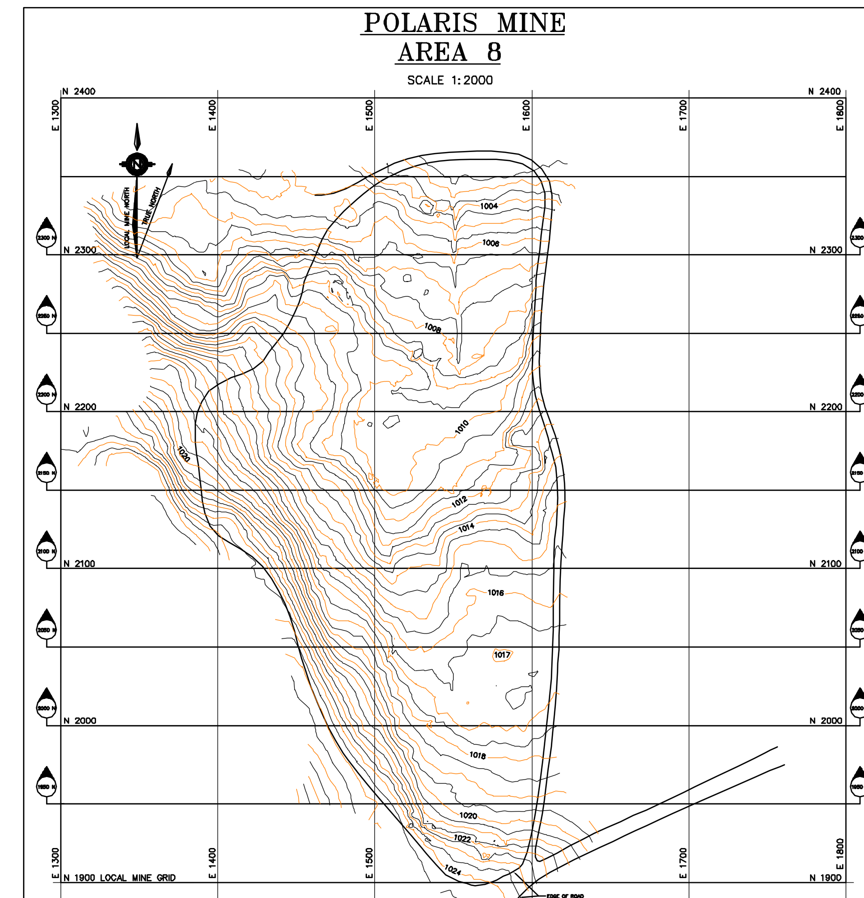
PROJECT No.:	Figure No.	REV.:
0131-062-01	11	0

K:\Projects\0131 DIAND\062 Polaris Mine 2009 Services\Graphics\Workspace\Figure 11.dwg Layout: 11 Plot Date Mar 23 10 Time: 1:34 PM

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010







LEGEND

S35 ↓ LOCATION OF SURFACE SUBSIDENCE MONITORING STATION

SOURCE: TECK COMINCO, 2008.

NOTES:
1. DATA COLLECTED JULY, 2006 BY TECK COMINCO REPRESENTATIVE.
2. SECTION CO-ORDINATES AND ELEVATIONS REFER TO LOCAL MINE DATUM.
3. CONTOUR INTERVALS = 0.5 m.
4. SECTIONS HAVE A 2:1 VERTICAL EXAGGERATION.

LEGEND:
- DENOTES 2008 SURFACE.
- DENOTES 2006 SURFACE.
- DENOTES 2005 SURFACE.
- DENOTES 2004 SURFACE. (THAW LAYER TO VIEW)
- DENOTES 2003 SURFACE. (THAW LAYER TO VIEW)

PROJECT:
POLARIS MINE POST CLOSURE
2008 ANNUAL SITE INSPECTION

DRAWING:
PLAN & SECTION VIEWS
SUBSIDENCE – AREA 8

DRAWN BY: T. M. TECH SERVICES
8-440
CLIENT:
DATE: NOVEMBER 17, 2008
SCALE: 1:500 HORZ. 1:250 VERT.
FIGURE No.: PM 2008 AREA 8
SHEET: 1 OF 1

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAR 2010
DRAWN: JL
DESIGNED: HHH
CHECKED: HHH
APPROVED: HHH

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

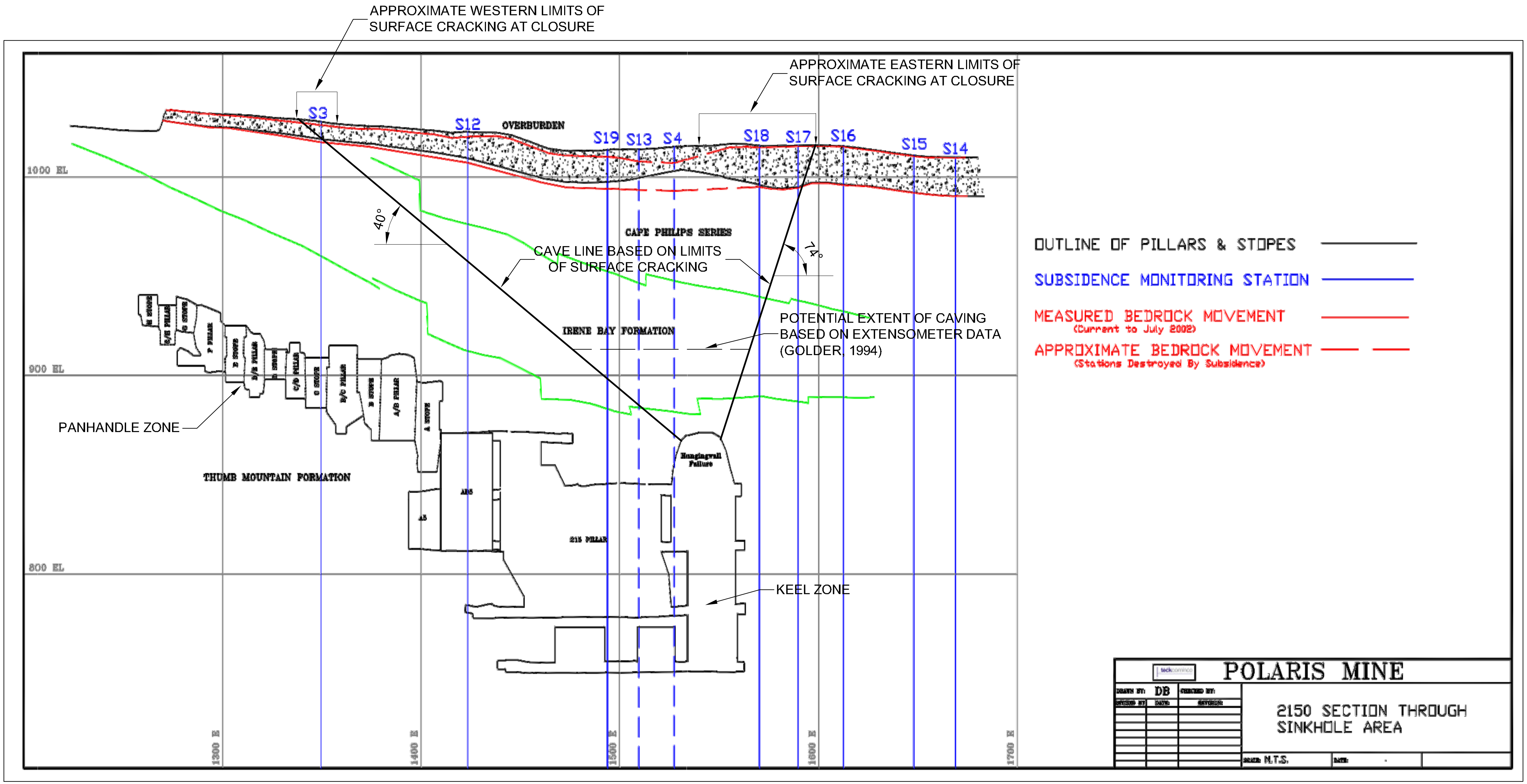
PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
PLAN & SECTIONS OF SUBSIDENCE AREA
SURVEYS 2003 - 2008

PROJECT No.: 0131-062-01
Figure No.: 12
REV.: 0

K:\Projects\0131 DIAND\062 Polaris Mine 2009 Services\Graphics\Workspace\Figure 12.dwg Layout: 12 Plot Date Mar 23 10 Time: 1:35 PM

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010



SOURCE: TECK COMINCO, 2003, MODIFIED BY BGC, 2009.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: AS SHOWN
DATE: MAR 2010
DRAWN: JL
DESIGNED: HHH
CHECKED: HHH
APPROVED: HHH

PROFESSIONAL SEAL:

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

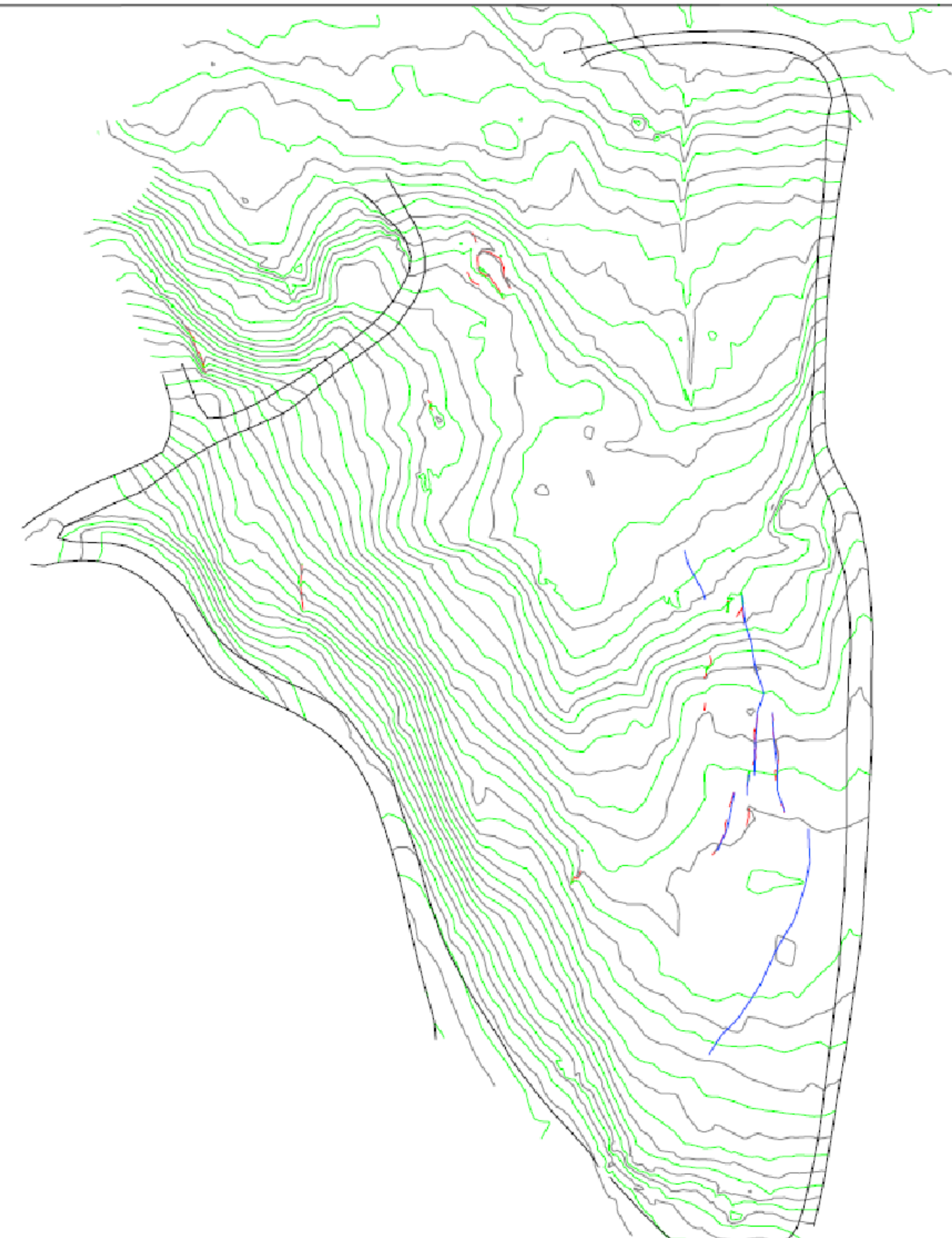
PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

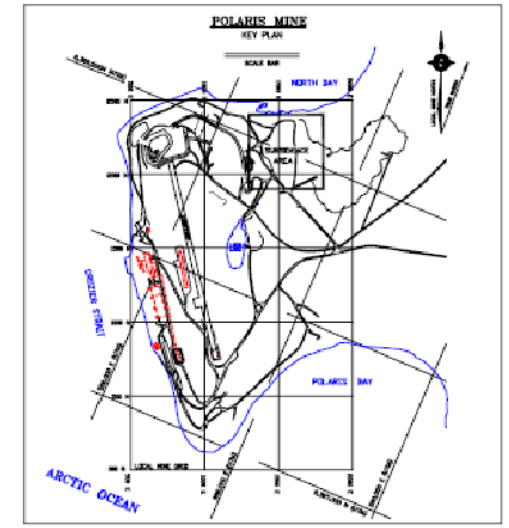
TITLE:
2150 SECTION THROUGH
SINKHOLE SUBSIDENCE AT CLOSURE

PROJECT No.: 0131-062-01
Figure No.: 13
REV.: 0

K:\Projects\0131 DIAND\062 Polaris Mine 2009 Services\Graphics\Workspace\Figure 13.dwg Layout: 13 Plot Date Mar 23 10 Time: 1:36 PM

DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010





POLARIS MINE
AREA 8

NOTES:

LEGEND:
- DENOTES 2009 SURFACE.
- DENOTES 2009 CRACKS SURVEYED
- DENOTES 2005 CRACKS SURVEYED

PROJECT:
POLARIS MINE POST CLOSURE
2009 ANNUAL SITE INSPECTION

DRAWING:
COMPARE 2005 TO 2009
SUBSIDENCE CRACKS – AREA 8

DRAWN BY: T. M. TECH SERVICES 9-506
CLIENT: Teck
DATE: JANUARY 12, 2010
SCALE: 1:2000
FIGURE No.: PM 2009 AREA 8
SHEET: 1 of 1

SOURCE: TECK, 2009 3rd QUARTER REPORT.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	AS SHOWN
DATE:	MAR 2010
DRAWN:	JL
DESIGNED:	HHH
CHECKED:	HHH
APPROVED:	HHH

PROFESSIONAL SEAL:

DRAFT

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Affaires indiennes et du Nord Canada
Indian and Northern Affairs Canada

PROJECT:
INDIAN AND NORTHERN AFFAIRS CANADA
POLARIS MINE - 2009 SITE INSPECTION

TITLE:
SUBSIDENCE ZONE CRACK MAPPING - 2009 vs 2005

PROJECT No.:	Figure No.	REV.:
0131-062-01	14	0

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DWG TO BE READ WITH BGC REPORT TITLED " INDIAN AND NORTHERN AFFAIRS CANADA POLARIS MINE - 2009 SITE INSPECTION" DATED MAR 2010

APPENDIX I

JULY 24, 2009 SITE VISIT SELECTED PHOTOGRAPHS

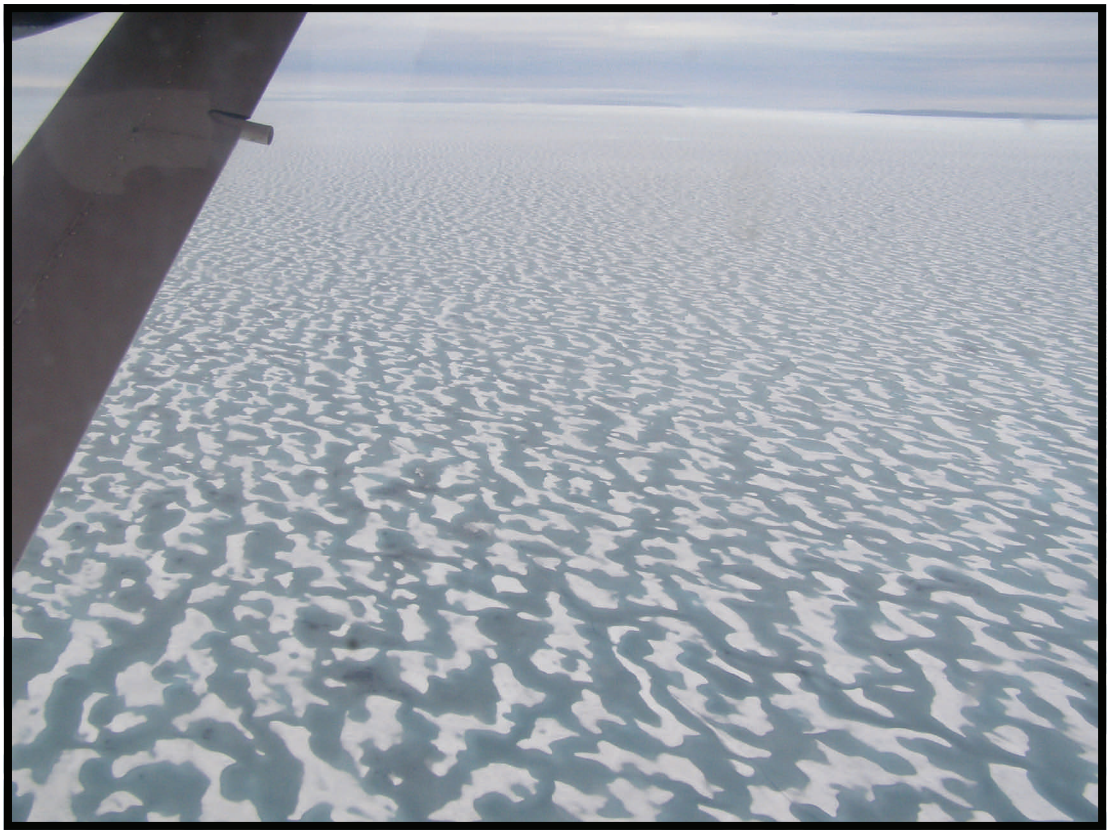
INDIAN AND NORTHERN AFFAIRS CANADA

POLARIS MINE DECOMMISSIONING AND RECLAMATION

SITE VISIT AND INSPECTION

Project 0131-062

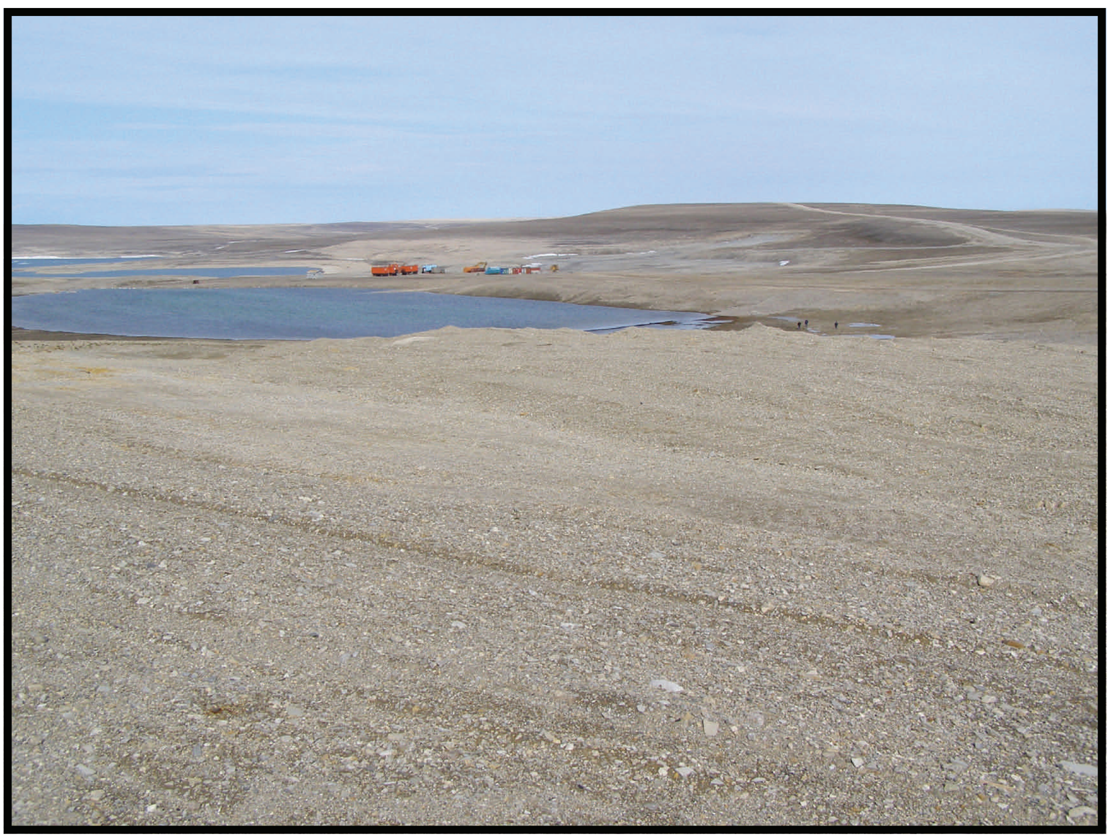
July 24, 2009



Sea ice conditions enroute to Little Cornwallis Island from Resolute Bay.

Arrival at Polaris airstrip via Twin Otter and unloading gear.

Foggy conditions developing shortly after landing at Polaris.



View of temporary camp from airstrip later in the day.

(HH021)- Buildings remaining at airstrip.

(HH022) - Another view of buildings remaining at airstrip.

(559)- Mobile temporary camp facilities.

(561)- Another view of remaining temporary camp facilities.

(562)- Equipment remaining on site- Cat excavator.

(563)- Equipment remaining on site- dump truck and bulldozer.

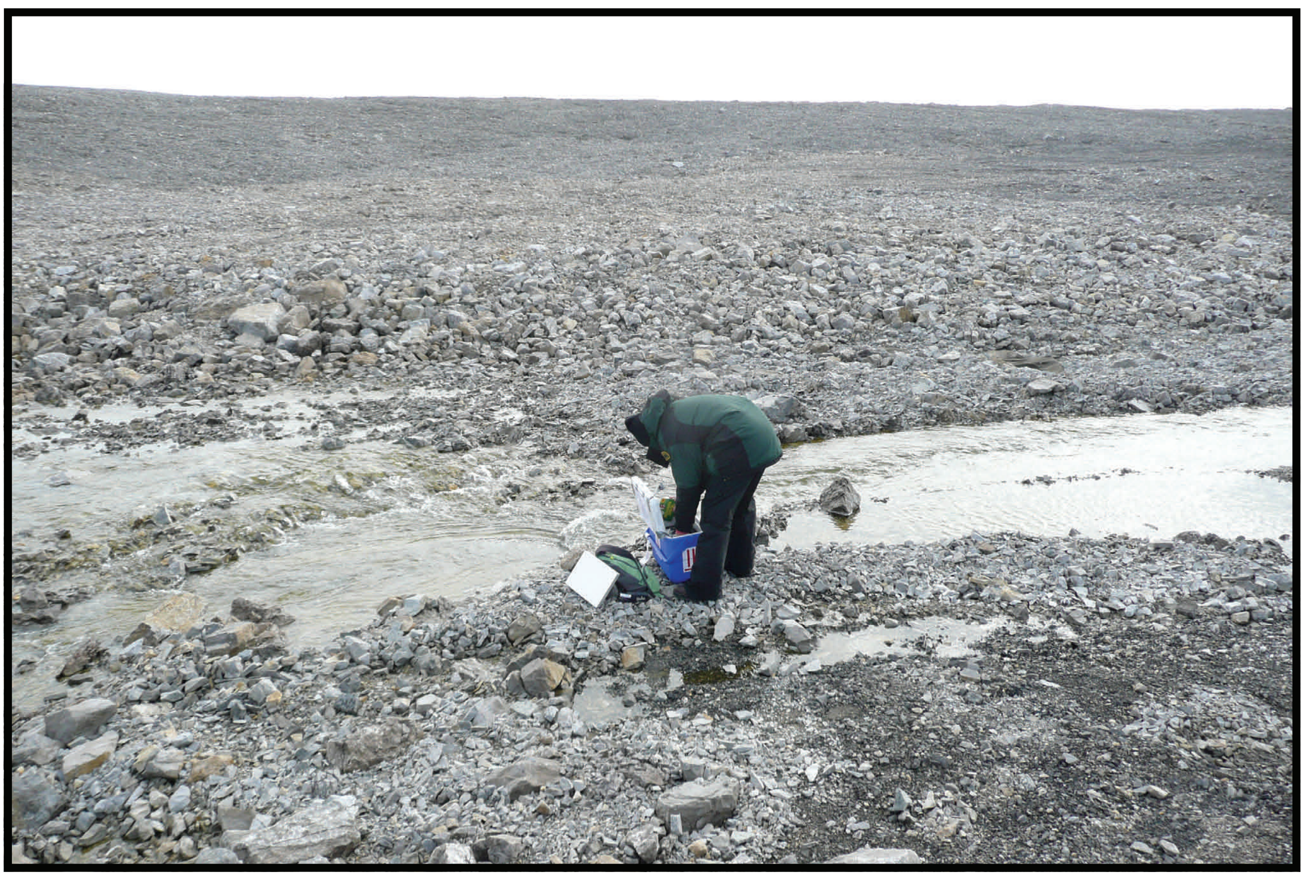
(564)- Storage tanks for various petroleum products on site.

(565)- Sea cans for storage adjacent to storage tanks.

(566)- General view of camp looking north.

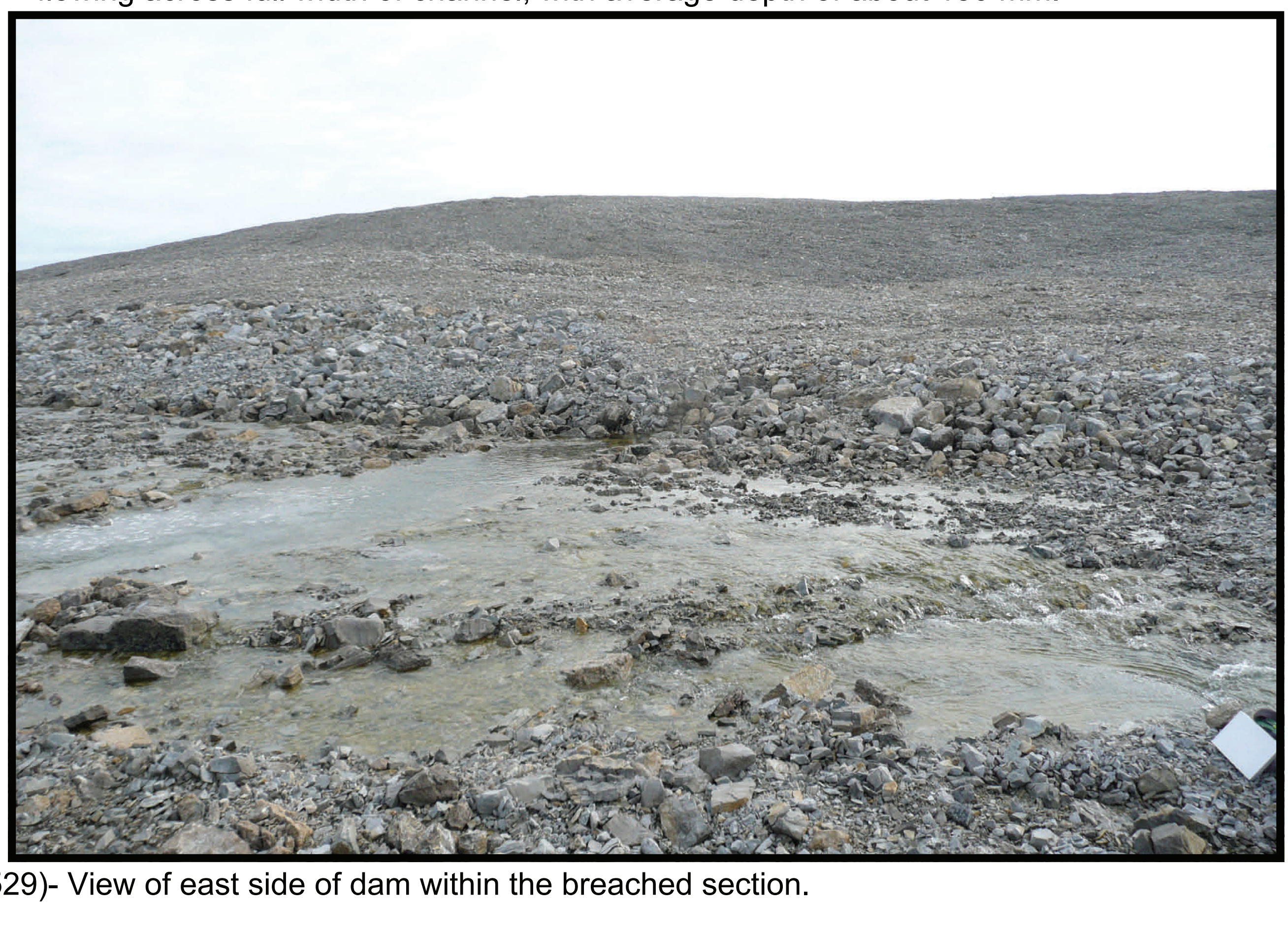
(567)- General view of camp area looking north.

(526)- Garrow Creek downstream of dam, view looking downstream .



(527)- INAC taking water quality samples from Garrow Creek downstream of dam,

(528)- View looking upstream along Garrow Creek through breached section in dam. Creek is flowing across full width of channel, with average depth of about 150 mm.



(529)- View of east side of dam within the breached section.

(530)- View along west side of breached section, looking upstream along interface with riprap and cut slope.

(531)- Small scale slump in downstream dam shell material exposed in breached section along west side of creek.

(532)- View looking upstream along west side of breach, near upstream side of dam.

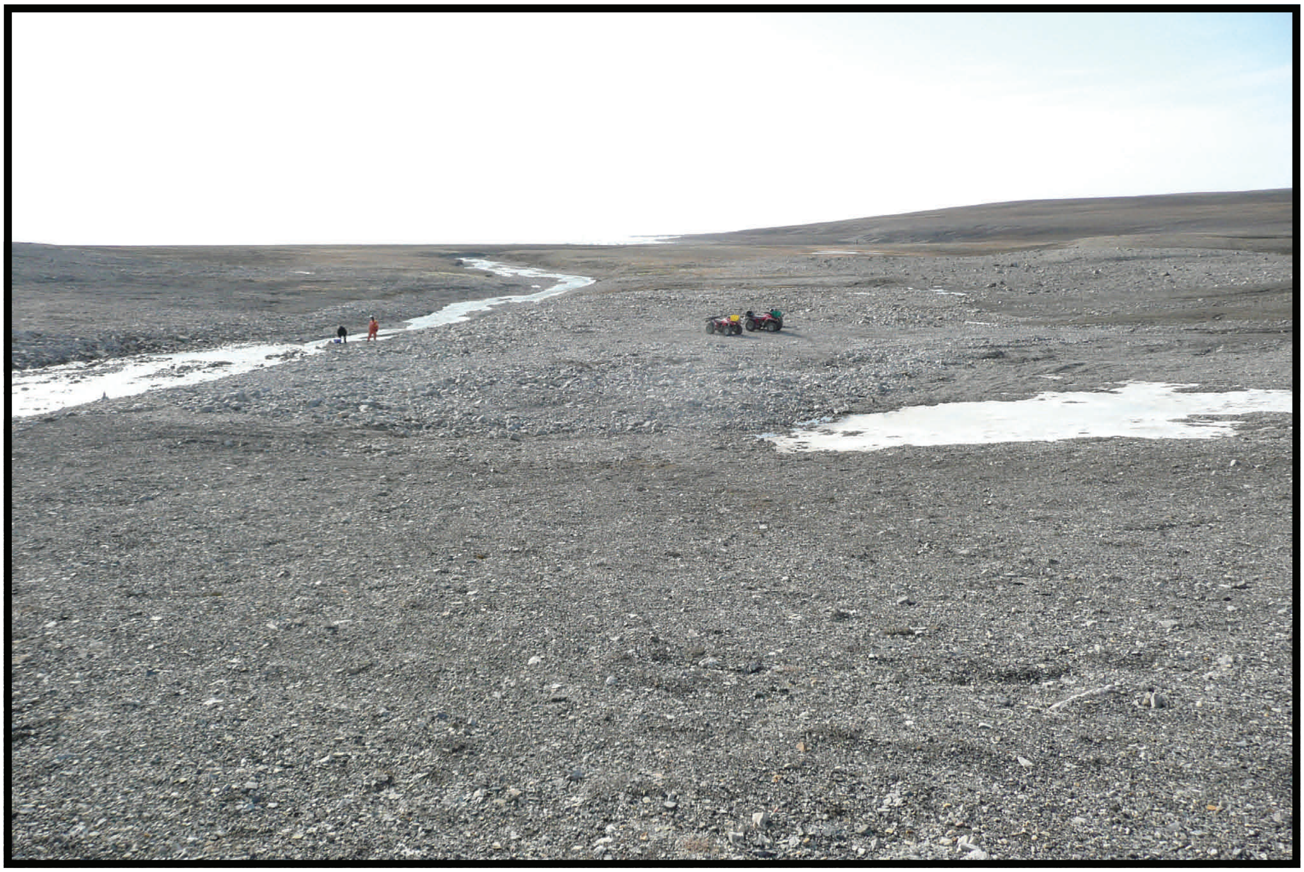
(533)- Upstream slope of west side of dam with slumped material.

(535)- Upstream slope of east side of breach as seen from west side. No signs of instability.

(534)- View looking upstream towards Garrow Lake.

(536)- View of slumped area on upstream side of dam on west side of breach from crest of dam.

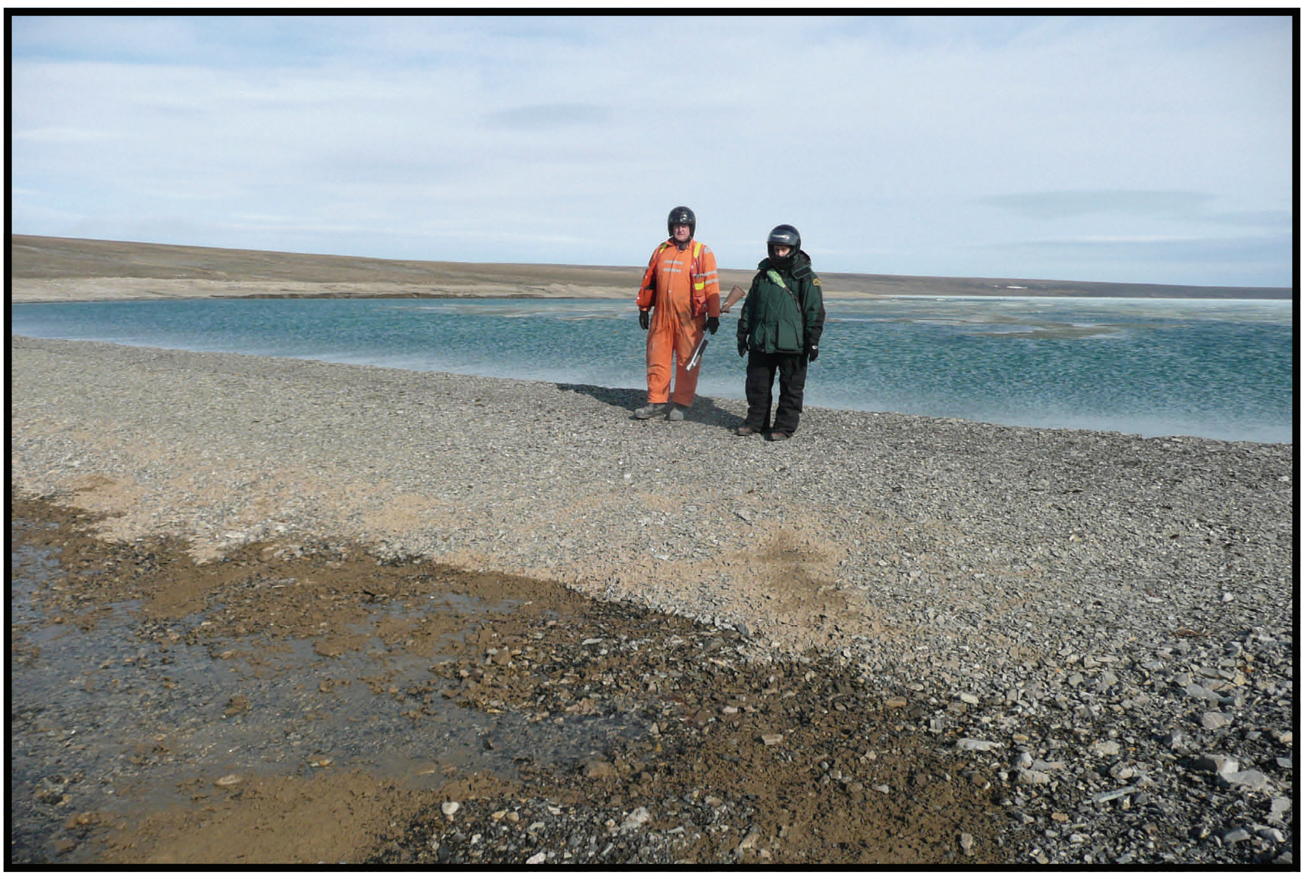
(537)- Another view of slumped area from crest. Note raised beach line in background showing elevation of Garrow Lake during mine operation.



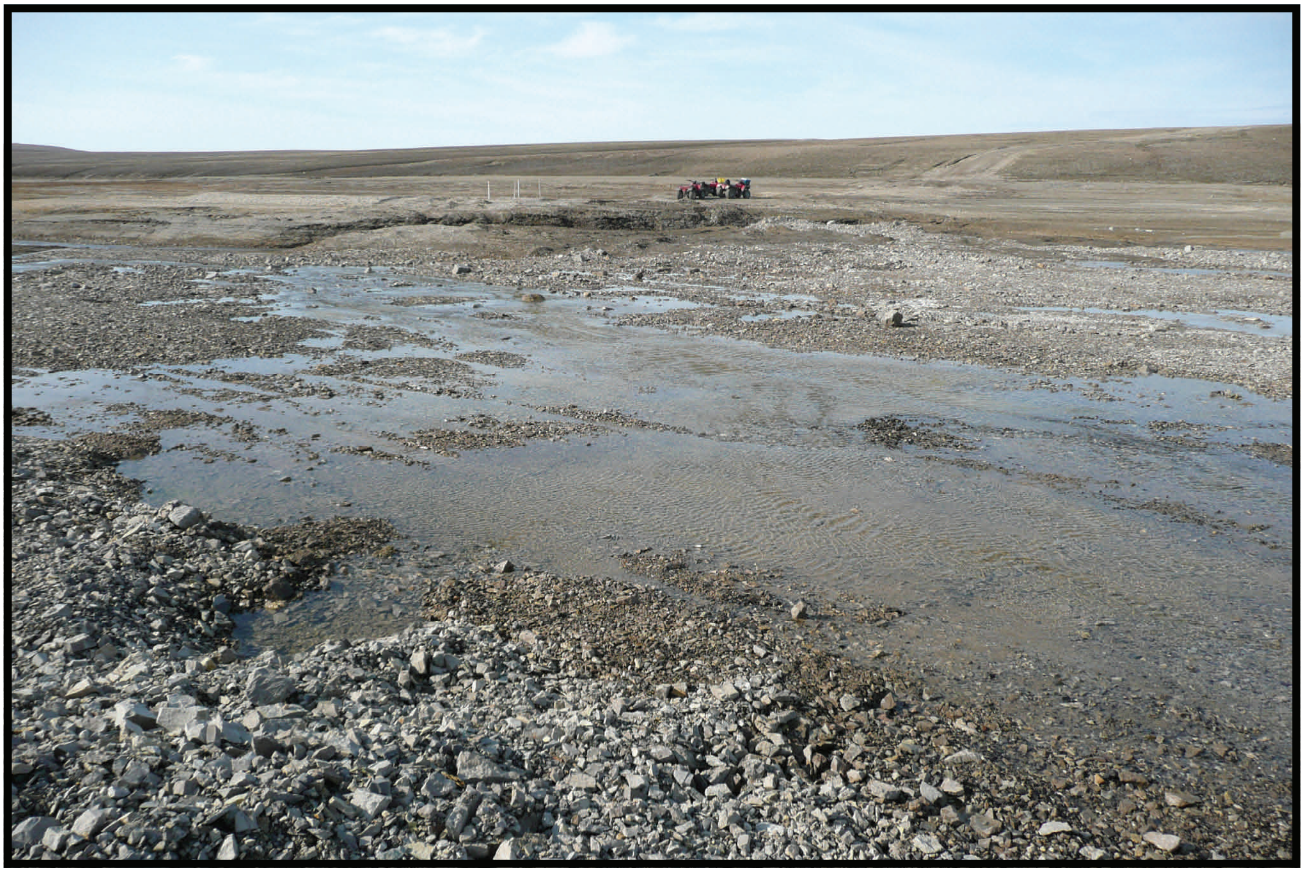
(538)- General view from crest of dam, looking downstream along west bank side.

(539)- Natural gravel berm being created at outlet of Garrow Lake, looking east from southwest corner of lake. Berm is now about 1 m above creek bed level. At time of inspection, Garrow Lake was about 100 mm higher than last year.

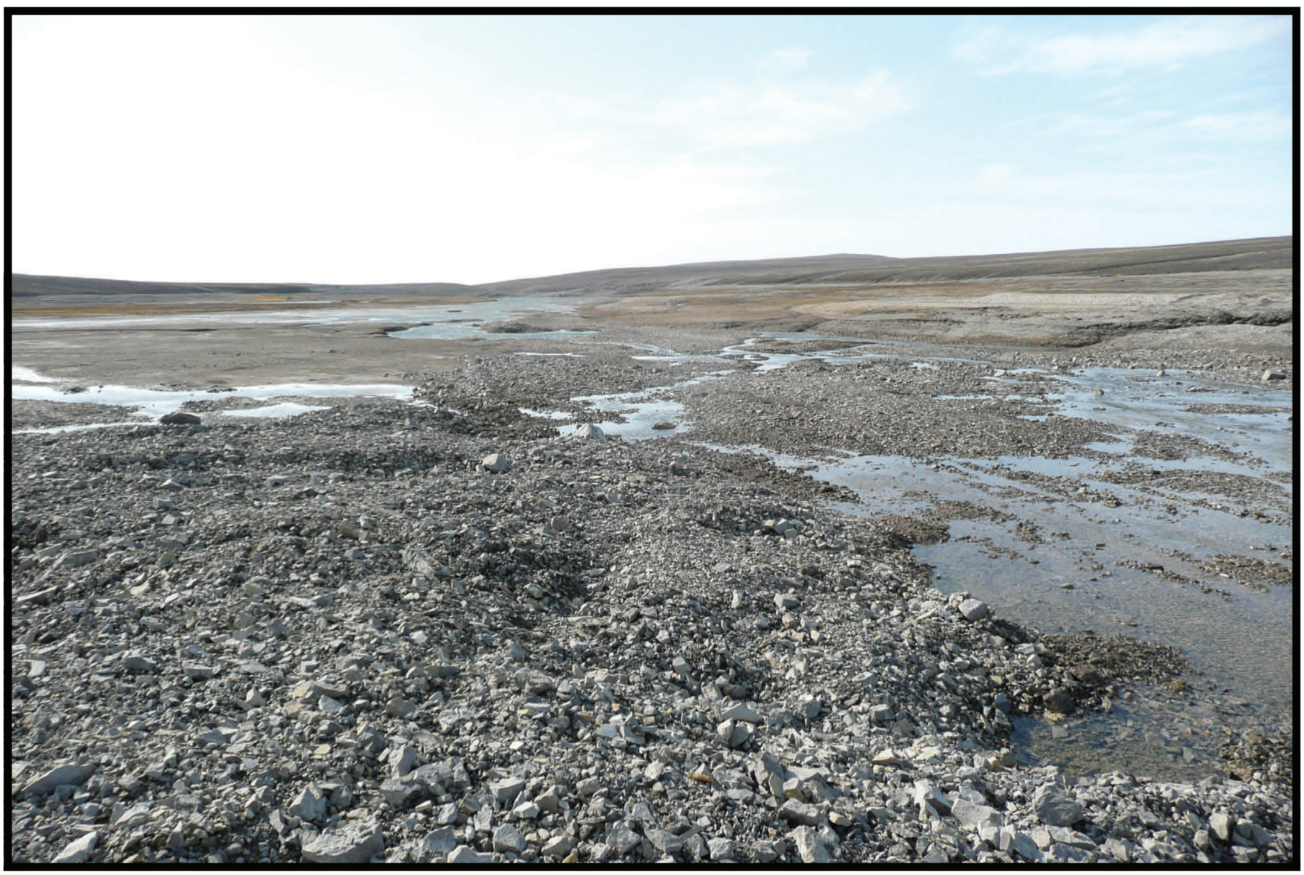
(540)- View of gravel berm looking west.



(541)- View of maximum height section of berm showing persons for scale. Note seepage through berm exiting along toe.

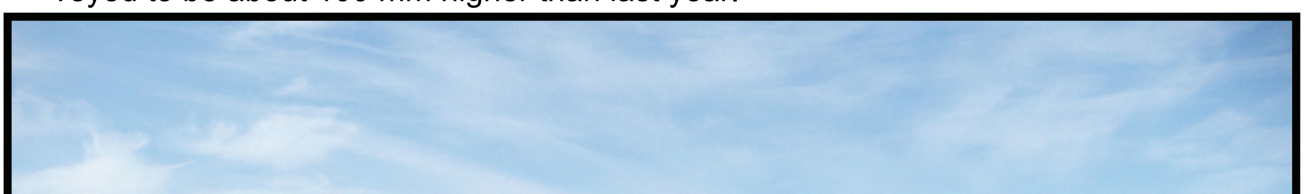


(542)- View of Garrow Creek looking southwest in vicinity of former wavebreak structure.



(543)- Looking downstream along Garrow Creek towards breached dam in distance. All water in creek channel is seeping through or under the natural berm.

(544)- View of Garrow Lake, with melting ice cover, from southwest corner. Lake level was surveyed to be about 100 mm higher than last year.



(545)- View looking west towards Operational Landfill, from height of land on road to Garrow Lake Dam

(546)- View of Garrow Lake looking east from previous location. Note extent of remaining thin, melting ice cover.

(547)- View from above location towards north west shoreline of Garrow Lake.

548)- Main portal backfill with lower buttress of rockfill along toe and re-grading to flatten over slope. Excavator left minor over steepened slope sections, which are expected to fail in the short term, but not expected to be detrimental to long term physical stability of backfill. Note steep rock slope along south side of fill.

(549)- Main portal backfill, north side, showing overall blending of backfill to surrounding slope.

(550)- Looking south from Main portal area, along slope to conveyor portal area. No signs of instability.

(551)- General view of foreshore area in the vicinity of the Main portal.

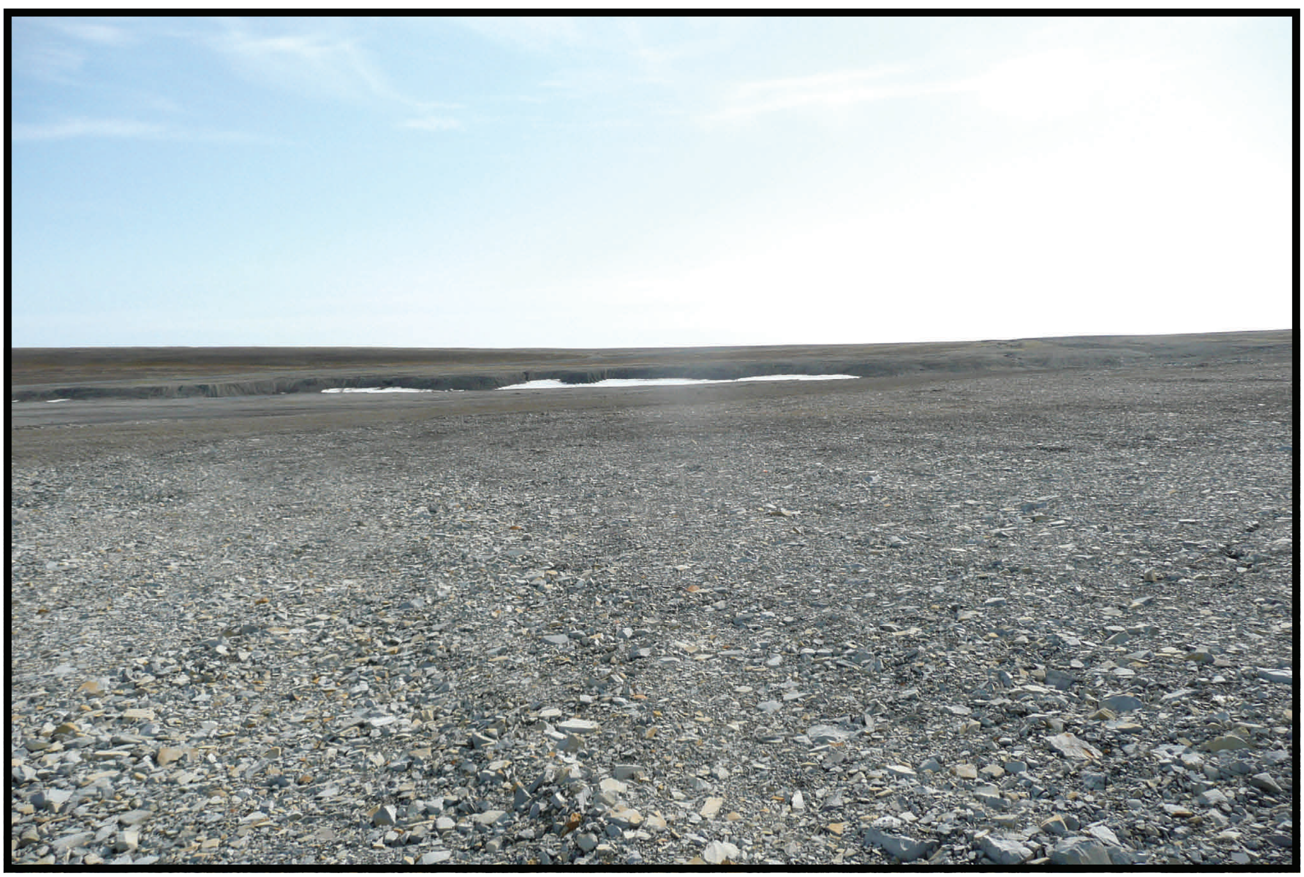
(552)- Ponding on subsidence area, looking north.

(553)- Small sinkhole associated with extensive surface cracking due to subsidence feature. No major change noted from previous years.

(554)- Overall view of subsidence crack in fill within subsidence zone.

(555)- View of subsidence zone looking south. Temporary camp is located next to excavator in background.

(556)- View east towards New Quarry, from subsidence area.



(557)- View southeast towards southwest corner of New Quarry.

(558)- General overview of subsidence area, looking north.

(HH15)- View from airstrip towards former dock site area and processing plant.

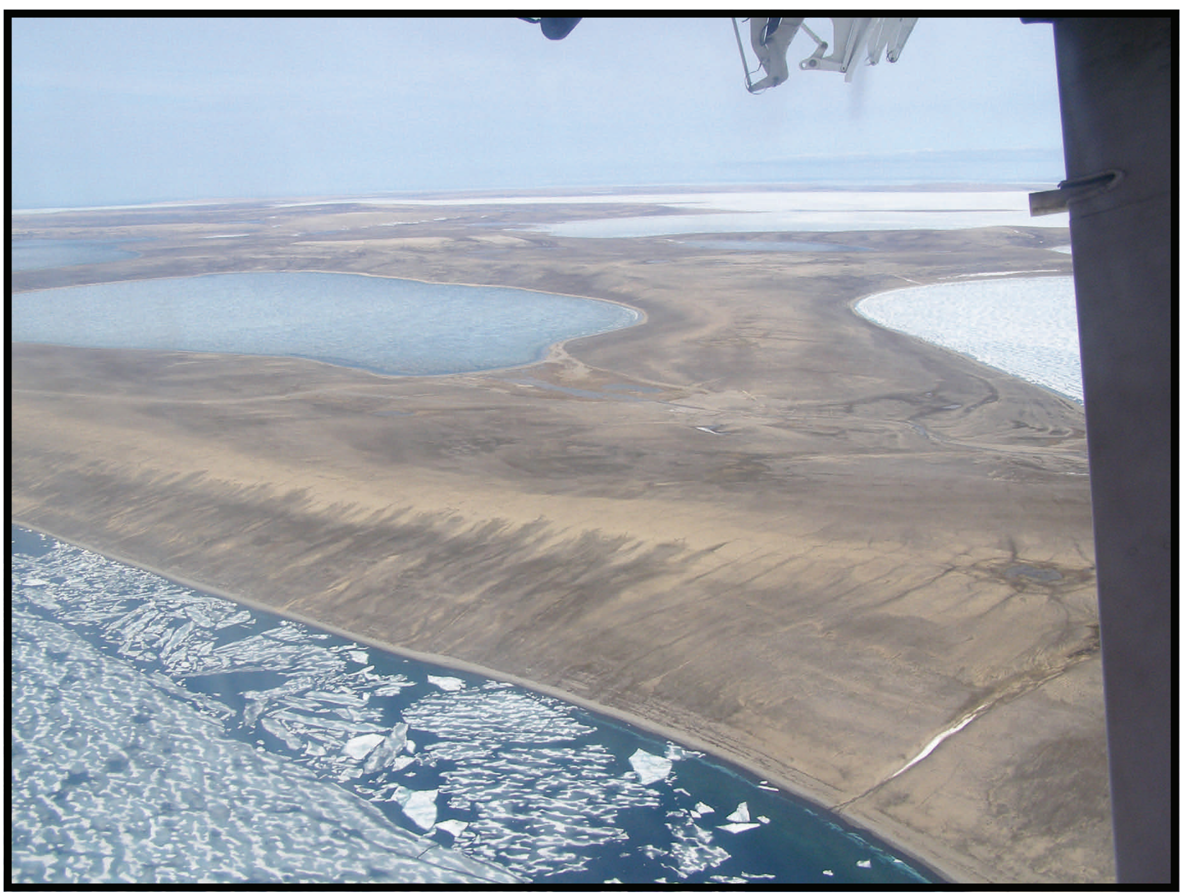
(HH16)- View looking south along west edge of airstrip.

(HH17)-Teck camp site personnel demobilizing from camp.

(HH19)- View looking north along airstrip.

(HH27)- Charter Twin Otter from Ken Borek returning to pick up staff from camp.

(HH30)- Loading plane.



(HH39)- Departing shot of Garrow Lake and Garrow Creek.

APPENDIX II

SUPPORTING DATA FROM TECK FOR SUBSIDENCE REVIEW

POLARIS MINE

RESPONSE TO REGULATORS QUESTIONS REGARDING

SUBSIDENCE AT THE RECLAMATION LANDFILL

Prepared by: Trevor Feduniak, P.Eng.

September 30, 2003

EXECUTIVE SUMMARY

The Polaris Mine Decommissioning and Reclamation Plan, March 2001 (‘DRP’) identifies the Reclamation Landfill area as being influenced by significant subsidence referred to as a ‘Sinkhole’. The Approved plan is to ensure that there is at least a 1.8 metre cap over the landfill area. However, this does not address the concern that the area is continuing to actively subside which could present a public/wildlife safety issue.

Required in the letter of Approval of the operating protocols for the landfills at the site, and as a result of a site inspection by DIAND in September of 2003, Polaris was requested to review the geotechnical aspects of the ‘Sinkhole’ area. This report presents the currently available data for this area, an explanation of the subsidence mechanisms at work, and a proposed course of action to respond to the potential issues of concern.

The caving of the overlying strata into the 202 Stage III stope has resulted in substantial localized subsidence (‘sinkhole’) that is atypical of subsidence being experienced elsewhere at Polaris. Monitoring of subsidence at Polaris indicates that subsidence over the majority of the mine is not a concern in either the short or long term. However, in the area of 202 Stope, substantial subsidence has been occurring since 1999 as evidenced by the precise subsidence monitoring conducted while the mine was operating. The last precise subsidence survey was conducted in 2002 and the sinkhole area was still actively subsiding at that time.

The development of subsidence prediction and modeling is a well developed science in Europe due to the impact of coal mining in populated areas on civil structures. While the behaviour of subsidence not exactly the same in base metal mines, the rock mechanic principles and empirical application of them to base metal mines does give guidance in understanding the subsidence mechanisms at work. Typically in coal mines, the length of time that subsidence occurs is measured in relatively few years. Similar trends have been observed at Polaris over other areas of the mine. In the area of the sinkhole, significant movement at surface has been measured for several years prior to 2002. Conducting a precise level survey in 2004 will indicate whether the subsidence has entered the decelerating phase of the subsidence cycle. Once these measurements have been obtained, a better assessment of the current and future expectations for ground movement around the sinkhole will then be possible. At that time a more informed decision as to whether or not any future action or monitoring is required.

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ATTACHMENTS

APPENDIX A

- Time / Subsidence Relationships – Subsidence Engineers' Handbook, National Coal Board, 1975
- Time – Subsidence Curve – Subsidence Engineers' Handbook, National Coal Board, 1975

APPENDIX B

- Plan of Subsidence Monitoring Stations and Outline of Mine Workings
- Graph of Surface Subsidence Versus Time Along Section 1500 E
- Graph of Surface Subsidence Versus Time for 2150 N Section – West
- Graph of Surface Subsidence Versus Time for 2150 N Section – East
- Cross Section titled '2150 Section Through Sinkhole Area'
- Plan View of Mine Area Identifying Locations of Surface Tension Cracks

APPENDIX C

- Excerpts from Report on 'Site Visit to Cominco Ltd.'s Polaris Mine' by Golder Associates Ltd., February 1994
- Excerpts from Report on 'Visit to Polaris Mine November and December 1995' by Golder Associates Ltd., May 31, 1996

APPENDIX D

- Polaris Operations Internal Memorandum – Trevor Feduniak (Senior Mine Engineer) to John Knapp (Manager) Regarding 'Subsidence Analysis', December 4, 2002

APPENDIX E

- 2003 Contour Survey of Subsidence Area by Focus Engineering.

RESPONSE TO REGULATORS QUESTIONS REGARDING SUBSIDENCE AT THE RECLAMATION LANDFILL

1. Introduction

Part H, Item 6 of Polaris's Water Licence requires an annual geotechnical inspection be conducted. Included in the approval of Polaris's Landfill Operating Protocol's, is the requirement 'That TCL provide assurance which demonstrates that the mine workings under the Reclamation Landfill have been sufficiently supported or backfilled to prevent further subsidence.' as part of the Annual Geotechnical Inspection.

The Department of Indian Affairs and Northern Development (DIAND) conducted a site inspection between September 8th to 10th, During the site visit, discussions were held with John Knapp (Site Manager) regarding ongoing subsidence over the underground mining area. The inspection report requested that the following issues be evaluated:

1. A description of the mechanism of subsidence
2. Thermal regime and ice conditions in the overburden
3. Thermal regime and need for installation of thermistors to monitor permafrost temperatures from the surface, around the underground opening
4. Impact of surface water pond on thermal regime and permafrost stability.
5. Impact of placing fill on the rate and amount of subsidence and the permafrost regime
6. Estimate of maximum extent and depth of subsidence zone
7. Assessment of physical stability and protection required
8. Recommendations for ongoing assessment and monitoring

This document will respond to all of the above comments although not in the order listed above.

2. Description of Mechanisms of Subsidence

2.1. Rock Mechanics and Subsidence Monitoring at the Polaris Mine

Monitoring and prediction of the stability of underground mine workings has been key to the successful mining of the Polaris ore body. The objective of recovering a mineral resource is to extract the maximum ore possible given safety and economic constraints. As such, mine planning attempts to maximize the volume of ore removed in a manner that minimizes the quantities of ore that must remain in place either because they are uneconomic or are required to support the ground around the mine workings (i.e. 'pillars').

Each underground mine is unique. The shape of the ore body, the composition of the ore and host rock, the depth of the ore body, its width, length and dip are all different. The types of rock underlying and overlying the mine differ from mine to mine. Faulting, weathering, ground water conditions, rock temperatures, faulting of the rock, and surrounding pre-mine ground pressures are all factors that affect the stability and behavior of the mine openings and surrounding rock masses. As a result of these and other variables, the prediction of subsidence is complex and reliant on site specific experience to develop an understanding of how the mining activities will influence subsidence at that site.

Pre-mining evaluations of mine designs are based on data collected at the exploration stage, through lab testing of the rocks to determine their physical characteristics, and experience of mining similar ore bodies at other locations. The development and refinement of mine designs evolve as experience and knowledge of individual ore bodies are gained during the mining process. As the mine is developed, rock mechanics instrumentation is utilized to monitor the physical conditions of the mine such as ground pressures, ground temperatures, and ground movements around the underground openings. At some mines, surface subsidence monitoring is an important aspect that is monitored. Visual observations by experienced mining personal are key in monitoring the immediate day to day stability of the ground surrounding the mine openings. Polaris Operations utilized graduate mining engineers (normally with at least one or more staff members registered as a Professional Engineer) to ensure competent planning and management of the mine design and monitoring process occurred.

At Polaris, early mining was done utilizing open stopes (i.e. areas where a volume of ore is removed is referred to as a ‘stope’) that were not re-filled (i.e. left ‘open’) after mining of that area was completed. For this method to work, the size of the stope was limited so that the ground surrounding the stope would stay intact. To allow for improved recovery of ore, and to provide for improved ground conditions (i.e. stable ground that was safe for personnel working in the area), the mine had to provide additional support to the mined out stopes by re-filling the void space in the stopes with fill (‘backfill’). Initially the backfill consisted of waste rock with water added to increase the structural strength. The permafrost conditions in the mine caused the water in the rock to freeze adding strength to the backfill. The placement of backfill must be done soon after the stope is mined, before the rock surrounding the stope starts to fail (i.e. break up falling into the stope). While the use of frozen backfill was successful, it became apparent that a stronger backfill would provide additional support allowing for even better recovery of ore. It was determined that the use of backfill consisting of cement mixed with waste rock (i.e. Cemented Rock Fill or ‘CRF’) would provide superior backfill strength and the strength would be obtained in a shorter period of time. Although this was a very expensive process, the improved ground support and improved ore recovery justified the additional cost. The improved support for the stopes had the additional benefit that the amount of subsidence measured at surface was reduced.

2.2. Subsidence Mechanisms

There is substantial technical knowledge related to the process of mining induced subsidence. This technical expertise was initially developed in Europe where coal mining near populated areas created significant damage related to the subsidence of roads, pipelines, houses and other civil structures. Subsidence related to coal mining typically differs from metal mining (‘hard rock mining’) subsidence in a number of ways. Normally coal mining is occurs in relatively thin coal beds (several metres thick not tens of metres thick as with Polaris), with relatively substantial thickness of cover (relative to the ore body thickness), and the extraction of the coal beds occurs over large areas (often extending for miles) using relatively uniform patterns of extracted areas and adjacent areas where ground has been left intact for support (‘pillars’). These configurations allow for relatively accurate mathematical predictions of amounts of subsidence, timing of subsidence, and amount of surface strains (i.e. surface cracking). Initial planning is done using information from similar mines/ground conditions documented in reference materials but as site specific empirical data is collected, the accuracy of the predictions are refined.

The following explanation is simplistic to give the reader an understanding of the subsidence mechanism coal mines. Typically, the subsidence is caused by the strata overlying the mining area bending uniformly as mining progresses. The overlying stratum behaves like a beam that sags as support is removed from beneath it (i.e. by the mining removing coal or other mineral). As there is less rock to support the weight of the overlying strata, the remaining rock (‘pillars’) must support increasing loads. At some point, the pillars are not capable of holding the amount of weight they are exposed to and they begin to fail. As the pillars crumble, the overlying strata subsides. The debris from the failed pillars (and roof over the mine openings) starts to partially fill the mine openings. As this process of crushing the pillars progresses, at some point, support for the overlying strata is gradually regained and the subsidence slows and eventually ceases. The surface of the ground appears to gradually and uniformly subside. Some coal mines (but not most), place fill into the areas where they have removed the coal to provide additional support and to reduce the amount of subsidence. The backfill must be placed soon after mining or else the area will start to fail before the backfilling is completed. If the coal seam is very thick and/or if the seam is close to surface, or if there are irregular patterns to the mine layout, or if the overlying strata if more brittle, different mechanisms of subsidence may occur and the resulting subsidence may not be uniform.

The mechanisms of surface subsidence are usually different for metal mines. While the same physical principles apply, the conditions surrounding metal mines are often very different from coal mines. The ore body is often much thicker so that mining open creates high stopes with tall, slender pillars between the stopes. Often, the distance to surface relative to the height of the stope is less that in a coal mine. The rock types are often much harder and more brittle in nature. If the width of the stope is narrow enough and the pillar adjacent to it is strong enough, the stope can remain stable over a very long period of time and there is no disturbance of the surface. If the stope is wider or the adjacent pillar is not strong enough, the roof of the stope or the pillar itself may fail in a brittle manner. As the failure progresses, series of rock pieces or larger blocks of rock from the roof and/or the pillar break up and fall into the stope. Broken rock occupies more space than solid rock due to the void spaces between the broken pieces. As failure of the surrounding rocks progress further and further from the opening, the area affected above the stope typically becomes wider (i.e. similar to the shape of an ice cream cone). As the failure of the overlying strata progresses further and further upward, the volume of broken rock continues to increase so that at some point it occupies enough space that the broken rock starts to provide support again until the remaining strata overtop of it is adequately supported and becomes stable (if the distance is far enough to surface). This mechanism can result in several different subsidence effects on surface. If the volume of the stope is small relative to the volume of rock overlying it, the overlying strata may bend so that at surface subsidence is similar to the example of the coal mine. Alternately, if the volume of the stope is substantial relative to the distance to surface, then failure of the overlying rock can progress through to surface causing a more localized area of subsidence where the surface subsides with steeply dipping angles (i.e. a 'sinkhole'). In extreme cases an open hole extending from surface down into the stope can occur (this would generally only occur when the volume of rock overlying the collapsing stope is relatively small compared to the volume of rock required to fill the stope, typically when the stope is very near surface). As ore bodies are not usually uniform, consequently mine designs are also not normally uniform. As a result, subsidence over the mine may be a mixture of the above subsidence mechanisms. Subsidence at Polaris is primarily smooth and uniform due to the use of backfill. Early in the mine life, there was one area (the 202 Stage III stope) where premature failure of the stope before it could be backfilled has resulted progressive failure of the overlying strata resulting in a 'sinkhole' type of subsidence to occur. The failure of this area emphasized the need to backfill stopes and was the standard procedure adopted for stopes after 202 Stope was mined This procedure has prevented other areas from experiencing excessive subsidence.

Empirical monitoring of subsidence at Polaris has been a useful tool in predicting the behaviour of the ground in response to mining. Monitoring of subsidence at Polaris has been done both utilizing precise survey measurements of the bedrock surface, and through visual observations of indications of subsidence. A network of monitoring pins anchored to bedrock was established over the mining area in the 1980's. While mining was active (until 2002), these monitoring stations were surveyed twice per year with adequate precision to detect small changes in pin elevations. These measurements have identified the expected maximum angle of draw of the subsidence zones (i.e. the angle from the extracted area to surface affected by subsidence) to be approximately 40 degrees. This information is useful predicting the ultimate boundaries of subsidence at surface. The length of time subsidence is active is influenced the area being mined, the depth of mining and the angle of draw. Appendix A shows a graph of subsidence over time at a typical coal mine (Subsidence Engineers' Handbook, National Coal Board). The graph illustrates the relationship between these factors and indicates that typical duration for subsidence to be active in a typical coal mine is up to 5 years. While these charts are not directly applicable to base metal mines, it does indicate that subsidence occurs over a relatively short period of time.

3. Estimate of Maximum Extent and Depth of Subsidence Zone

Subsidence progresses through a series of phases over time starting from no movement, to accelerating vertical movement, to decelerating rate of movement, and finally to little or no movement. A typical graph of the amount of subsidence compared to time is presented in the Subsidence Engineers Handbook and is also included in Appendix A. At Polaris, while the time frames for subsidence to occur will be different from the example in the Handbook, the process will be similar showing the same series of phases of changing rates of subsidence over time. Appendix B contains the following figures:

- Location Plan of Subsidence Monitoring Stations and Outline of Mine Workings
  This drawing shows the outline of the mine workings in plan view indicating the locations of the subsidence survey monitoring stations. The majority of these stations are no longer required due to little on-going ground movement and have been

destroyed intentionally as part of re-contouring the site as part of the reclamation activities, through substantial ground movement (in the sinkhole area) or by accident. Our contractor has been instructed to save key monitoring stations around the sinkhole area for future monitoring requirements.

- Graph of Surface Subsidence Versus Time Along Section 1500 E.
  This graph indicates the total subsidence over time for a series of monitoring stations that extend in a North – South line at about the 1500 E section line. The chart shows that subsidence is in the deceleration phase at the south end (Station Sub-5), is still undergoing substantial subsidence just north of the sinkhole (Stations Sub 20 and Sub 22), and has substantially decreasing rates of subsidence as you move further north from the sinkhole (as the amount of mine workings under the stations decrease).
- Graph of Surface Subsidence Versus Time for 2150 N Section – East
  This graph shows the subsidence compared to time for stations east of the sinkhole area. As can be seen from the plan drawing, the location of these subsidence monitoring stations start at the edge of mining and extend out over un-mined areas. The amount of subsidence of these stations is relatively small and subsidence is nearing completion.
- Graph of Surface Subsidence Versus Time for 2150 N Section – West
  This graph shows the subsidence compared to time for stations near the sinkhole area and extending to the west. The stations closest to the sinkhole area are still undergoing significant subsidence and the stations further west are still subsiding significantly but at reducing rates the further away from the sinkhole area. All of the stations in this graph are located over top of mining areas with substantial extraction and that have experienced continuing mining activity throughout the monitoring period. With the cessation of mining, subsidence rates in these areas will start to decrease. The data in this graph is current as of the summer of 2002.

The 'sinkhole' area of subsidence is located directly over top of 202 Stage III stope. A cross section of the stopes in this area relative to the surface identifies the location of this ground failure (Appendix B). Golder Associates Ltd., a mining/rock mechanics engineering consulting firm reviewed this problem as part of their report 'Site Visit to Cominco Ltd.s' Polaris Mine' dated February 1994. This report indicates that a block over top of this stope failed and moved downward in excess of 3.5 metres at the 850 Level (report Section 5.3, Appendix C). The report includes several generalized sketches indicating the observations of the block failure as evidenced underground. Referring to Section 3.3 of Golder Associates' 1995 site visit report (Appendix C), makes a number of observations:

a) Most subsidence monitors at the mine are maintaining constant velocity or de-accelerating.
b) Monitoring data suggests an angle of draw of about 40 degrees.
c) 'At Polaris, the ore is both shallow and thick, and various coal subsidence formula become difficult to apply.'
d) 'A recent review by Golder Associates ….found that published information on subsidence over base metal mines was extremely limited and mainly referred to caving. Thus, there is little precedent which can be used to assess future subsidence (North Keel and Ocean Zone) at Polaris. More or less sole reliance will be on the

> information currently being gathered and mine derived relationships (assisted, for example, by numerical modeling).'

The Golder report has photographs of the surface tension cracks which are also included in Appendix C.

Monitoring in the active area of the sinkhole is difficult as the ground movements are large enough that the survey stations have been destroyed and subsequently buried as fill has been placed into the sinkhole. Maximum vertical movement in the area is estimated to be in the order of 10 metres. Subsidence west of the sinkhole is active but more moderate. The area west of the sinkhole is also over areas where thick sections of ore have been mined. However, relative to the horizontal distances involved the change in surface contours are more modest and are not of any concern. A drawing titled '2150 Section Through Sinkhole Area' (Appendix B) indicates the approximate surface over this area and shows the changes to surface contours as a result of subsidence up until relative total subsidence to July of 2002. As there is data missing within the most active area of the sinkhole, the drawing does not necessarily accurately represent the area in the middle of the sinkhole.

As previously identified, most of the monitoring stations have either been destroyed through ground movement or were removed in 2003 as part of the reclamation re-contouring activities. However, key subsidence stations related to the sinkhole area are being retained so that they can be re-surveyed in 2004. It is anticipated that the 2004 survey will indicated decreasing rates of subsidence.

A simple method of observing subsidence is from visual observations. At the boundaries of subsidence where the slope of the surface ground changes, the ground surface is placed into tension causing cracks to form in the surface soils. During the snow free months, recording the locations of new tension cracks is a practical method of monitoring if the area of subsidence is expanding. These observations have been mapped on a regular basis with the results plotted on a surface plan (refer to Appendix B). This data was last updated in 2002. As the ground surface was being re-graded during 2003 during reclamation activities, no observations of surface cracks were made. It is planned to identify and map any new cracks during the summer of 2004.

4. Impact of Placing Fill on the Rate and Amount of Subsidence and the Permafrost Regime

4.1. Impact of Placing Fill on the Rate of Subsidence

As referred to in Section 2.2 above, the Subsidence Engineers' Handbook states that the length of time that subsidence is active is a function of mining depth, draw angle and the rate of extraction, and that the time to complete subsidence is measured in years. While the time frames are extended at Polaris, it still indicates that the time frame for active subsidence to be occurring is limited.

The Handbook also indicates that increasing the depth of cover increases the length of time for subsidence to finish (Appendix A). In the area of the Sinkhole, there is approximately 150 metres of cover, so even if 10 or 15 metres of fill were added, the relative change in cover thickness is small and would have little effect on subsidence rates.

4.2. Impact of Fill on the Permafrost Regime

Placing fill in the sinkhole area is no different from placing fill anywhere else on the island. Permafrost will be established in the fill over a relatively short period of time. The thicker the fill, the more time it would take for the permafrost to be fully re-established. The primary purpose of placing fill in the sinkhole area to restore previous elevations of the ground surface in this area. Whether or not permafrost is reinstated in the new fill in several months or in a few years has no impact on the ground surface elevation which is the primary issue of concern.

5. Thermal Regime at the Polaris Mine Site

5.1. The Need for Installation of Thermistors to Monitor Permafrost Temperatures from the Surface and/or Around Mine Workings

There is an extensive history of ground temperature monitoring related to the mine workings at the Polaris Mine. The mine has measured rock temperatures in and adjacent to mining areas for mining planning purposes. Some examples are:

a) Ground Stability of Mine Workings Due to Thermal Regime
   Prior to developing mine workings in an area, mine engineers needed to be confident that the planned workings would be in an area where the ground is frozen. Thermistors were installed in drill holes that were drilled from surface into the ground ahead of mining. Additional thermistors were placed into drill holes that were drilled from underground workings to confirm the temperature forecasts provided by the surface drill holes. Figure 7 in Volume 1 of the Decommissioning and Reclamation Plan (March 2001) was developed though the collection of this data.

b) Ground Stability of Mine Workings Due to Summer Air Temperatures – the stability of the ground immediately surrounding the underground mine workings was key to providing safe working conditions for personnel working underground. Mines utilize high horsepower fans to force large volumes of fresh air underground to provide fresh air for diesel equipment and to provide clean air for personnel. Experience has shown that if the surfaces of the rock around the tunnels underground are allowed to thaw (in summer when air temperatures are above freezing), that localized sections of rock become unstable (referred to as 'Loose') and are a hazard to personnel working in the area. Thermistors were commonly placed into drill holes in the walls and roofs of the tunnels to monitor rock temperature changes related to local mining activities and seasonal temperature changes. This data indicates that warming of the rock face underground is affected within only a few metres of the mine openings during the warm summer months. It is important to note that after the completion of placing contaminated soils underground in 2004, all of the entrances to the mine will be sealed preventing any air flow in the mine so that the warming effect by air during the summer months will no longer be a factor.

c) Performance of Backfill – as indicated earlier in this report, the mine utilized a water/waste rock backfill to increase the stability of most stopes once mining had been completed. It was important from an operational stand point to determine how quickly the water/rock backfill froze as it would not provide adequate strength until this occurred. Thermistors were placed into this fill and into the adjacent pillars to confirm that the fill had frozen and that the surrounding ground did not thaw as a result. Monitoring of the fill indicated that up to two years was required for fill in large stopes to completely freeze. An individual stope could have upwards of 110,000 tonnes of fill placed that would be frozen as a result of the surrounding ground temperatures. The thermal mass of the surrounding ground is immense. Disturbing the thermal regime by placing materials in the mine is very localized and temporary.

Given over 20 years experience monitoring temperatures in and around the mine during on-going mining and backfilling of openings has clearly demonstrated that there are no concerns with the thawing of the ground at that depth. There is no need to verify this by additional monitoring using thermistors.

5.2. Thermal Regime and Ice Conditions in the Overburden

Temperature monitoring of surface and near surface ground temperatures has been conducted at Polaris for a number of years. Near surface permafrost conditions are a consideration for civil structures at the site such as Garrow Lake Dam and the Operational Landfill. Starting in 2004, monitoring of the Little Red Dog Quarry Landfill will be initiated and continue until 2011. Monitoring of the Garrow Lake dam and the Operational Landfill clearly demonstrates that large quantities of fill placed on surface quickly freeze and within a short period of time, only a relatively shallow active layer (less than 1.5 metres deep) temporarily thaws during the summer season. The effects of global warming were reviewed to determine the effect in the thickening of the active layer related to the landfill cover designs proposed in the DRP. Conservative forecasts indicate on slight increases in the thickness of the active layer (refer to the Polaris Mine Decommissioning and Reclamation Plan, Volume 2, Landfill Closure Report).

The rate of subsidence in the sinkhole area is expected to continue at a decreasing rate over the next few years. Past experience has shown that water pooling over this area during the summer months can infiltrate into new surface cracks caused by ongoing settlement. The depth that this water penetrates the strata overlying the mine has not been investigated. The immense thermal mass of the frozen overburden and bedrock freezes the water before it penetrates into the mine workings (refer to the Conclusion section of the memorandum prepared by Trevor Feduniak titled ‘Subsidence Analysis’ attached in Appendix D). Once the subsidence in the sinkhole area slows, there will be no new surface cracking and no new conduits for water to flow into the overburden will be created. Existing cracks will be ice filled in a self healing process. Any water penetrating cracks in the near surface strata adds to the strength of the strata as it freezes (a ‘healing’ process).

5.3. Impact of Surface Water Ponding on Thermal Regime and Permafrost Stability.

During the DIAND site inspection in September 2003, the option of allowing water to pond rather than placing fill into the Sinkhole was discussed as a method of filling any holes caused by subsidence of the sinkhole. It is felt that making this decision is premature at this time until further subsidence data can be collected in 2004.

6. Assessment of Physical Stability and Protection Required

The following is a listing of the types of conditions that if formed by the subsidence referred to as the 'sinkhole' area, could represent a hazard to the public and/or wildlife:

1. If the surface of the ground is unstable it could present a danger to the public/wildlife walking or the public operating motorized equipment over the sinkhole area. The potential danger is that subsidence of the bedrock continues to occur while the overlying soils form a bridge overtop of it. If the activities of people or wildlife were to break the bridging, then the soils could potentially suddenly slump into the underlying void causing harm to those overtop of this area.
    - This area has in the order of 10 to 20 metres of overburden soils overlying the bedrock. During the initial period of active subsidence in this area, heavy mobile equipment has operated adjacent to it and over top of it, placing fill and re-contouring the area without incident. There has never been any evidence of this occurring.
    - As the rate of subsidence decreases, the risk is further reduced as the ground surface has more time to react (i.e. settle).
    - The potential for unexpected, sudden subsidence caused by people or wildlife walking over this area or from operating light motorized equipment is considered remote based on previous experience (at Polaris as well as at other Teck Cominco mine sites) although one can not say categorically that it would never occur.

2. If the slope of the ground is excessively steep, this could represent an unexpected hazard to persons operating motorized equipment in the area. Also at some point, if the slopes are too steep, wildlife could also become trapped in the sinkhole area:
    - The slope of the ground in the area is relatively smooth with low slopes so that there is no concern of thus type of problems at the current time.
    - While there was no survey conducted during 2003, visual observations did not identify localized movement in the Sinkhole area.

- The area will be inspected (and surveyed) in 2004 and if significant subsidence has occurred by that time, adjacent slopes could be re-contoured as there will still equipment available on site.
- Beyond 2004, the rate of subsidence is expected to be decreasing so that the potential for steep slopes forming is a decreasing risk. A survey review in 2004 will be required to confirm this and to forecast future subsidence rates.

3. If the surface contours are altered so that water collects in the low areas creating a pond, there is a potential that the public and/or wildlife could drown in the water.
   - This is not considered a hazard any more or less than any other pond or lake on the island.
   - If ponding of water were to occur, it is not anticipated that any action would be required from a public/wildlife safety perspective.

7. Recommendations for On-going Assessment and Monitoring

As previously discussed the precise surveying of subsidence monitoring stations installed in the surface bedrock were established to provide information for mine planning and design activities. Vertical subsidence movements as little as 0.01 metres were monitored. Now that mining has been completed, the need for this level of accuracy of monitoring is not required. The purpose of monitoring subsidence is now one of public safety which requires a much coarser level of survey accuracy. Once the 2004 precise survey has been completed, subsidence rate curves will be updated and a forecast of future subsidence trends will be more definitive.

Inspection of the mine area will be conducted to determine if there are any new tension cracks in the soils. If there are, these will be surveyed and plotted onto the surface plans to identify any trends indicating changes in the subsidence boundaries. This monitoring can be conducted post 2004 as part of the annual site inspections.

In preparation for longer term monitoring of the site, a topographical survey was completed in 2003. Apart from a final precise survey of the remaining subsidence monitoring stations in 2004, future subsidence monitoring should consist of topographical monitoring of the soil surface to identify potential changes of drainage patterns and for public safety (i.e. settlement causing hazards to the public riding on quads or snow mobiles) purposes. A copy of this survey is included in Appendix E. As with monitoring of the tension cracks, it is recommended that some key locations are surveyed as part of the annual site inspections.

Yours truly,

Trevor Feduniak, P.Eng.
Civil/Mining/Demolition Supervisor
Teck Cominco Metals Ltd.

APPENDIX A

1. **Time / Subsidence Relationships – Subsidence Engineers' Handbook, National Coal Board, 1975**

2. **Time – Subsidence Curve – Subsidence Engineers' Handbook, National Coal Board, 1975**

Subsidence Engineers' Handbook

NCB

National Coal Board
Mining Department 1975

Time/Subsidence Relationship

Permanent repairs should not normally be carried out if a damaged property is due to be undermined again in another seam or by another face in the same seam lying within the critical area. First-aid repairs are often satisfactory for short periods, but discretion is necessary when long intervals are likely to occur between successive excavations or when the property is going to be in an unstable state over a long period.

If the stability of a building is affected and the site is required for development, an estimate should be made of the earliest date when building could safely commence. This should be done by plotting a development curve or a time/subsidence curve and usually ignoring any possible residual subsidence period, which in any case would probably be covered by the site preparation period.

The nomogram in Fig. 33 may be used for this estimation of total time for a single face working. Starting at the depth line, the limit angle is next chosen and this gives the diameter of the critical area (2R). The value for the rate of advance of the face is next intersected to give the total time on the right-hand half of the base line. In the example the broken line shows that for a seam 450 m deep and an angle of draw of 35°, the width of the critical area is 630 m. With a face advance of 1400 m per year the time taken to work the panel is about 6 months.

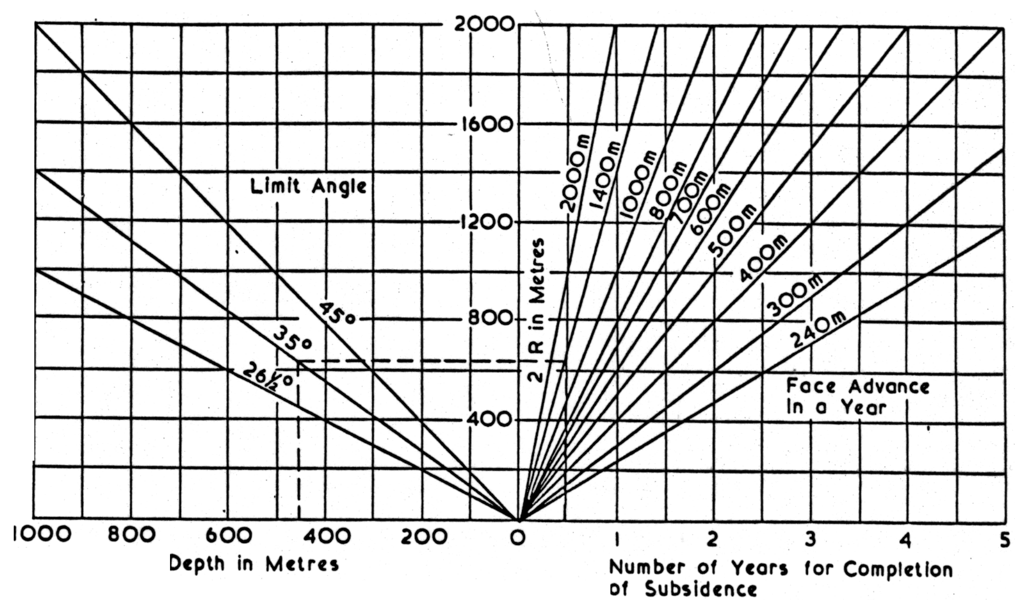

Fig. 33 Nomogram for estimating duration of subsidence.

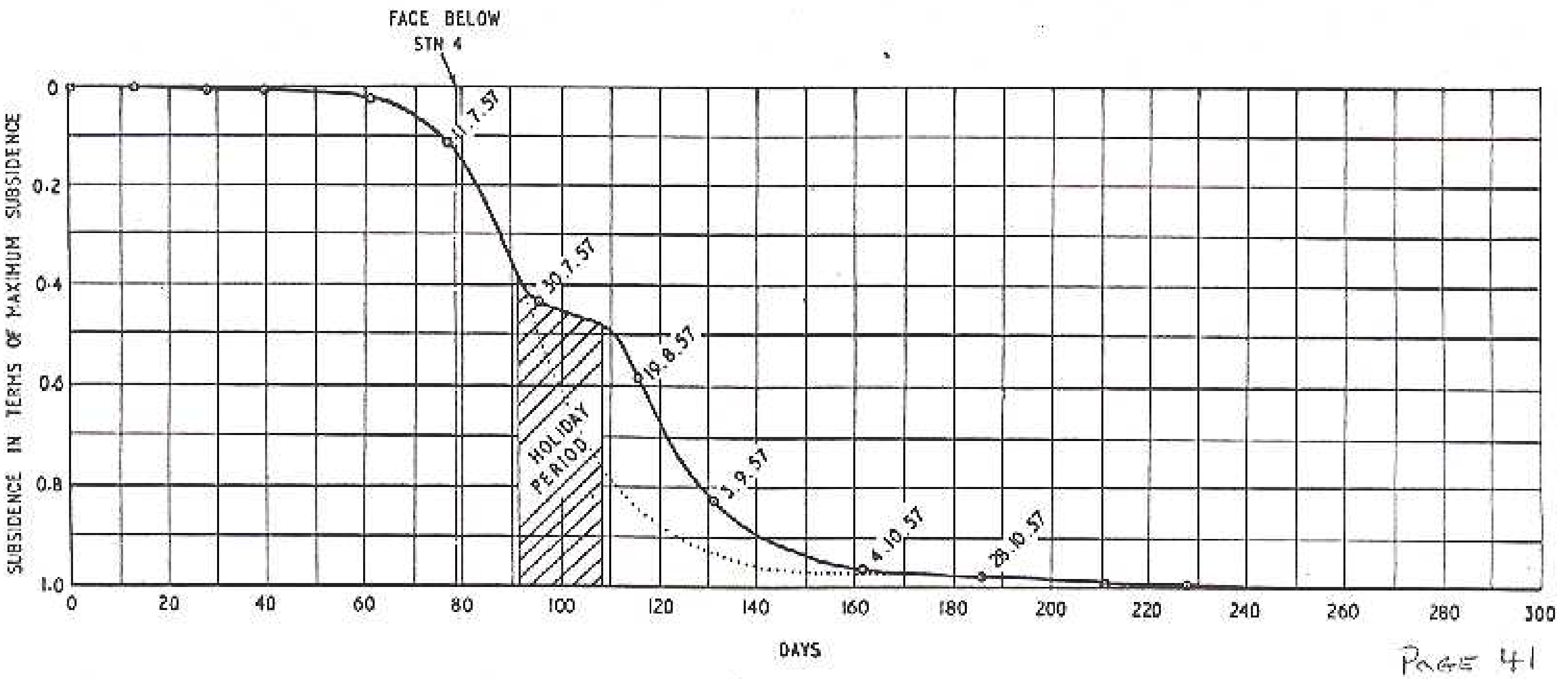

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Fig. 30 National Case No. 9—time-subsidence curve.

APPENDIX B

1. **Plan of Subsidence Monitoring Stations and Outline of Mine Workings**

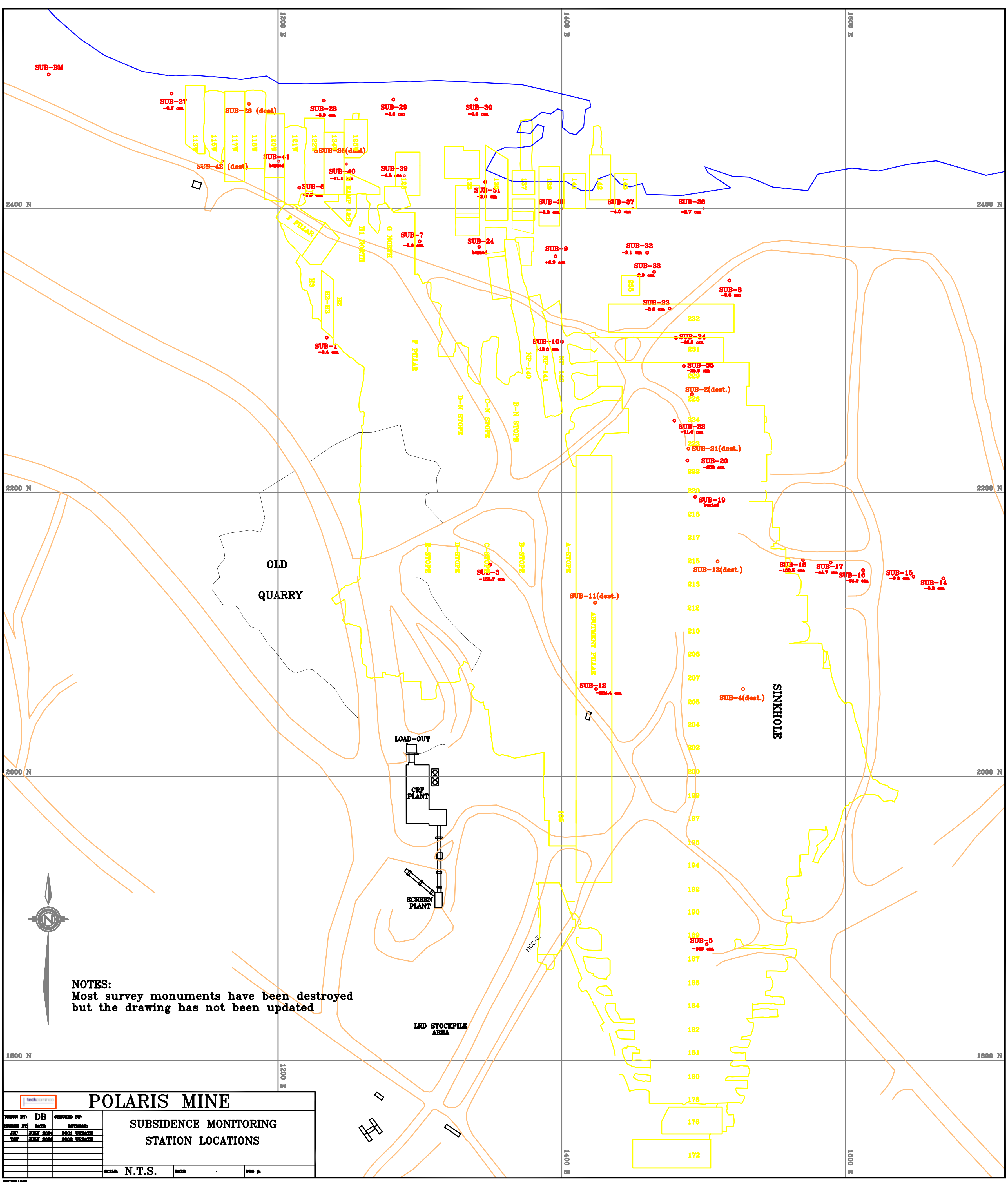
2. **Graph of Surface Subsidence Versus Time Along Section 1500 E**

3. **Graph of Surface Subsidence Versus Time for 2150 N Section – West**

4. **Graph of Surface Subsidence Versus Time for 2150 Section – East**

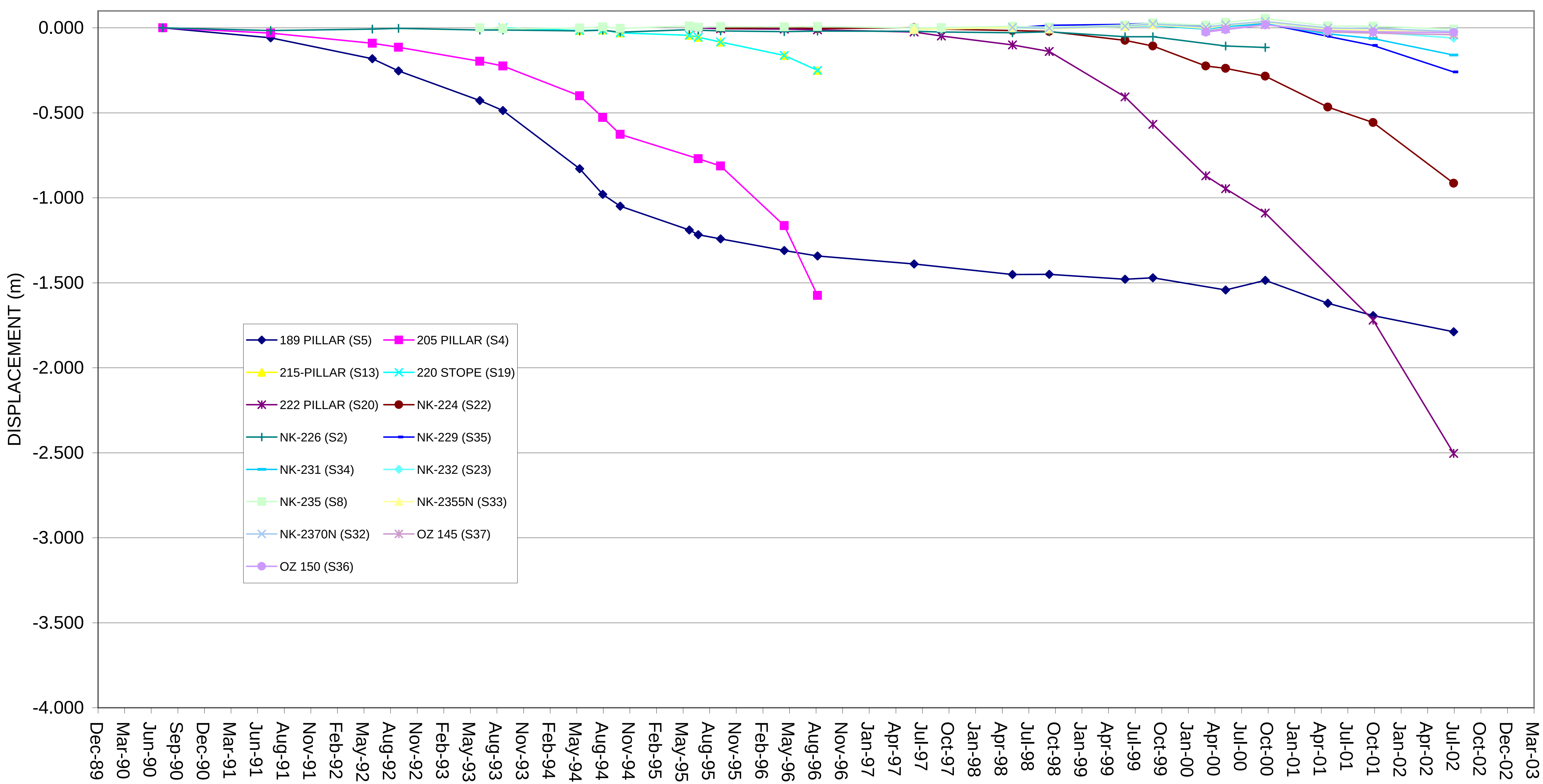
5. **Cross Section Titled ‘2150 Section Through Sinkhole Area’**

6. **Plan View of Mine Area Identifying Locations of Surface Tension Cracks**

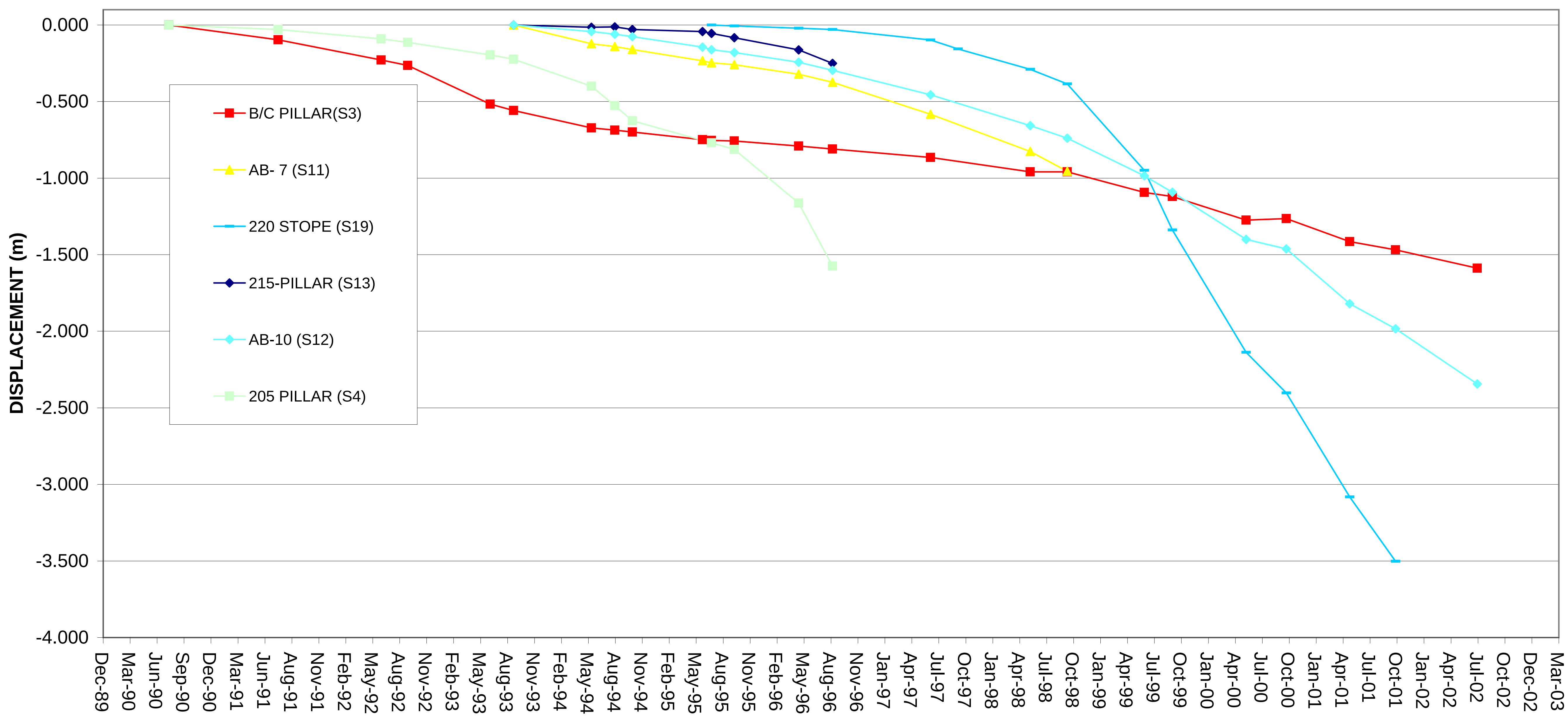


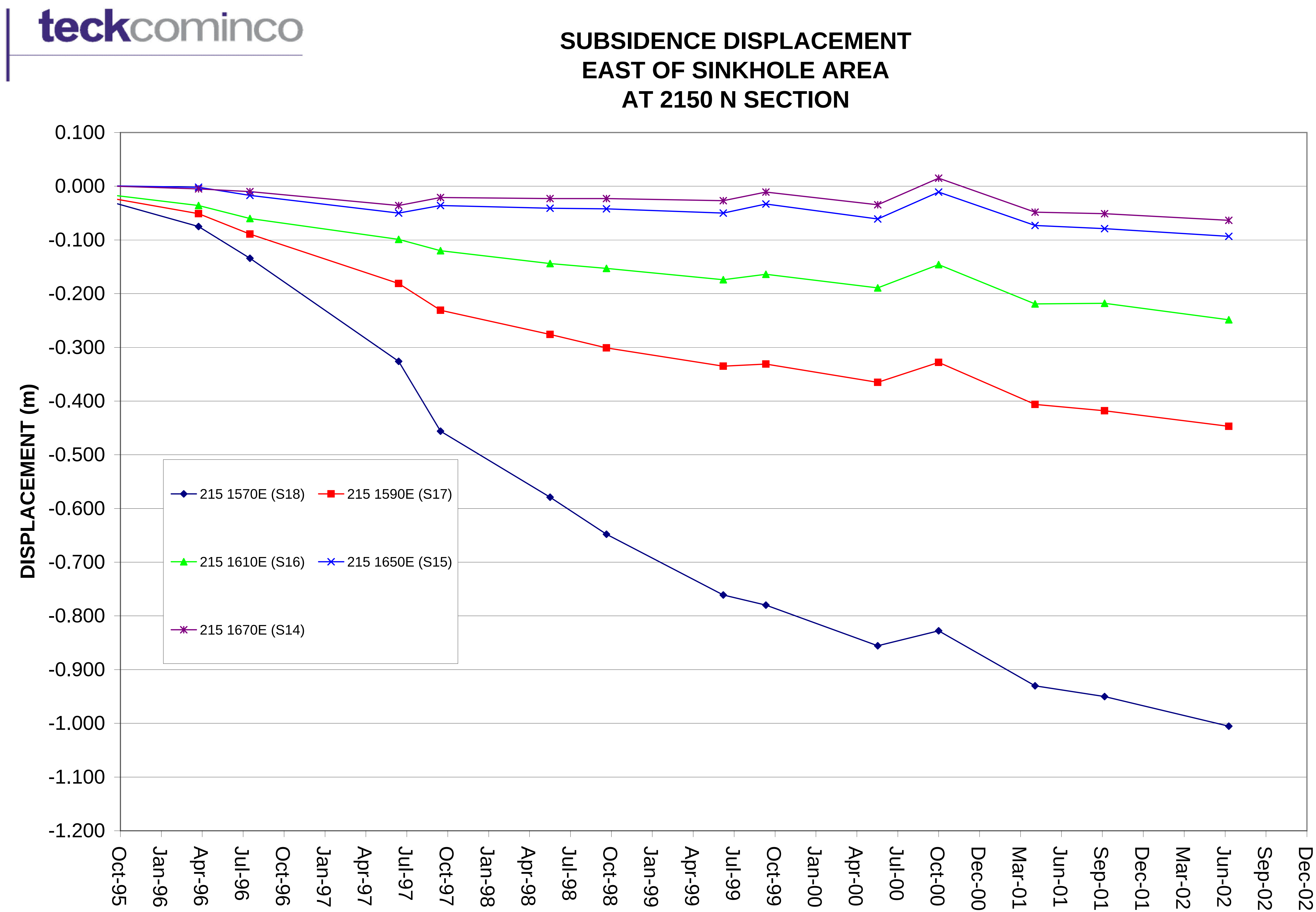
POLARIS MINE
SUBSIDENCE MONITORING
STATION LOCATIONS
N.T.S.
DB
JULY 2001 2001 UPDATE
JULY 2002 2002 UPDATE
NOTES:
Most survey monuments have been destroyed
but the drawing has not been updated
SINKHOLE
OLD
QUARRY
LOAD-OUT
CRF PLANT
SCREEN PLANT
LRD STOCKPILE AREA
ABUTMENT PILLAR
F PILLAR
SUB-BM
SUB-27
SUB-26 (dest)
SUB-28
SUB-29
SUB-30
SUB-41
SUB-42 (dest)
SUB-25(dest)
SUB-40
SUB-39
SUB-6
SUB-38
SUB-37
SUB-36
SUB-7
SUB-24
SUB-9
SUB-32
SUB-33
SUB-8
SUB-23
SUB-1
SUB-10
SUB-34
SUB-35
SUB-2(dest.)
SUB-22
SUB-21(dest.)
SUB-20
SUB-19
SUB-13(dest.)
SUB-3
SUB-11(dest.)
SUB-12
SUB-4(dest.)
SUB-16
SUB-17
SUB-18
SUB-15
SUB-14
SUB-5
2400 N
2200 N
2000 N
1800 N
1200 E
1400 E
1600 E

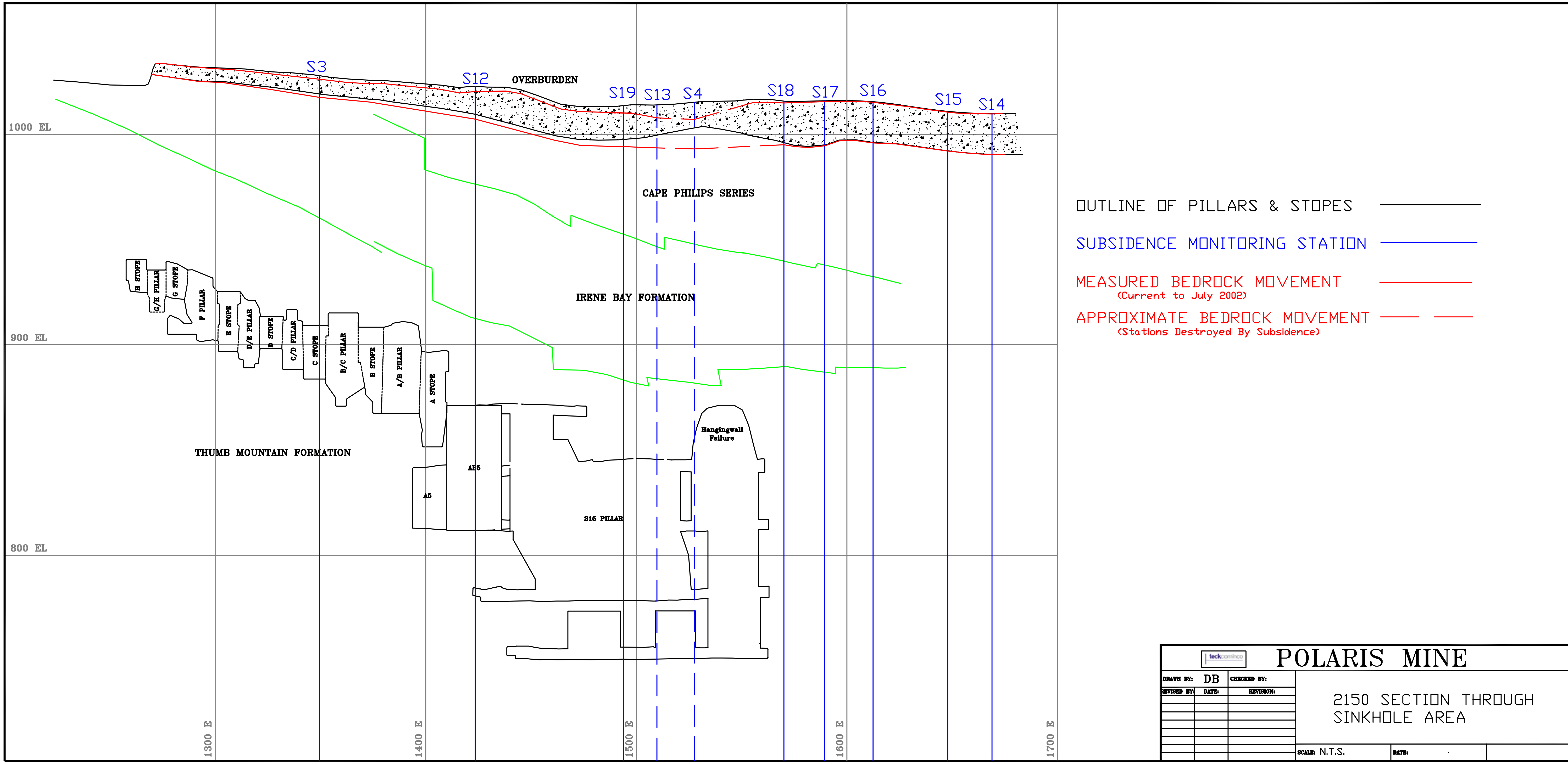
SUBSIDENCE DISPLACEMENT
NORTH - SOUTH THROUGH SINKHOLE AREA
AT 1500 E SECTION



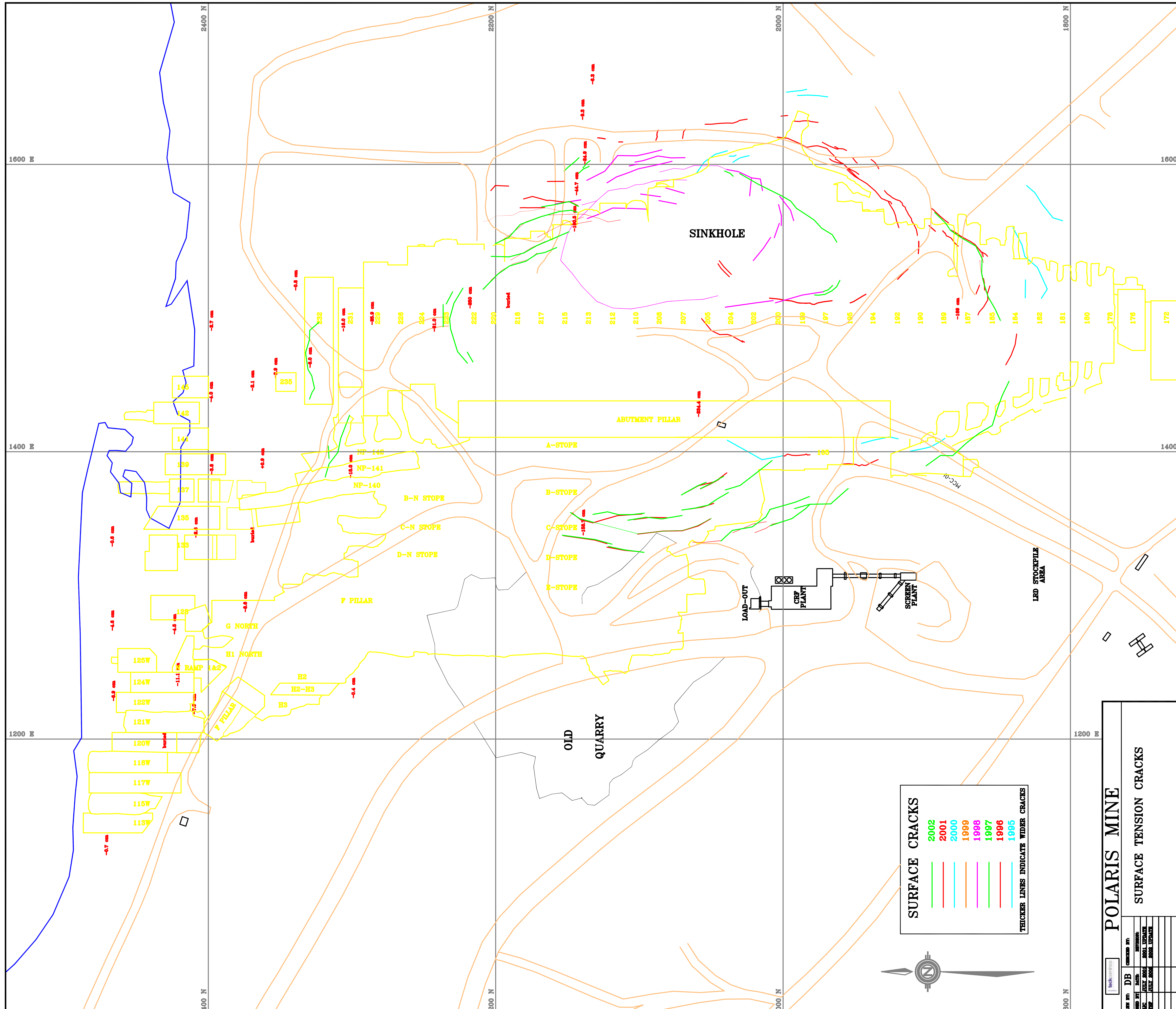
SUBSIDENCE DISPLACEMENT
WEST OF SINKHOLE AREA
AT 2150 N SECTION




teckcominco
SUBSIDENCE DISPLACEMENT
EAST OF SINKHOLE AREA
AT 2150 N SECTION
DISPLACEMENT (m)
0.100
0.000
-0.100
-0.200
-0.300
-0.400
-0.500
-0.600
-0.700
-0.800
-0.900
-1.000
-1.100
-1.200
215 1570E (S18)
215 1590E (S17)
215 1610E (S16)
215 1650E (S15)
215 1670E (S14)
Oct-95
Jan-96
Apr-96
Jul-96
Oct-96
Jan-97
Apr-97
Jul-97
Oct-97
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00
Jul-00
Oct-00
Dec-00
Mar-01
Jun-01
Sep-01
Dec-01
Mar-02
Jun-02
Sep-02
Dec-02



S3
S12
OVERBURDEN
S19
S13
S4
S18
S17
S16
S15
S14
1000 EL
900 EL
800 EL
CAPE PHILIPS SERIES
IRENE BAY FORMATION
THUMB MOUNTAIN FORMATION
H STOPE
G/H PILLAR
G STOPE
F PILLAR
E STOPE
D/E PILLAR
D STOPE
C/D PILLAR
C STOPE
B/C PILLAR
B STOPE
A/B PILLAR
A STOPE
AE5
A5
215 PILLAR
Hangingwall Failure
1300 E
1400 E
1500 E
1600 E
1700 E
OUTLINE OF PILLARS & STOPES
SUBSIDENCE MONITORING STATION
MEASURED BEDROCK MOVEMENT
(Current to July 2002)
APPROXIMATE BEDROCK MOVEMENT
(Stations Destroyed By Subsidence)
POLARIS MINE
DRAWN BY: DB
CHECKED BY:
REVISED BY:
DATE:
REVISION:
2150 SECTION THROUGH SINKHOLE AREA
SCALE: N.T.S.
DATE:


POLARIS MINE
SURFACE TENSION CRACKS
SCALE: N.T.S.
DRAWN BY: DB
CHECKED BY:
REVISED BY: JJC DATE: JULY 2001 REVISION: 2001 UPDATE
TSP JULY 2002 2002 UPDATE
DATE:
DWG #:
FILENAME
SURFACE CRACKS
2002
2001
2000
1999
1998
1997
1996
1995
THICKER LINES INDICATE WIDER CRACKS
SINKHOLE
ABUTMENT PILLAR
A-STOPE
B-STOPE
C-STOPE
D-STOPE
E-STOPE
B-N STOPE
C-N STOPE
D-N STOPE
F PILLAR
G NORTH
H1 NORTH
H2
H2-H3
H3
OLD QUARRY
LOAD-OUT
CRF PLANT
SCREEN PLANT
LRD STOCKPILE AREA
1600 E
1400 E
1200 E
2400 N
2200 N
2000 N
1800 N

APPENDIX C

1. **Excerpts from Report on 'Site visit to Cominco Ltd.'s Polaris Mine' by Golder Associates Ltd., February 1994**

2. **Excerpts from Report on 'Visit to Polaris Mine November and December 1995' by Golder Associates Ltd., May 31, 1996**

Golder Associates Ltd.

500 - 4260 Still Creek Drive
Burnaby, British Columbia, Canada V5C 6C6
Telephone (604) 298-6623
Fax (604) 298-5253

REPORT ON

SITE VISIT
TO
COMINCO LTD.'S
POLARIS MINE

1994

Submitted to:

Cominco Ltd.
Polaris Operations
Polaris, NWT
X0E 0Y0

DISTRIBUTION:

3 copies -	Cominco Ltd. Little Cornwallis Island, NWT
3 copies -	Cominco Ltd. Vancouver, B.C.
2 copies -	Golder Associates Ltd. Vancouver, B.C.

February 1994 932-1510

- Movements on the 880 level were difficult to interpret due to erratic results.

Due to problems with maintaining convergence stations, the program was discontinued and is being replaced by a qualitative visual monitoring program.

4.3 Subsidence

Surface subsidence measurements continue over the Keel and Panhandle Zones. In 1993, an additional eight stations were added to the existing five. The locations of the monitoring points are shown in Figure 1. The new stations will provide information above the abutment pillar and northern stoping areas

Two measurements have been made since the December 1992 visit. Only three stations, B/C, 189 and 205 are showing significant movement. The movement recorded at these three stations is summarized in Table 1 and graphed in Figure 2.

Table 1

Summary of Subsidence 1990-1993 for B/C, 189 and 205 Stations

Station	Total Movement (mm)	1990-1991 Movement (mm)	1991-1992 Movement (mm)	1992-1993 Movement (mm)
B/C	558	97	167	294
189	486	58	195	233
205	224	30	84	110

Table 1 shows a yearly trend of increasing subsidence at the B/C and 189 stations. This corresponds to the nearly 100% extraction of the ore beneath these stations. The station above 205 is beginning to show the effects of the northward advance of the mining front.

4.4 Surface Extensometer

The two surface extensometer installations adjacent to the B/C and 189 surface subsidence stations have been monitored since 1988. Plots of cumulative movement of these two extensometers are presented in Figures 3 and 4. Total movement recorded for the B/C extensometer is 19 millimetres and for the 189 extensometer, 77 millimetres. These values are approximately 4% and 16% of total subsidence measured at that point.

Both extensometers record some minor separation at 40-60 metres depth. The disparity between the measured surface subsidence and the movement indicated by the extensometers indicates that the hangingwall may be moving as a relatively cohesive mass (or as a series of large blocks).

5.0 KEEL PILLAR MINING

Pillar mining in the Keel Zone has rapidly become the primary source of ore at the Polaris Mine. Pillar ore now forms 72% of production tonnes versus 14% in 1988.

5.1 Review of Pillar Mining Experience

A considerable amount of information has been collected on the pillar mining carried out to date. This information was reviewed and will be applied to the analysis of future pillar mining operations.

5.1.1 Pillar Recovery

Table 2 presents experience with pillar mining to date. The percentage extraction of both tonnes and metal are included as well as comments on stability related issues.

Table 2

Summary of Keel Pillar Mining Experience

Pillar	% Tonnage Recovery	% Metal Recovery	Comments
180	-	60	Backfill problems
182	-	100	Back failure in Stage II
185	85	75	Backfill problems in Stage I, back failure in Stages II and III
189	105	95	
192	92	85	Backfill problems in Stage I Back failure in Stage IV
195 *	100	85	Back/hangingwall failure in Stage III, 90 metre high fill exposure
199 *	72	70	Significant ore loss in Stages I and III. Major back/hangingwall failure in Stage III
202-I	88	81	
202-II	102	99	Major failure of 820/850 block in Stage II

* Pillar not complete

The first pillars to be recovered tended to encounter problems with fill wall stability. However, with improved fill quality these problems appear to be resolved (for the fill wall dimensions currently being exposed). Recently there has been an increased incidence of back failures. These failures appear, in part, to be influenced by the various faults that traverse the orebody.

Recovered metal range from a low of 60% to a high of 100% with an average of 80%. Recovered tons range from a low of 72% to a high of 105%. The ratio of % metal to % tonnage is an average 0.92.

5.1.2 Backfill Performance

Backfill performance during pillar extraction is summarized in Table 3

Table 3

Summary of Exposed Backfill Stability*

Pillar	Stage	Maximum Height of Backfill Exposure (m)	Maximum E-W Span of Backfill (m)	Comments
185	II	50	24	
189	II	66	34	
192	I	65	33	Fail
192	II	65	25	
195	II	69	25	
195	III	71	26	
195	IV	95	22	
199	I	80	37	Fail
199	II	83	10	
199	III	87	28	Fail
199	IV	95	25	
202	I	51	26	

* Note: This table does not include early failures that were attributed to poor quality backfill.

Backfill stability would appear to be controlled by the following factors:

- The content and distribution of water in the fill;

  The time allowed for the fill to freeze;

- The height and width of exposed fill wall;

- The length of time between exposing a fill wall and backfilling of the pillar;

A reasonable amount of information is available on the water content and distribution within specific fill blocks. Where low moisture fill is anticipated, a "skin" of ore may be left to reduce the potential for fill dilution. The time required for the fill to freeze is also relatively well established and blocks are scheduled to allow sufficient time for ice formation. Stable exposure heights and widths have yet to be established. The data in the above table and in Figure 5 would indicate that the exposed width may play as big a role as the exposed height. This may be a result of the surfaces formed during fill deposition as shown in Figure 5.

5.2 Current Status of Pillar Mining in the Keel Zone

Active pillars in the Keel Zone are:

- 192 Stage III
  - Good recovery, no major problems to date.
- 195 Stage V
  - Mining block adjacent to major back failure, cable bolted back next to failure in good condition.

  199 Stage IV
  - Mining block adjacent to major back failure, some drilling problems on 850 level.
- 202 Stage II
  - Good recovery in 760/790 block, severe problems in 820/850 block with large ground displacements (see Section 5.3).
- 205 Stage I
  - Initial block development in place at eastern end.

5.3 202 Pillar Mining

The following outlines the sequence of events in mining of Stage II:

Mine and fill 760 to 790 level;

- Observed horizontal cracking and difficulty in maintaining blasthole integrity;

Mass blast 820 to 790 level;

- Continuous movement of the 850 to 820 block after the mass blast.

The block is bounded on the west by a steeply dipping structure and appears to be bounded by a similar structure on the eastern side. The top of the block is between 6 and 12 metres above the 850 Level. Figure 6 shows the approximate size of the block and the associated structures.

Total downward movement of the block is in excess of 3.5 metres on the 850 level (see Photographs 14 and 15). The block appears to be moving as a large mass and not rubblizing internally. **It is important to note that the total void space above the level must be equal to 3.5 metres.**

Important considerations in developing a plan to recover the block are as follows:

- 17,000 tonnes of ore from the 820/790 block remains on the 790 level;
- The 35,000 tonnes of ore in the 820/850 block is primarily from the high grade P1 horizon;
- Material above and to the east of the failure will be low grade or barren rock;
- The ultimate hangingwall on the 880 level has not been cable bolted;
- Significant back failures had occurred in both the 195 and 199 pillars.

From a geotechnical point of view it is important that any mining plan incorporate the following:

- Test holes towards the 199 pillar to establish the north-south extent of the back failure;
- Cable bolt the ultimate hangingwall on the 880 Level and, dependent upon the condition of the block below 880, cable bolt downwards to secure the ground above the sliding block. It must be recognized that due to the magnitude of the movements which have occurred that cable bolting may not be successful;
- Ensure that the drawpoint on 790 level is kept full to minimize the impact of any potential air blast should the sliding block fail suddenly;
- Development of a plan to fill the void should it become necessary;
- If an option is to mine Block III to induce failure of Block II then the size of Block III should be kept to minimum. This will reduce the size of the backfill exposure when both blocks are empty.

In evaluating a recovery plan it is very important to consider the risks associated with the plan and the consequences of both success and failure. The problem is 202 cannot be analyzed in isolation from the other stoping areas.

A number of controls exist that influence the course of action. These include:

- backfill disrupts float circuit and causes metal losses

- hangingwall dilution can slow the mill, but does not tend to cause metal loss
- the implication of these is that fill failure may be more costly ton for ton than hangingwall failure
- there is little flexibility in the overall extraction sequence (ie. few primary stopes remain that can be used to augment production when disruptions occur)

A number of potential recovery options were discussed. A final plan was developed at a ensuing meeting the week after the site visit.

5.4 General Pillar Mining Comments

5.4.1 Mass Blasting

A number of mass blasts have been undertaken during pillar recovery operations. Mass blasts are only considered when ground movements in the mining block become a potential safety concern or cause significant blasthole stability problems. Mining blocks of up to 40,000 tonnes have been mass blasted with large quantities of explosives assigned to a limited number of delays. Often, the blasts have had only minor void space.

Mass blasting has both positive and negative results.

Positive

- Efficiency gains through concentrated blasthole loading operations and reduced redrilling potential.
- Good fragmentation potential and therefore efficient mucking operations.

Negative

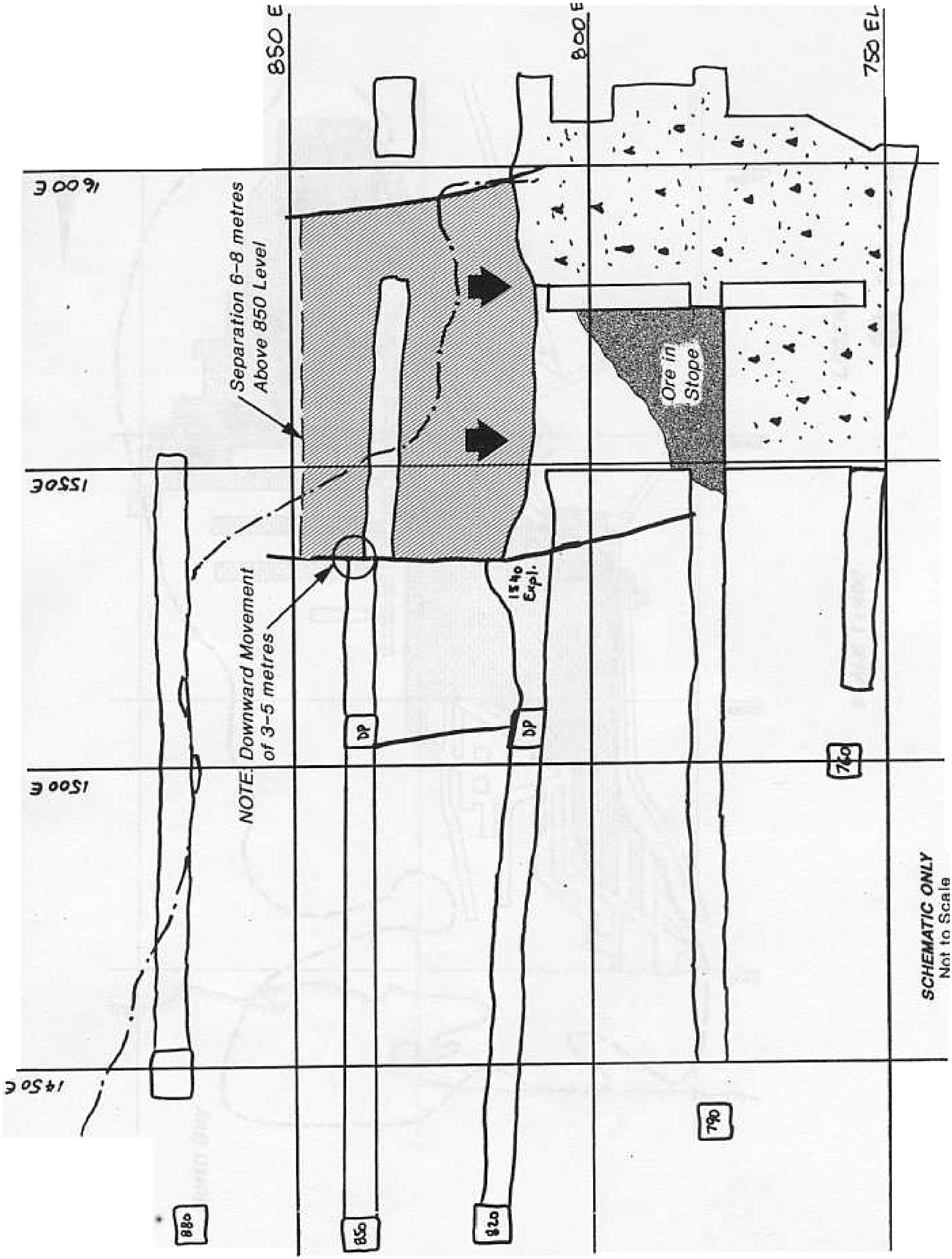
- High explosive quantities detonating over a short time period and small void ratio will result in high vibration and gas levels. This could potentially result in both new fracture creation, extension and opening existing fractures (blast damage).
- Large blast volumes will result in larger local stress redistribution and potentially more severe stress effects.

5.4.2 Size of Mining Blocks

When stability problems have been either identified through geologic mapping or encountered during pillar extraction, the post pillar location has been changed. In most cases the stage size has been increased to include the problem area.

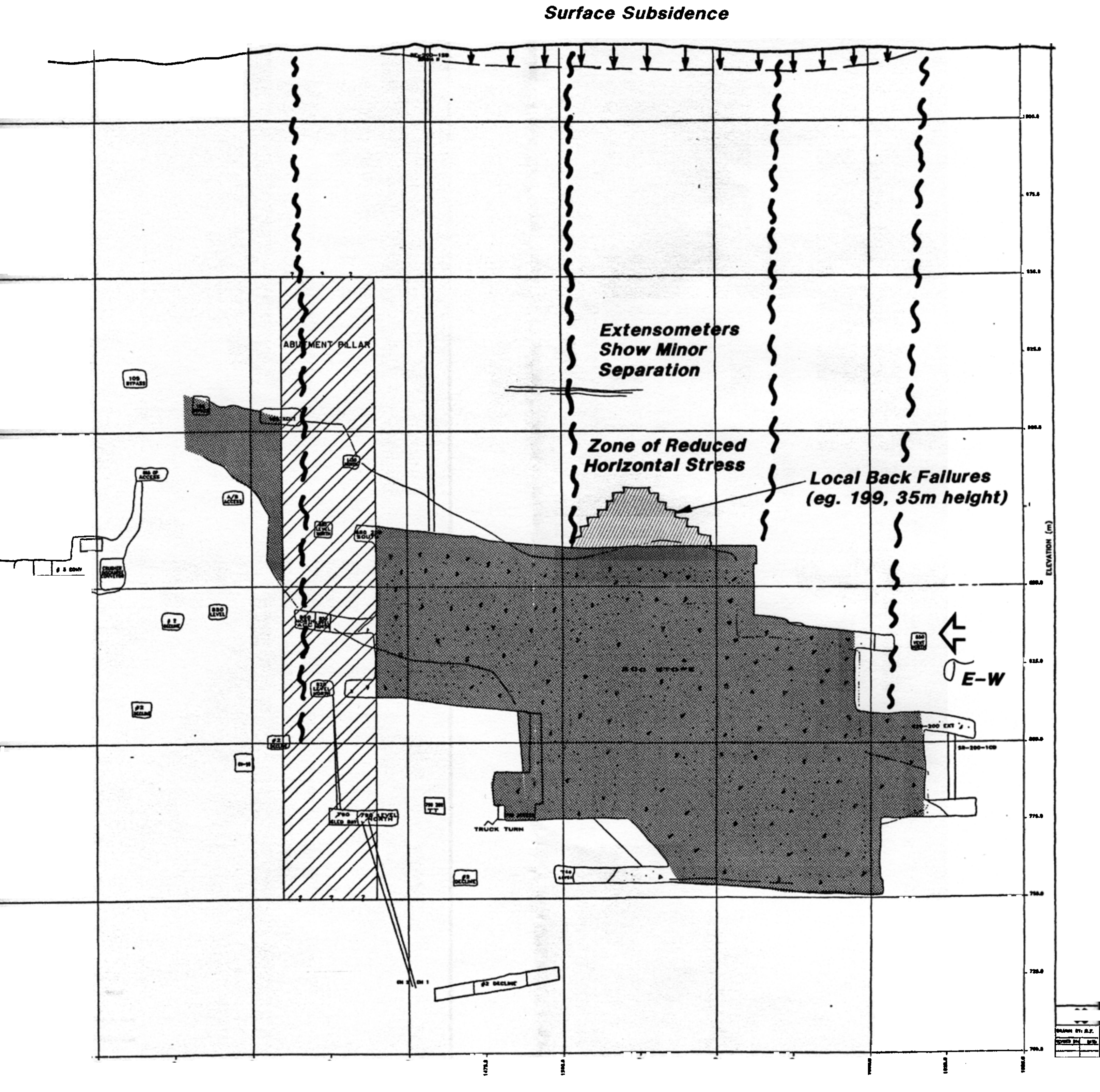
202 PILLAR SECTION

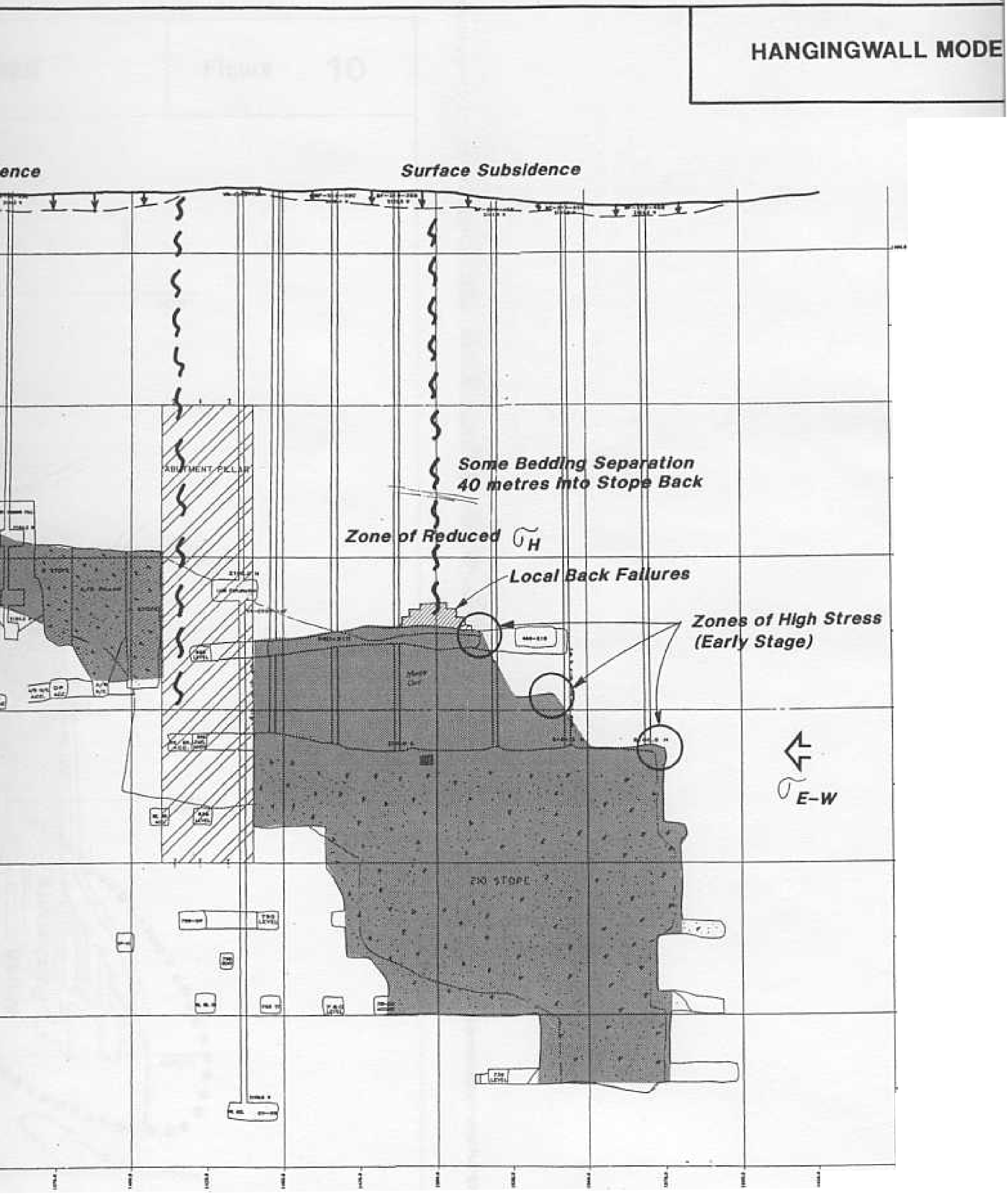
Figure 6



PROJECT NO DRAWN REVIEWED DATE

HANGINGWALL MODEL




HANGINGWALL MODE
ence
Surface Subsidence
ABUTMENT PILLAR
Some Bedding Separation
40 metres into Stope Back
Zone of Reduced σ_H
Local Back Failures
Zones of High Stress
(Early Stage)
σ_{E-W}
210 STOPE

Golder Associates Ltd.

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Burnaby, British Columbia, Canada V5C 6C6
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Golder Associates

REPORT ON

VISIT TO POLARIS MINE
NOVEMBER AND DECEMBER 1995

Submitted to:

Cominco Ltd.
Polaris Operation
Polaris, NWT
X0E 0Y0

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May 31, 1996

952-1472

150 Area (see Photograph 28 and 29)

- **850L:** Stringer ore at fringes of main orebody will provide secondary ore source. Ground conditions rated as "fair". Back supported with Split Sets.

Lower S. Keel (see Photograph 30)

- **790L:** Stringer ore, secondary source. Back conditions rated as "good".

General

- Ground conditions do not appear to have substantially changed between the November and December visits. Overall, observed conditions were better than those during 1994 visit. In part, this is a result of more attention to ground support, both quality and timing of installation;

- Poorest observed ground conditions in abutment development were on the 880 mL;

- Poorest observed pillar conditions were along the 850 mL drill sub in the 208 and 212 pillars.

Support

- More screen is being installed. The quality of installation has improved substantially compared to the 1994 visit. In particular, screen is now being placed tight to the walls and back.

- A remote arm for placement of shotcrete has been built in the mine shops (see Photograph 20). Initial trials have indicated a number of problems with operating the arm and the quality of the placed shotcrete;

Subsidence

- Subsidence induced cracks have appeared on surface (see Photographs 44 to 48).

3.0 GROUND CONTROL

3.1 Current Ground Control Problems

Ground problems continue in the Keel Pillar stopes; for example, loss of access in the 208 pillar and wedging in the 212 pillar. These problems include:

hangingwall failures - Irene Bay;

wall slabbing in P1 ore;

wedging all north-south structure;

movement of ground in all stopes.

The cause of these problems has been discussed in previous visit reports. The important issue is, however, that problems will continue to occur as the highest, widest and weakest of the Keel Pillars are now being mined. The problems encountered in 208 can thus be expected in 212. Access will be lost (850/820), wedging will occur and re-drills will be necessary all leading to slower production and lower recovery.

As discussed in the following section, the majority of ground control problems appear to manifest themselves during Stage III stoping. This is due to a number of factors including thicker ore, weaker ground, etc. Improved support will mitigate against some of the problems. Other approaches include faster mining (with the aid of CRF) or a change in stage size. Observations, made by mine staff, that ground problems increase if a stage remains open for more than about 90 days, underline the benefits of faster mining.

3.2 Stoping Achievements

The mine has maintained a database on a number of key statistics on pillar mining. A review of this database indicates the following:

- Pillar recovery has decreased from approximately 92% of blasthole reserves in 1993 to approximately 82% of blasthole reserves in 1995, Figure 1a;
- Average daily production rates have been very variable (see Figure 1b), ranging from a high of 2,750 tonnes/da to less than 500 tonnes/da. Achievable daily production rates appear to be in the 500 to 750 tonnes/da range (see Figures 1b and 2). Discussions with mine staff indicate that production delays were largely associated with ground control problems;
- Average recoveries by stage were remarkably similar (see Figure 3a). However, the variation in recovery as measured by the co-efficient of variation (standard deviation/mean) clearly demonstrates the substantial risk of not meeting production targets during Stage II and Stage III mining (see Figure 3b);

- A typical section through a Keel pillar is given in Figure 4. This section illustrates that Stage III generally is tallest section and therefore weakest of the overall pillar; closest to the overlying, poor quality, Irene Bay; and contains the highest portion of high grade, weak ore. In addition, loss of access to the 850/820 drill subs leads to production delays due to increased support and poorer fragmentation;

3.3 Subsidence

The following summarises salient events regarding subsidence:

- Subsidence induced cracking has been observed at surface over and adjacent to the Keel mining area. The location of the cracks is shown in Figure 5.

- Surface cracking appears to be closely associated with those areas in the Keel where there has been 100% ore extraction. No cracking has been *observed* over the Panhandle mining area or over partially extracted areas of the Keel. The cracks appear to be located near vertically over the mined out outline on the 850/820 level.

  Surface monitoring shows continuing ground movement (see Figure 6). The maximum *measured* subsidence is approximately 1.25 m and is located over the 189 pillar area.

- Most subsidence monitors are maintaining constant velocity or de-accelerating.

- Analysis by mine staff of the monitoring data suggest an angle of draw of 40°.

- Given the location of the surface cracking, the angle of cave along the east and western sides of the orebody may be about 20° to 30°.

This information will assist in planning the North Keel and Ocean Zones where undue subsidence could lead to water inflow. A number of relationships exist for the prediction of surface subsidence. Unfortunately, these were generally developed for coal mining, where the ratio of depth to mined thickness (coal seam thickness) is high, often 50 or greater. At Polaris, the ore is both shallow and thick, and various coal subsidence formula become difficult to apply.

A recent review by Golder Associates (see Appendix II) found that published information on subsidence over base metal mines was extremely limited and mainly referred to caving. Thus, there is little precedent which can be used to assess future subsidence

(North Keel and Ocean Zone) at Polaris. More or less sole reliance will be on the information currently being gathered and mine derived relationships (assisted, for example, by numerical modelling).

3.4 Support

Improvements continue to be made in ground support practices. These include:

- screening and strapping of walls;
- installation of support prior to changes in ground conditions; and
- substantial reduction in backlog of support installation.

Salient comments are as follows:

Screening in the weak P1 ore should be to the sill. Bolts should be installed at the base of the screen. There may be some operational difficulties with this approach. It will enhance the effectiveness of the screen.

- The shotcrete arm should be modified in order to obtain a better application. Continued experimentation with shotcrete is required.
- The use of Split Set bolts instead of resin bar as a means of wall support has been proposed. From a purely ground control perspective, Split Set bolts can provide effective support. However, it is questionable whether the changes can be economically justified. ?

3.5 Cemented Rock Fill

The CRF plant is in the process of being commissioned. A number of start-up problems are being experienced which have been exacerbated by the extreme climate at Polaris.

The requirements and opportunities associated with CRF have been discussed in previous review reports and extensively by Polaris staff. The major impact of CRF with be the greater stoping control that can be realised and the faster stope cycle time that can be achieved. It is believed that this will be a significant factor in the mining of the abutment pillar.

PHOTOGRAPH 43

Surface subsidence cracks.

PHOTOGRAPH 44

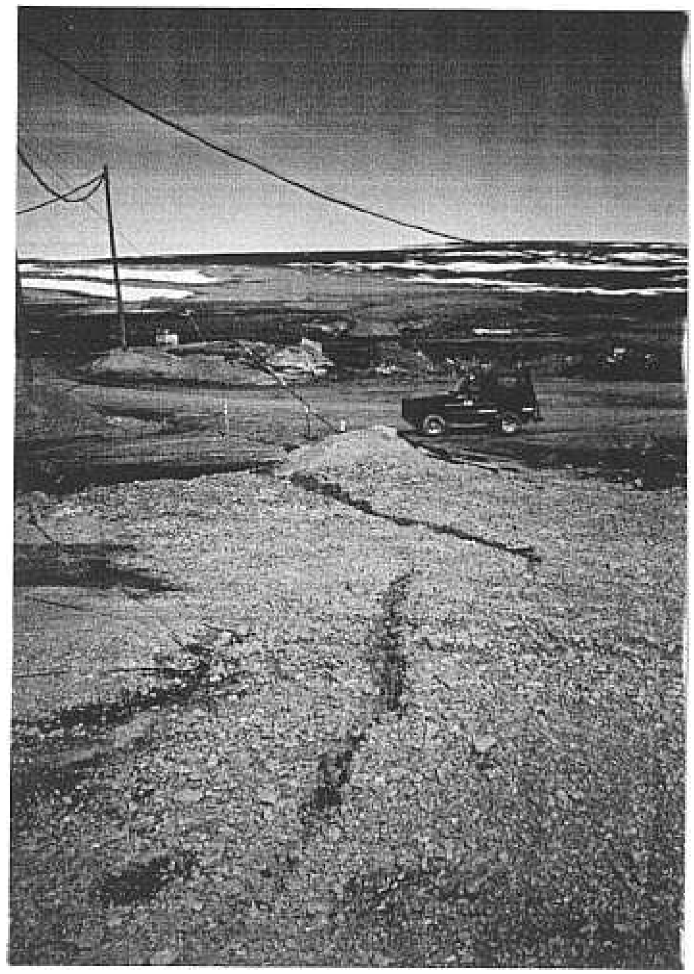
Surface subsidence cracks.

PHOTOGRAPH 46

Surface subsidence cracks.

PHOTOGRAPH 45

Surface subsidence cracks.



PHOTOGRAPH 47

Surface subsidence cracks.

PHOTOGRAPH 48

Surface subsidence cracks.

APPENDIX D

1. **Polaris Operations Internal memorandum – Trevor Feduniak (Senior Mine Engineer) to John Knapp (Manager) Regarding 'Subsidence Analysis', December 4, 2002**

teckcominco

Memorandum

To: John Knapp – Mine Manager

From: Trevor Feduniak – Senior Mine Engineer

Date: December 4, 2002

Subject: Subsidence Analysis

A surface subsidence analysis was conducted in the fall of 2002.

Measurement Method:

Subsidence at Polaris has been measured since 1990 by surveying the elevation of monitor posts at strategic locations. New posts have been added over the years to provide more detail, most recently in summer 1999. Some attrition has occurred; posts have fallen over due to large amounts of subsidence, and more commonly, posts have been damaged by surface mining activities.

The survey is done using a leveling instrument, using a benchmark post (located far from mining-influenced ground) as a reference. The posts are measured in sequence, and the loop is closed back at the benchmark. Closure error is distributed evenly among all measurements. In an effort to reduce the closure error, or at least distribute it more accurately, the surveys for the past couple of years were done as a series of sub-loops rather than one large loop of all stations. The results indicate that the new method increases our accuracy.

Typically only two measurements per year are practical, due to the leveling instrument's sensitivity to the cold weather and wind. This year, only one level loop was conducted (July). A measurement in September was not possible due to a decrease in manpower, a direct result of the scheduled completion of mining activities at the end of August.

Analysis:

Subsidence at Polaris is defined as a drop of greater than 50mm from original elevation, along with a downward trend observed over several readings. Closure accuracy, natural ground movement from freeze-thaw cycles, and heavy equipment activity nearby prevent us from defining mining-induced subsidence any more closely. It is important to observe the same post over a long period of time before drawing any conclusions.

The posts have been divided into several areas for convenience of analysis:

Sinkhole:

Located over the centre of the Keel mining zone, the Sinkhole has subsided more than 10 meters (a rough estimate). The Keel Zone was 120m top to bottom, and was mined without leaving posts or pillars. Hangingwall ground support in the stopes was limited to 8' swellex. Large-scale hangingwall caves at 880 level were induced in Pillars from 190 to 212, leaving large voids that were impossible to backfill. Tension cracks appeared on surface (see surface drawing for location).

There is comparatively little subsidence data on the Sinkhole area. Monitor posts were installed in ground that was likely already moving, and were destroyed or fell over quickly.

The attached graph of post movement near the sinkhole is at a different scale compared to the other areas to show the larger movements involved.

SUB-20, started to move in 1998, and has dropped 2.50m. We expect the deceleration phase to begin soon, and when this happens, we would probably be able to predict the final level of subsidence in this area.

SUB-22, continuing north, started moving in 1999. Currently down 0.91m, this post is still in the high velocity part of the expected curve.

SUB-3 is located west of the Sinkhole, over the Panhandle zone. This station has been moving at a fairly constant rate since 1994. Panhandle pillars have been mined during that time. Tension cracks in this area are quite pronounced and extend throughout the cement storage pad area. These cracks may be related to Abutment mining and were probably affected by the undercutting of A Stope late last year.

SUB-12 is right over top of the Abutment Pillar. This post showed some movement before Abutment mining began in 1997, but increased in velocity afterwards. It is down 2.34m. This station should enter the deceleration phase in the near future.

SUB-5 is at the south end of the Sinkhole. There has been very little mining at this end of the ore body in recent years, and the graph shows that this post underwent acceleration, rapid movement, and then deceleration. This station is currently at 1.69m, the same as a year ago. No further subsidence to the south is expected after backfilling 185 Stope during the reclamation phase.

Subsidence Front:

Immediately north of the Sinkhole, the Subsidence Front covers the northern limit of ground movement, and beyond that, posts that have just started to move. These posts are above the North Keel Zone, which has been mined differently than the Central Keel. The North Keel is 30m high, deeper underground, and is filled entirely with CRF. The entire hangingwall has been supported with 26’ or 40’ grouted cables.

SUB-23 passed the 50mm limit that defines subsidence, having been displaced 0.06m to date. This station is located directly above 232 Stope, our most northern large tonnage North Keel stope. This stope is completely filled with dry fill and is 80m from the shoreline.

SUB-33, 32, 36, 37 and 8 are located north of SUB-23 and none of these stations are defined as subsidence (>50mm). With little to no extraction in this area and no signs of major acceleration, large-scale subsidence similar to the sinkhole is not expected.

North:

These subsidence posts are located over the Ocean Zone and are beginning to trend downward; however, the movement isn’t characterized as subsidence. The Ocean Zone has been mined 30m high, with 4m rib pillars running north-south and 5m posts running east-west between pillar stages. The entire hangingwall has been supported with 26’ grouted cables. Mining of the Ocean Zone has spanned 4 years with no subsidence. No hanging wall failures have occurred and all stopes were completely dry filled. No major subsidence concerns are anticipated in the Ocean Zone.

Also in the northern end of the orebody is SUB-10. SUB-10 was installed to monitor the northern limit of the Panhandle, which is not part of the Ocean Zone. This station is located over NP-142 stope. This station has entered the high acceleration range due to the recent mining of NP141. This station has been displaced 0.18m and surface tension cracks have appeared on surface. The cracks run parallel to the extraction limits of the Panhandle, not the Ocean Zone. It is expected that the conservative mining method of the Ocean Zone will contain any major subsidence caused from mining in the southern part of the mine.

East:

Delineating the eastern limits of subsidence, this series of posts runs from the end of 215 Pillar (part of the Central Keel) towards the New Quarry.

SUB-18, closest to 215 Pillar, has subsided 1.05m. There was a large hangingwall cave in Stage 1 of 215 Pillar (the easternmost stage). The rest of the pillar was taken in smaller stages and filled with CRF, and no further hangingwall damage was incurred.

The rest of the posts show constant and diminishing movement as they get further from 215 Pillar, as expected. All stations are defined as subsidence with SUB-14 having been displaced 0.063m. Surface tension cracks have not extended further to the east and we predicted that this would also be true for major surface subsidence.

West:

Located over the West Panhandle, these posts have just moved into the classification of subsidence, with measurements ranging from 70mm to 110mm. We can measure these posts most accurately because they are closest to the Benchmark. Like the North Keel, the West Panhandle is filled with CRF and dry fill. The panhandle also has a few 5m posts and the hangingwall has been supported with 26' grouted cables. In 2002, mining in this area experienced high levels of activity with 35% of our total production from this Panhandle zone. Some subsidence was expected due to the high activity levels in this zone this past year.

Conclusions:

The principle reason to monitor subsidence is to predict the possibility of connecting the mine workings directly to the ocean via a large crack. The worst case scenario is a high volume failure flooding the mine before the completion of reclamation backfilling. A lesser problem would be flooding after closure.

From observations of the Sinkhole, tension cracks visible on surface form long before there is a route for large volumes of water to drain underground. It should be noted that we have never had surface water enter the mine workings, even with the existence of surface tension cracks and large seasonal runoff. We will continue to watch for the formation of surface tension cracks during the reclamation project. Underground, we have kept the hangingwall stable through intensive ground support measures and conservative recoveries by leaving large posts behind.

The extent of the subsidence limits is a direct footprint of the orebody with the exception of the Ocean Zone, which has not experienced any subsidence. The stability of the Ocean Zone can be attributed directly to the conservative mining extraction and extensive measures taken in ground support.

The different mining methods for the north end of the ore body will not induce subsidence similar to that experienced over the Central Keel; and there is no significant risk of an inflow of water.

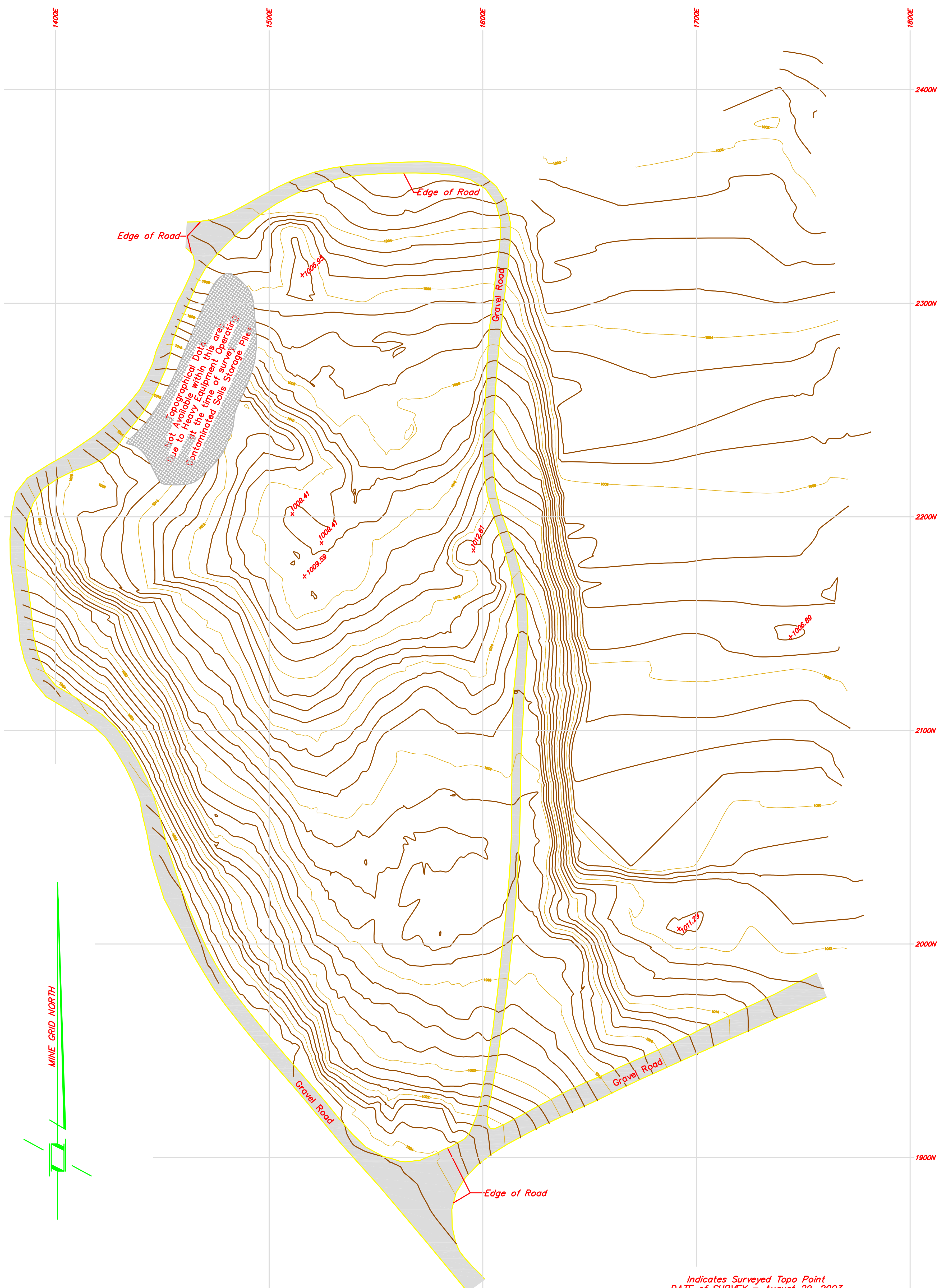
Trevor Feduniak, P.Eng.

Senior Mine Engineer

APPENDIX E

TOPOGRAPHIC SURVEY OF SIBSIDENCE AREA

By FOCUS SURVEYS



+ Indicates Surveyed Topo Point
DATE of SURVEY = August 29, 2003
CONTOUR INTERVAL = 0.5 m.
DATUM FOR ELEVATIONS IS C.P.#2 = 1065.34 m.

DATE	REVISIONS	DR/CK

TOPOGRAPHIC SURVEY OF SUBSIDENCE AREA POLARIS MINE NUNAVUT

teckcominco

FOCUS
Focus Surveys
A DIVISION OF THE FOCUS CORPORATION LTD.

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DATE : SEPTEMBER 12/03	SCALE: 1:1000
JOB : 322789-00	FILE NO.
DWG : SUBSIDENCE TOPO.DWG	SHEET 1 OF 1

Introduction to Longwall Mining and Subsidence

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Revision A
August 2007

DOCUMENT REGISTER

Revision	Description	Author	Reviewed	Date
A				2/8/07

.

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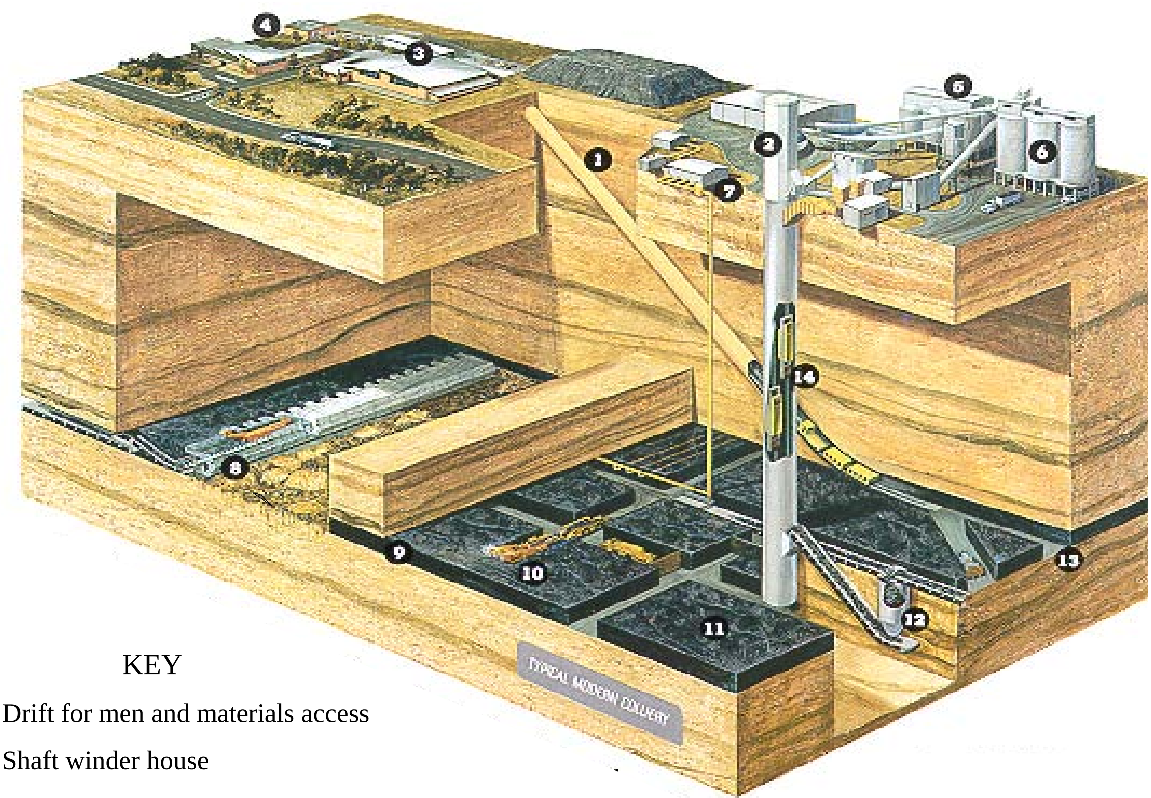
CHAPTER 1. INTRODUCTION TO LONGWALL MINING AND SUBSIDENCE

1.1. The Longwall Mining Process

Fig. 1.1, below, shows a cutaway diagram of a typical longwall mine. The main features of the mine are indicated in the key below the diagram. The longwall face is indicated by the number 8 in the diagram.



KEY

1. Drift for men and materials access
2. Shaft winder house
3. Bathhouse and administration building
4. Workshops
5. Coal preparation plant
6. Coal storage bins
7. Gas drainage system
8. Longwall face equipment
9. Coal seam
10. Continuous miner unit
11. Coal pillar
12. Underground coal bin
13. Main roadway or heading
14. Coal skips to carry coal to the surface

Fig. 1.1 Cutaway View of a Typical Longwall Mine

In longwall mining, a panel of coal, typically around 150 to 300 metres wide, 1000 to 3500 metres long and 2 to 5 metres thick, is totally removed by longwall shearing machinery, which travels back and forth across the coalface. A typical section through a coal face is shown in Fig. 1.2 and a photograph of typical longwall face equipment is shown in Fig. 1.3. The shearer cuts a slice of coal from the coalface on each pass and a face conveyor, running along the full length of the coalface, carries this away to discharge onto a belt conveyor, which carries the coal out of the mine.

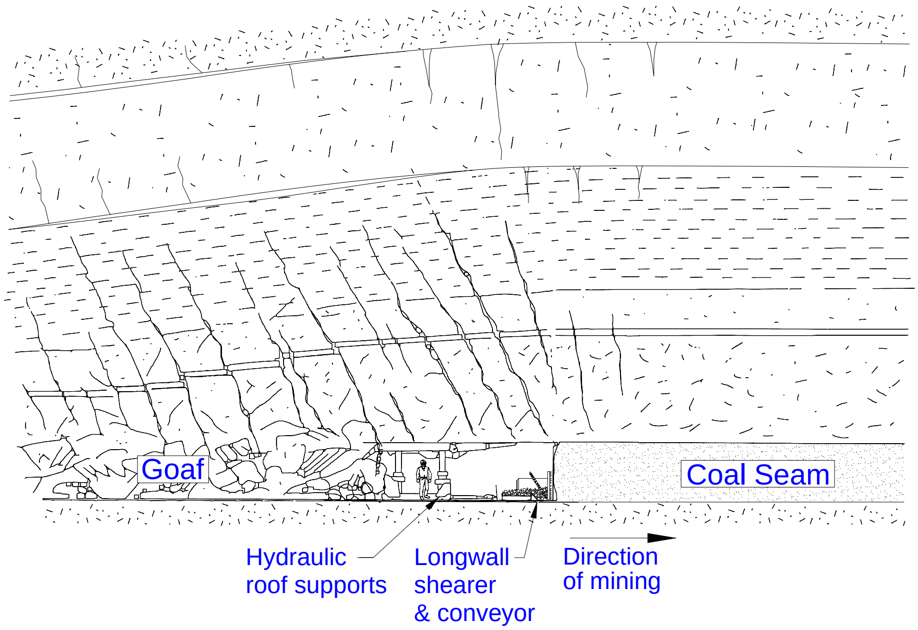


Fig. 1.2 Cross Section of a Typical Longwall Face

The area immediately in front of the coalface is supported by a series of hydraulic roof supports, which temporarily hold up the roof strata and provide a working space for the shearing machinery and face conveyor. After each slice of coal is removed, the hydraulic roof supports, the face conveyor and the shearing machinery are moved forward. Fig. 1.3 shows the arrangement of machinery on a typical longwall face, with the hydraulic roof supports on the left hand side and the coal face on the right hand side of the picture. The drum in the background is the rotating cutting head of the coal shearer and the chain conveyor can be seen in the foreground.

Fig. 1.3 Typical Longwall Face Equipment

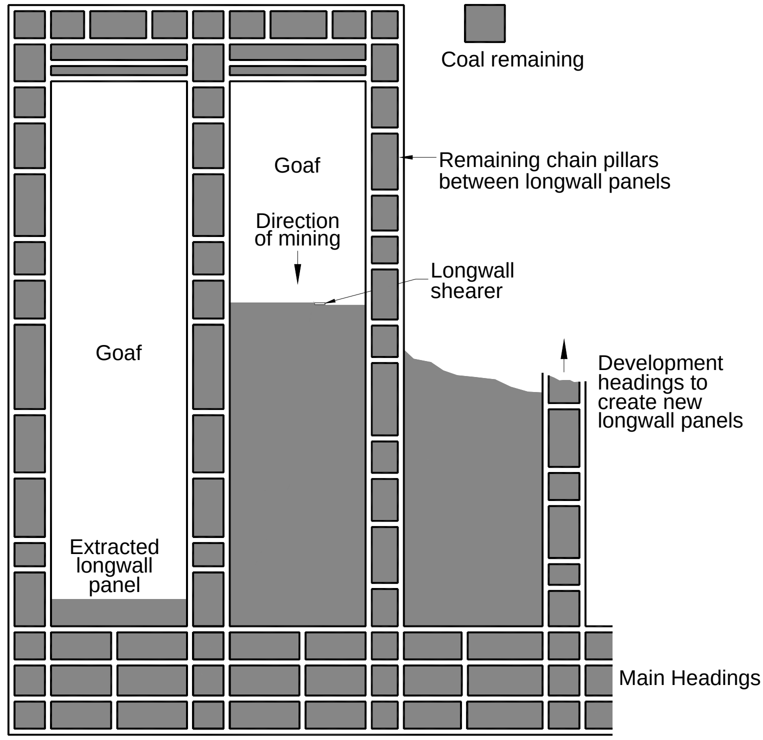


Fig. 1.4 Typical Plan View of a Series of Longwall Panels

Fig. 1.4 shows a typical layout of a group of longwalls. Before the extraction of a longwall panel commences, continuous mining equipment extracts coal to form roadways (known as headings) around the longwall panel. These roadways form the mine ventilation passages and provide access for people, machinery, electrical supply, communication systems, water pump out lines, compressed air lines and gas drainage lines. The roadways, which provide access from the mine entrance to the longwalls, are referred to as the main headings. Once the main headings have been established additional roadways, known as development headings, are driven on both sides of the longwall panel and are connected together across the end of the longwall.

The longwall face equipment is established at the end of the panel that is remote from the main headings and coal is extracted within the panel as the longwall equipment moves towards the main headings. This configuration is known as retreat mining. Typically, a longwall face retreats at a rate of 50 metres to 100 metres per week, depending on the seam thickness and mining conditions. The coal between the development headings and between the main headings is left in place as pillars to protect the roadways as mining proceeds. The pillars between the development headings are referred to as chain pillars.

When coal is extracted using this method, the roof immediately above the seam is allowed to collapse into the void that is left as the face retreats. This void is referred to as the goaf. Miners working along the coalface, operating the machinery, are shielded from the collapsing strata by the canopy of the hydraulic roof supports. As the roof collapses into the goaf behind the roof supports, the fracturing and settlement of the rocks progresses through the overlying strata and results in sagging and bending of the near surface rocks and subsidence of the ground above, as illustrated in Fig. 1.2.

If the width of an extracted panel of coal is small and the rocks above the seam are sufficiently strong, it is possible that the roof will not collapse and hence no appreciable subsidence will occur at the surface. However, to maximise the utilisation of coal resources and for other economic reasons, wide panels of coal are generally extracted and, in most cases, the roof is unable to support itself.

Longwall panel widths between 250 metres and 300 metres are becoming common as collieries strive towards more cost-efficient production and some collieries are now considering longwall widths of 400 metres or more.

1.2. The Development of Subsidence.

1.2.1. Subsidence Mechanisms

As the immediate roof strata, i.e. the rocks immediately above the seam, collapse into the goaf, the rocks above them lose support and sag to fill the void beneath them. The mechanism progresses towards the surface and the affected width increases so that at the surface, an area somewhat larger than the extracted panel of coal undergoes settlement. Fig. 1.5 shows a typical subsidence profile above an extracted longwall panel and it can be seen that the majority of the subsidence occurs over the centre of the longwall and tapers off around the perimeter of the longwall. The subsidence is typically less than the thickness of coal extracted underground.

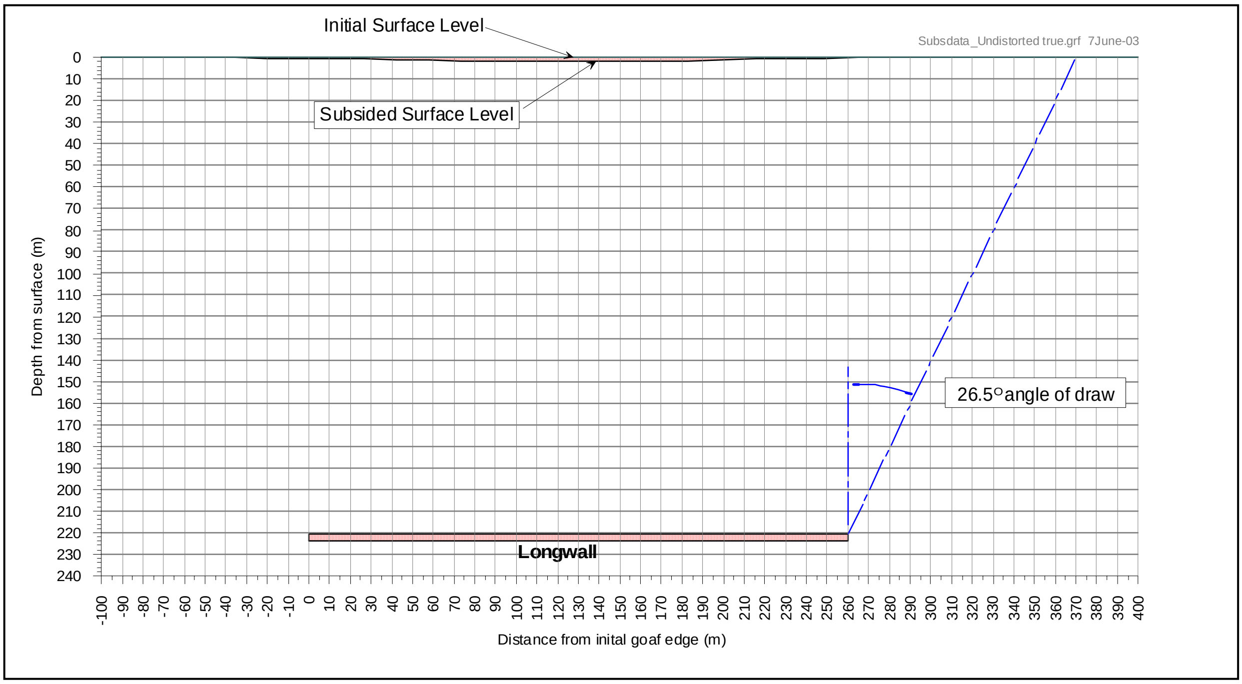


Fig. 1.5 Typical Subsidence Profile Drawn to a True Scale

The angle at which the subsidence spreads out towards the limit of subsidence, at the surface, is referred to as the angle of draw. The angle of draw depends upon the strength of the strata and the depth of cover to the coal seam and typically lies between 10 and 35 degrees from the vertical, depending on how the limit of subsidence is defined.

It is generally accepted that subsidence of less than 20 mm will have negligible effect on surface infrastructure and this is generally adopted as the cut-off point for determination of the angle of draw. In the Coalfields of NSW, if local data is not available, the cut-off-point is taken as a point on the surface defined by an angle of draw of 26.5 degrees from the edge of the extraction, i.e. a point on the surface at a distance of half the depth of cover from the goaf edge. Where local data exists and it can be shown that the angle is generally less than 26.5 degrees, then, the lower angle of draw can be used.

The subsidence of the surface is considerably less than the thickness of coal removed, due to the voids that are left within the collapsed strata. The extent of the settlement at the surface is therefore dependent upon the strength and nature of the rocks overlying the coal seam and is a direct function of their capacity to bridge over the voids.

When a panel has a width that is small, relative to the depth of the seam below the surface, the fractured rocks have a tendency to bridge over the goaf by arching between the solid abutments on each side of the panel, thus reducing the amount of subsidence.

As the panel width is increased, however, the overlying rocks are less able to arch over the goaf and a limiting panel width is reached where no support is available and maximum subsidence occurs. This limiting panel width is referred to as the critical width and is usually taken to be 1.4 times the depth of cover. It does, however, depend upon the nature of the strata.

Where several panels are mined in a series and chain pillars are left between the panels, the maximum subsidence does not occur unless each panel is, at least, of critical width. The chain pillars crush and distort as the coal is removed from both sides of them, but, usually, they do not totally collapse and, hence, the pillars provide a considerable amount of support to the strata above them.

Where large super-critical areas are extracted, the maximum possible subsidence is typically 55% to 65% of the extracted seam thickness, but, because chain pillars are normally left in place, and provide some support, this maximum possible subsidence is rarely reached.

Research has shown that the incremental subsidence of a second or subsequent panel in a series is greater than the subsidence of an individual isolated panel of identical geometry. Because the subsidence effects above a panel extend beyond its goaf edges, these effects can overlap those of neighbouring panels.

Where the width to depth ratios of the panels in a series are sub-critical, which is normally the case in the Southern Coalfield, the amount of subsidence in each panel is determined by the extent of these overlaps, which are further influenced by the widths of the chain pillars. In this situation, the first panel in a series will generally exhibit the least subsidence and the second and subsequent panels will exhibit greater subsidence due to disturbance of the strata caused by mining the preceding panels and consequential redistribution of stresses within the strata.

The subsidence at the surface does not occur suddenly but develops progressively as the coal is extracted within the area of influence of the extracted panel. In many cases, when the cover over the coal seam is deep, a point on the surface will be affected by the extraction of several adjacent panels.

When extraction of coal from a panel is commenced, there is no immediate surface subsidence, but as the coal within the panel is extracted and the resulting void increases in size, subsidence develops gradually above the goaf area. As mining continues, a point is reached within the panel where a maximum value of subsidence occurs and despite further mining beyond this point, within the panel, this level of subsidence is not increased.

As further adjacent panels are extracted, additional subsidence is experienced, above the previously mined panel or panels. However, a point is also reached where a maximum value of subsidence is observed over the series of panels irrespective of whether more panels are later extracted.

The subsidence effect at the surface occurs in the form of a wave, which moves across the ground at approximately the same speed as the longwall face retreats within the longwall panel. The extraction of each panel creates its own wave as the panels are mined in sequence.

The development of subsidence at any point on the surface of the ground can be seen to be a very complex mechanism and the cumulative effect of a number of separate movements.

1.2.2. Subsidence Parameters

Subsidence, tilt, horizontal displacement, curvature and strain are the subsidence parameters normally used to define the extent of the surface movements that will occur as mining proceeds and generally form the basis for the assessment of the impacts of subsidence on surface infrastructure. These parameters are illustrated in Fig. 1.6 which shows a typical subsidence profile drawn to an exaggerated vertical scale.

Subsidence

Subsidence usually refers to vertical displacement of a point, but subsidence of the ground actually includes both vertical and horizontal displacements. These horizontal displacements can in many cases be greater than the vertical subsidence, where the subsidence is small. The amplitude of subsidence is usually expressed in millimetres.

Tilt

Tilt is calculated as the change in subsidence between two points divided by the distance between those points. Tilt is, therefore, the first derivative of the subsidence profile. The sign of tilt is not important, but the convention usually adopted is for a positive tilt to indicate the ground increasing in subsidence in the direction of measurement.

The maximum tilt, or the steepest portion of the subsidence profile, occurs at the point of inflection in the subsidence trough, where the subsidence is roughly equal to one half of the maximum subsidence. Tilt is usually expressed in millimetres per metre.

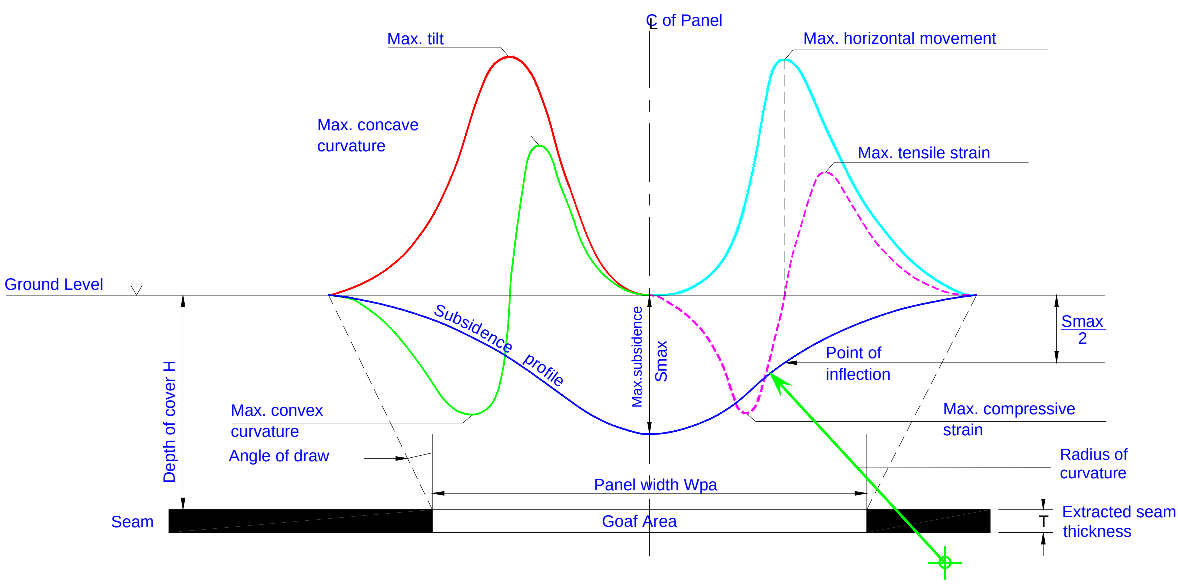


Fig. 1.6 Subsidence Parameter Profiles above a Single Longwall Panel

Horizontal Displacement

The horizontal component of subsidence, or horizontal displacement, is greatest at the point of maximum tilt and declines to zero at the limit of subsidence and at the point of maximum subsidence. Horizontal displacement is usually expressed in millimetres.

Curvature

Curvature is the second derivative of subsidence, or the rate of change of tilt, and is calculated as the change in tilt between two adjacent sections of the tilt profile divided by the average length of those sections. Curvature is usually expressed as the inverse of the radius of curvature with the units of 1/km, or km^{-1}, but the value of curvature can be inverted, if required, to obtain the radius of curvature, which is usually expressed in kilometres.

Curvature is convex or ‘hogging’ over the goaf edges and concave or ‘sagging’ toward the bottom of the subsidence trough. The convention usually adopted is for convex curvature to be positive and concave curvature to be negative.

Strain

Strain is caused by bending and differential horizontal movements in the strata. Measured strain is determined from monitored survey data by calculating the horizontal change in length of a section of a subsidence profile and dividing this by the initial horizontal length of that section.

If the section has been extended, the ground is in tension and the change in length and the resulting strain are positive. If the section has been shortened, the ground is in compression and the change in length and the resulting strain are negative.

The unit of measurement adopted for strain is millimetres per metre. The maximum strains coincide with the maximum curvature and hence the maximum tensile strains occur towards the sides of the panel whilst the maximum compressive strains occur towards the bottom of the subsidence trough.

1.2.3. Subsidence Impacts at the Surface

The most significant impacts on surface infrastructure are experienced during the development of the subsidence trough, when maximum ground movements normally occur.

As the subsidence wave approaches a point on the surface, the ground starts to settle, is displaced horizontally towards the mined void and is subjected to tensile strains, which build from zero to a maximum over the length of convex or hogging curvature, as shown in Fig. 1.7.

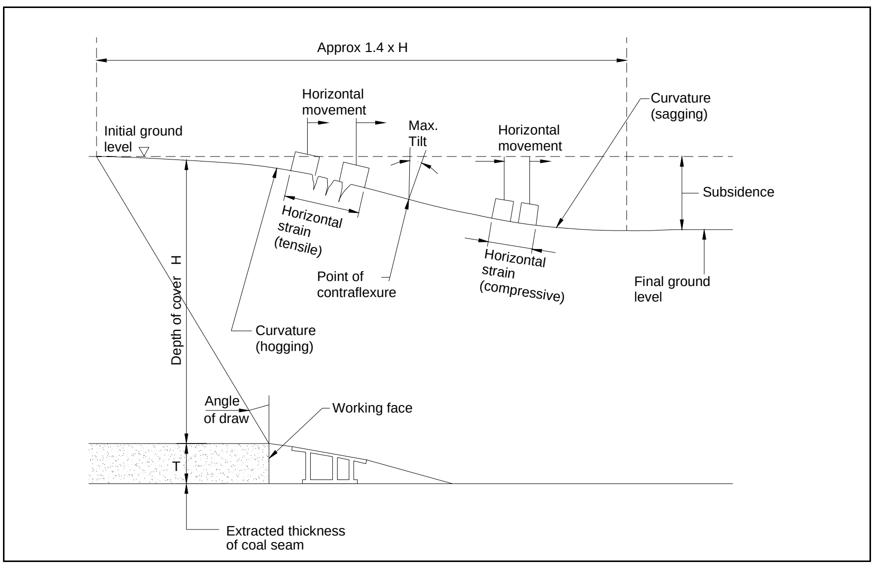
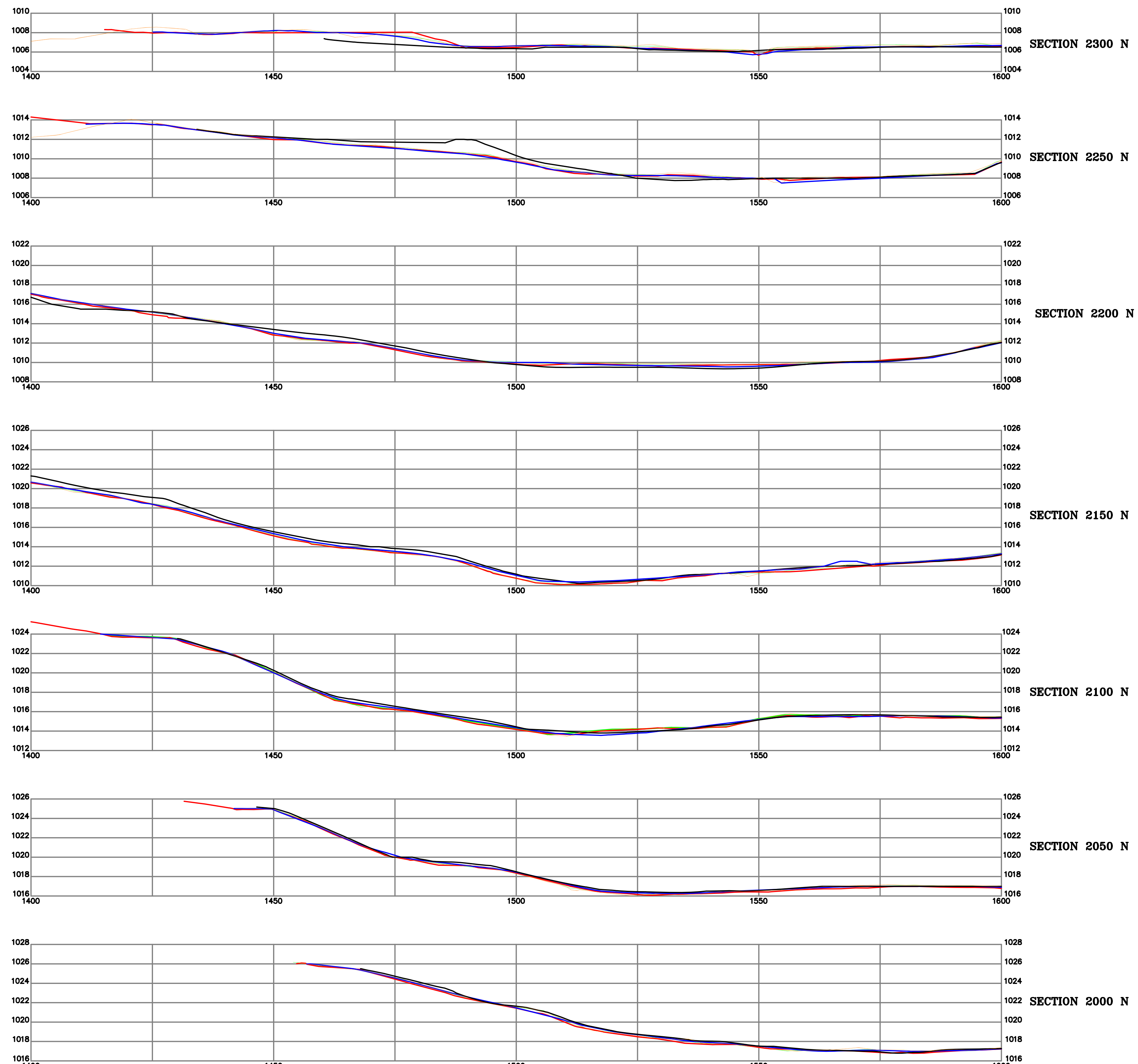


Fig. 1.7 Development of a Subsidence Trough (to an exaggerated vertical scale)

The position of maximum hogging curvature is the position of maximum tensile strain. When vertical subsidence is approximately half of the maximum subsidence, i.e., as the face passes under the surface point, the ground reaches its maximum horizontal displacement and the strain reduces to zero again.

As the longwall face moves further away from the surface point the settlement continues, horizontal displacement reduces and the ground is subjected to compressive strains, which build from zero to a maximum over the length of concave or sagging curvature and then decline to zero as maximum subsidence is reached. The position of maximum sagging curvature is the position of maximum compressive strain. When the subsidence is complete, the ground is commonly left with no horizontal displacement and little residual tilt or strain.

Between the tensile and compressive zones is the point of inflection, which is the point at which maximum tilt and maximum horizontal displacement occurs. For critical extraction conditions, it is also the point at which the subsidence is, approximately, equal to half the maximum subsidence.



NOTES:

1. DATA COLLECTED JULY, 2006 BY TECK COMINCO REPRESENTATIVE.
2. SECTION CO-ORDINATES AND ELEVATIONS REFER TO LOCAL MINE DATUM.
3. CONTOUR INTERVALS = 0.5 m.
4. SECTIONS HAVE A 2:1 VERTICAL EXAGGERATION.

LEGEND:

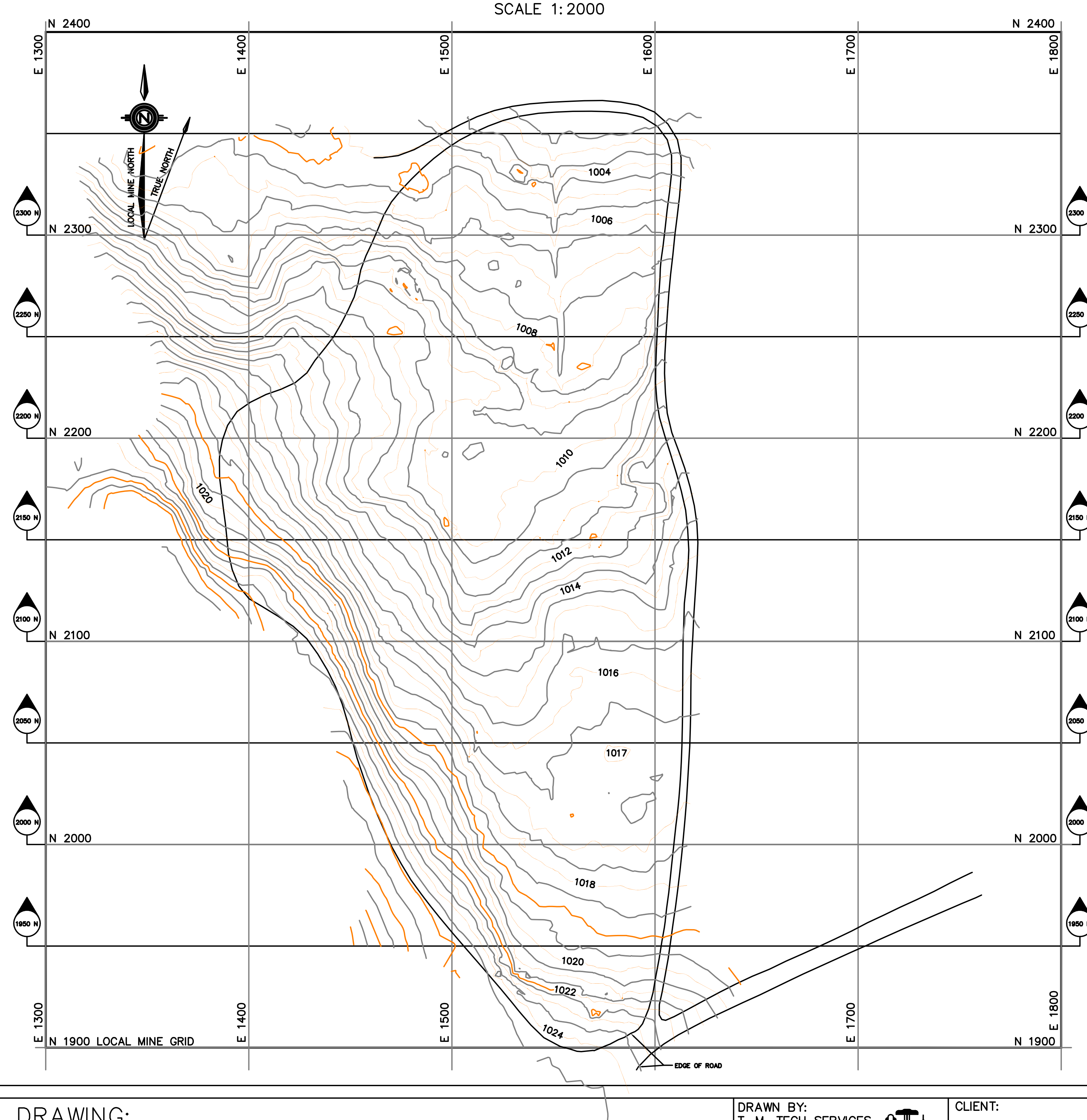
- DENOTES 2008 SURFACE.
- DENOTES 2006 SURFACE.
- DENOTES 2005 SURFACE.
- DENOTES 2004 SURFACE. (THAW LAYER TO VIEW)
- DENOTES 2003 SURFACE. (THAW LAYER TO VIEW)

PROJECT:

POLARIS MINE POST CLOSURE
2008 ANNUAL SITE INSPECTION

POLARIS MINE
AREA 8

SCALE 1:2000



DRAWING:

PLAN & SECTION VIEWS
SUBSIDENCE – AREA 8

DRAWN BY: T. M. TECH SERVICES 8–440		CLIENT:
DATE: NOVEMBER 17, 2008		SCALE: 1:500 HORZ. 1:250 VERT.
FIGURE No. PM	2008 AREA 8	SHEET: 1 OF 1

As the longitudinal wave passes, the transverse subsidence profile gradually develops and is completed as maximum subsidence is reached. The transverse subsidence profiles over each side of the panel are similar in shape to the longitudinal subsidence profile and have the same distribution of tilts, curvatures and strains. Most of the points on the surface will thus be subjected to three-dimensional movements, with tilt, curvature and strain in both the transverse and longitudinal directions. The impact of subsidence on surface infrastructure is therefore dependent upon its position within the trough.

The above sequence of ground movements, along the length of a panel, only applies to surface structures if they are located at a point where the maximum subsidence is likely to occur. Elsewhere, the impacts, in the both the transverse and longitudinal direction are reduced.

If a structure is located on the perimeter of the subsidence trough, it will only be slightly affected, will suffer little settlement and will have little residual tilt or strain.

A structure or surface feature on the side of the trough between the tension and compression zones will experience some subsidence, and will be left with residual horizontal displacement and tilt, but will be subjected to lower curvatures and strains. Structures or surface features located at the positions of maximum curvature and strain would generally suffer the greatest impact.

As each panel within a series is extracted in turn, an incremental subsidence trough is formed above it. If the width-to-depth ratios of the panels are low, the incremental subsidence troughs overlap at the surface and the resulting subsidence at any point, in these circumstances, is a combination of the effects of a number of panels.

A point on the surface may then be subjected to a series of subsidence waves, which occur as each panel is extracted, and the duration of these impacts will depend upon the position of the point relative to each of the subsidence troughs that are formed.

CHAPTER 2. REFERENCES

ARMA/USRMS 05-881

Modeling Block Cave Subsidence at the Molycorp, Inc., Questa Mine—A Case Study

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This paper was prepared for presentation at Alaska Rocks 2005, The 40th U.S. Symposium on Rock Mechanics (USRMS): Rock Mechanics for Energy, Mineral and Infrastructure Development in the Northern Regions, held in Anchorage, Alaska, June 25-29, 2005.

ABSTRACT: The evolution of surface subsidence is an important focus of study above Molycorp, Inc.'s newest block cave at the Questa molybdenum mine near Taos, New Mexico. The case study compares mature glory hole subsidence over the Goathill Orebody and subsidence emerging in its earliest stage over the new D Orebody block cave. Subsidence above the D Orebody was first detected in April 2003, 30 months after caving was initiated. Caving propagated to surface through 550 m of overburden at an average rate of 0.21 m per day. At the end of 2004, an average of 100 m of draw over a 1.4-hectare (ha) block produced a near-circular subsidence basin 5.8 m deep at its center and 90 m offset from the center of the block. Observations to date indicate a cave ratio of 10:1 and a gross cave bulking factor on the order of 10%. Historically, cave-angle projection models have been used to predict subsidence extents for reclamation planning. In light of evolving regulatory concerns, efforts are underway to develop a more accurate subsidence predictor using a three-dimensional (3D) numerical model. Particle Flow Code (PFC3D), a discontinuum "ball" code, was selected for modeling because of its ability to simulate stress fracturing of the rock mass and large-scale mass flow underground and at the surface, which are believed to be the dominant physical phenomena governing the formation of block cave subsidence. Advances simulating subsidence in the Goathill and D orebodies with PFC3D are discussed.

1. INTRODUCTION

The Molycorp, Inc. (Molycorp), Questa block caving mine is located near the northern New Mexico town of Questa, as shown in Figure 1. Molybdenum has been mined at Questa for over 80 years. Molycorp began large-scale open pit mining in 1965, but by the mid-1970s, plans for underground mining were developed to combat high stripping ratios. By the end of 1976, a substantial high-grade deposit was delineated by exploratory drilling southwest of the open pit. The block caving method was selected because of the well-fractured nature of the rock mass, and the size and shape of the deposit [1]. Figure 2 shows the general layout of the current underground mine and the two main block caves: (1) the 300-m-deep Goathill Orebody and (2) the 600- to 800-m-deep D Orebody.

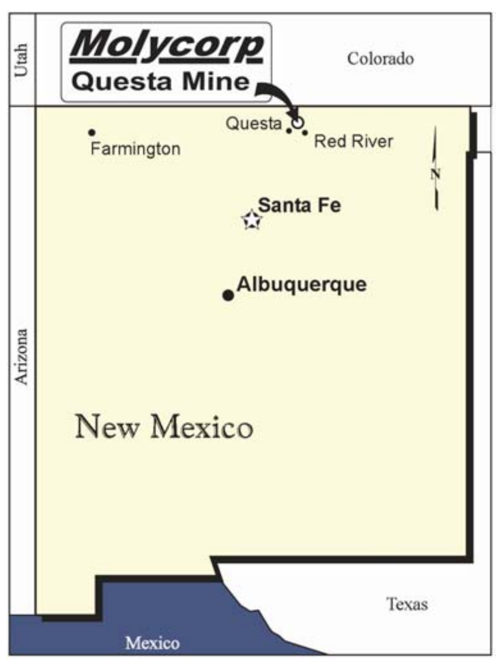

Figure 1. Location of Molycorp, Inc., Questa Mine

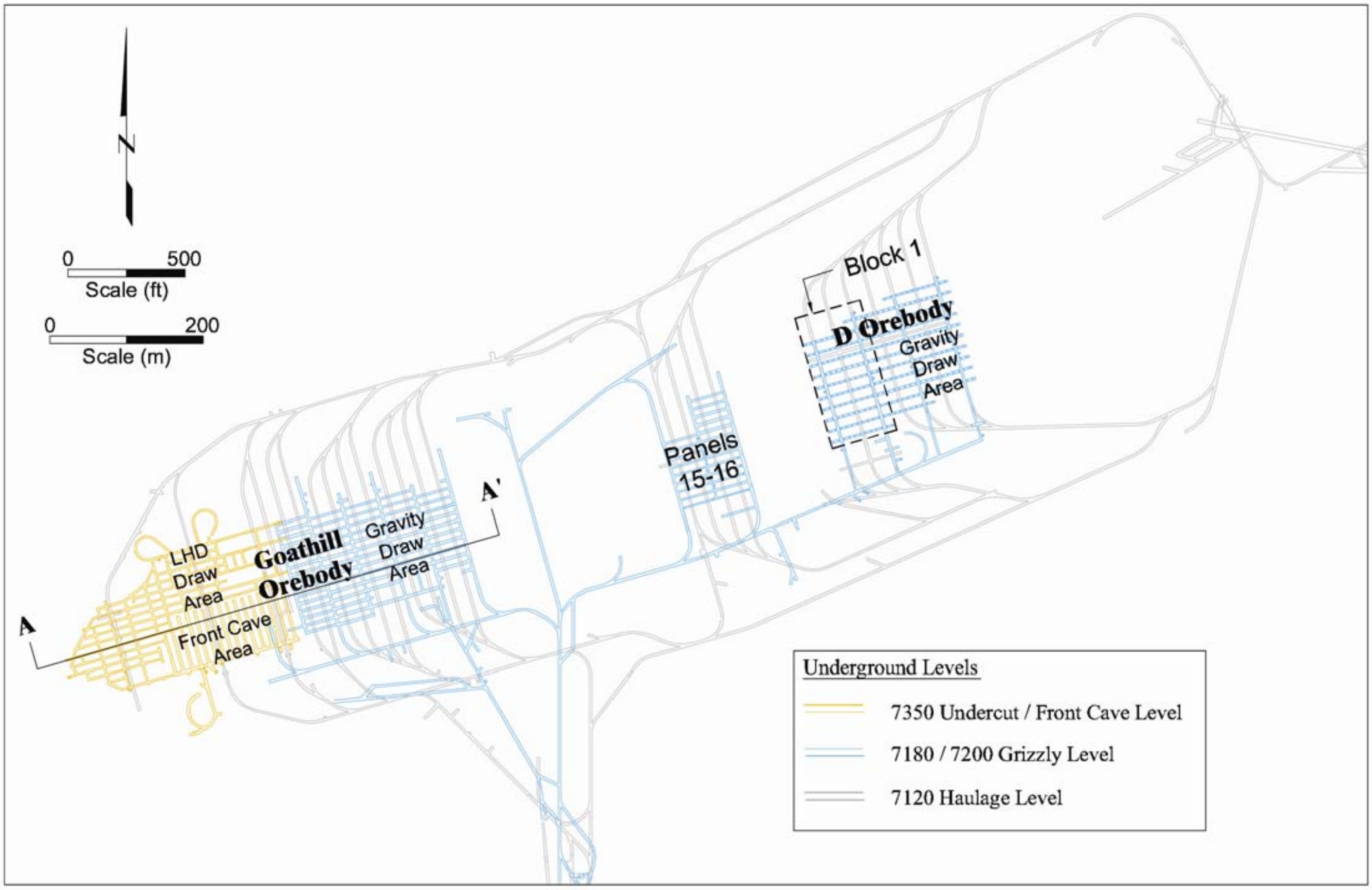

Figure 2. Plan View Mine Layout

Underground development began in 1979, followed by initial production in 1983 from the Goathill Orebody using the gravity draw method. Production peaked in the mid-1980s, reaching 16,000 tonnes per day. By 1992, the mine was placed in standby mode in response to declining molybdenum prices.

The mine was reactivated in 1995 and caving operations in the Goathill Orebody were converted from manual gravity draw to highly-mechanized, load-haul-dump (LHD) draw. In 1998, front caving, a variant of LHD mining, was attempted for 2 years. The front caving block pulled ore from the southern boundary of the original gravity cave. The individual gravity, LHD, and front caves were adjacent to one another and coalesced to form one single cave responsible for the formation of the Goathill glory hole shown in Figure 3. Mining was complete in the Goathill Orebody in 2000 when production shifted to the D Orebody.

Molycorp reverted to the original and proven gravity draw system in the D Orebody (Figure 4), which was favored for better ground control, cave fragmentation, and lower ventilation requirements [2]. The D Orebody comprises three sub-zones: D, Deep D, and Vein. The D sub-zone is divided into Blocks 1, 2, and 3. Caving was initiated in Block 1 in October 2000 and is the only part of the D Orebody in production as of February 2005. A total of 3.3 million tonnes have been produced by gravity draw from Block 1 as of the end of 2004.

Figure 3. Center of Goathill Glory Hole in 2004 (view to southwest)

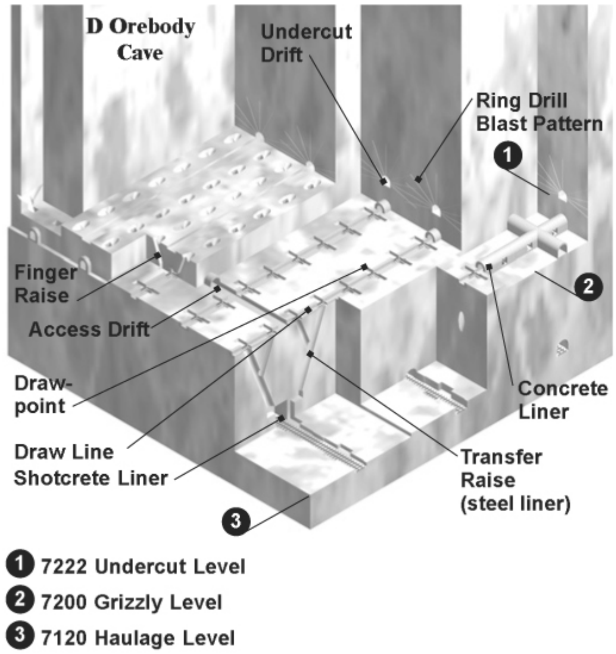

Figure 4. Gravity Draw System

Surface subsidence is a key concern for eventual mine closure and reclamation. In the past, conventional cave-angle projection models have provided reasonable estimates of the areal extents of subsidence for reclamation planning. In light of changing regulatory concerns, Molycorp recently invested in more sophisticated numerical modeling to improve the accuracy and precision of subsidence predictions. Leading this effort is the development of a 3D discontinuum caving and subsidence model utilizing PFC3D [3]. PFC3D shows considerable promise in its ability to simulate the principal mechanisms of caving and subsidence, and to replicate the historical subsidence behavior at the Questa Mine.

This paper discusses historical subsidence above the Goathill Orebody as an example of mature glory hole subsidence, followed by a discussion of subsidence in its earliest stage above the D Orebody. The cases represent the two extremes of subsidence for the Questa Mine and serve as valuable calibrators for modeling. Lastly, the paper describes efforts to model subsidence in both orebodies using the cave-angle method and PFC3D.

2. GOATHILL OREBODY SUBSIDENCE

2.1. Production History

Undercut levels in the Goathill Orebody ranged in depth between 260 and 365 m. Between 130 and 190 m of ore were ultimately drawn, constituting between 40% and 63% of the total overburden column, as illustrated in cross section in Figure 5. The ultimate extraction footprint measured approximately 5.3 ha. Total production from Goathill is summarized as follows:

Block	Total Production (million tonnes)
Gravity	16.0
LHD	5.5
Front Cave	0.2
TOTAL	21.7

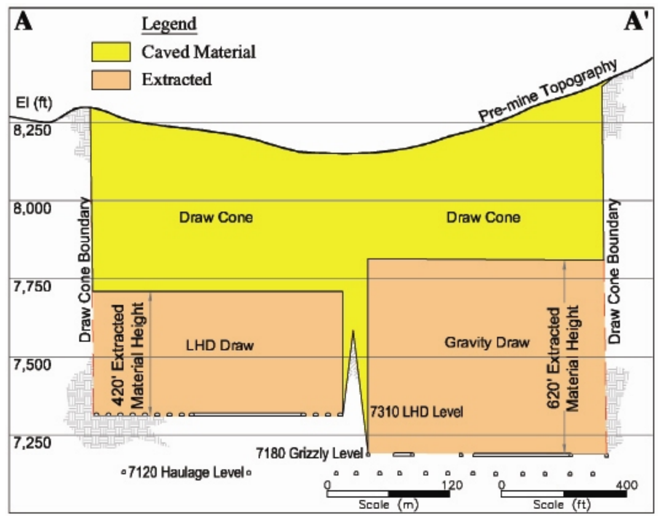

Figure 5. Goathill Orebody Cross Section

2.2. Subsidence Characteristics

Block caving subsidence is typically characterized by two zones of surface disturbance: (1) a primary subsidence zone, i.e., the "glory hole," and (2) a secondary subsidence, or "relaxation zone," peripheral to the primary subsidence zone. The primary subsidence zone is characterized by mass movement on the order of tens to hundreds of feet, while only moderate ground movement, on the order of tens of inches, is characteristic of the relaxation zone. Within the relaxation zone, subsidence can include visually discernable effects such as tension cracks, scarps, tilting, sliding, and damage to vegetation. Demarcation between the zones is oftentimes obvious on the ground and is normally taken to be the precipice of the glory hole.

The limits of the Goathill glory hole and relaxation zone in 2004 are shown in Figure 6.

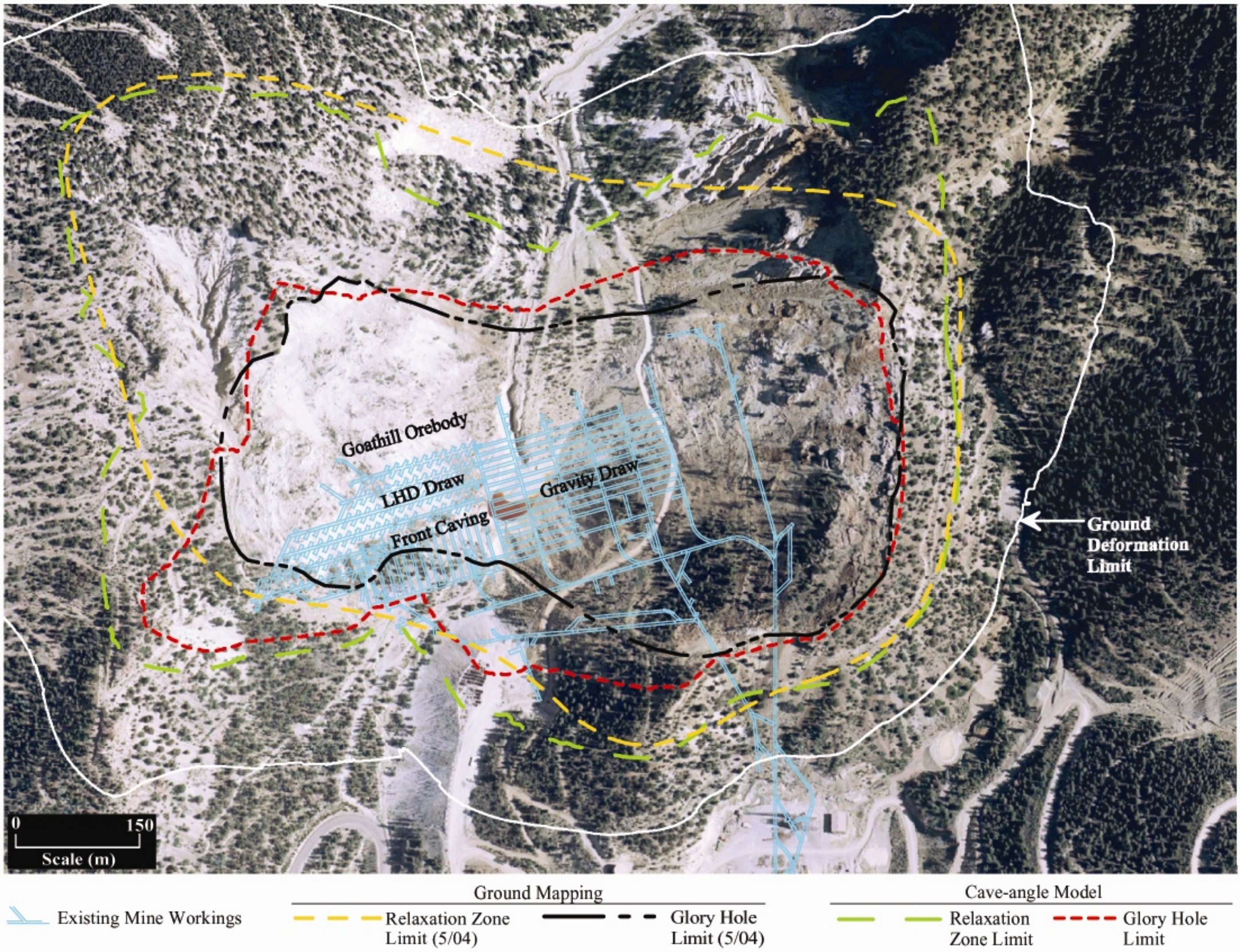

Figure 6. 2003 Aerial Photograph of Goathill Glory Hole and Subsidence Limits

The limits are based on (1) ground mapping and (2) detailed study of aerial photographs. The extents of the Goathill subsidence zones in May 2004 are summarized as follows:

Subsidence Zone	Total Area (ha)	Perimeter (m)
Glory Hole	29.5	2,365
Relaxation Zone	34.4	3,150

Cave angles (measured from horizontal at the edge of the undercut to the edge of surface cracking) range from 70° to 85° based on the 2004 subsidence extents. Relaxation angles (measured from horizontal at the edge of the undercut to the outer limits of relaxation features on surface) range from 51° to 84°. The volumetric difference between the total underground extraction (8.2 million cubic meters) and volume of the glory hole (4.7 million cubic meters) indicates a gross cave bulking factor between 9% and 21%, assuming that the zone of bulking is defined by cave angles ranging between 70° and 85°.

The glory hole continues to grow gradually by mass wasting along its periphery. An area encompassing approximately 14.2 ha on the eastern wall of the glory hole shows evidence of large-scale sliding. Slide features include escarpments, fresh cracks, block toppling, surface rubblization, tree tilting, and disturbance to hillside vegetation (Figure 7). While no subsurface measurements of movement exist, the gross surface expression of the east wall slide suggests that the slide is relatively shallow-seated (<60 m deep) and is occurring along a planar or near-planar surface.

Sliding is also evident on the northwest wall at the base of Goat Hill. Sliding originally occurred

Figure 7. Goathill Glory Hole East Wall Slide (view to east)

along a high-angle, southeast-dipping fault in mid-1997, forming a large headscarp. The headscarp currently measures more than 60 m tall. The slide and headscarp are shown in Figure 8. Structural mapping in the area suggests that similar, parallel structures exist uphill from the existing headscarp and that fault-controlled sliding will likely progress further up Goat Hill in the future. Future subsidence resulting from cave consolidation is likely to be partly obscured by erosion and sedimentation in the glory hole.

Figure 8. Goathill Glory Hole Goat Hill Slide (view to northwest)

3. D OREBODY SUBSIDENCE

3.1. Production History

The D Orebody Block 1 undercut ranges in depth between 550 and 670 m. The ore column ranges in height between 90 and 200 m, comprising between 16% and 37% of the total overburden column. As of the end of 2004, 50% of the ore column, or 100 m on average, was extracted in Block 1 over an area measuring 1.3 ha.

3.2. Subsidence Characteristics

Subsidence was first discovered in the form of surface tension cracks on the steep west-facing hillside above Block 1 in April 2003, approximately 900 days after the initiation of caving. By July 2004, a grid of 142 survey monuments was established for monitoring ground movement. By August 2004, the survey grid was expanded to 303 points to capture far-field movement. Surveys were conducted approximately every 2 months.

Subsidence at the end of 2004 is described by the map in Figure 9. Contours of (vertical) subsidence and horizontal displacement vectors are shown on the map relative to the underground workings. Salient features are summarized as follows:

- Maximum measured subsidence reached 5.8 m since monitoring began in July 2003. An additional 3 m or more of subsidence likely occurred prior to monitoring based on the scale of surface tension cracking at the time of discovery.
- The center of subsidence focused at a point approximately 90 m to the north-northwest of the center of Block 1 and 15 m past the north boundary of the Block 1 undercut. Horizontal deviation from the center of draw is attributed to local faulting.
- Maximum measured horizontal movement reached 4.6 m. Maximum horizontal movement focused immediately to the east and uphill from the center of subsidence.
- The average rate of subsidence at the center of subsidence was 1.43 cm per day (43.0 cm per month).
- The average rate of horizontal movement at the point of maximum horizontal movement was 1.13 cm per day (34.1 cm per month).
- The rate of surface subsidence showed no apparent correlation with fluctuations in the draw rate.

Based on the timing of the breakthrough of the cave to surface, Block 1 exhibits (1) an average cave ratio of 10:1 (height of cave line:height of drawn ore column), (2) a cave bulking factor of 10% or slightly less, and (3) a cave propagation rate on the order of 0.6 m per day. These

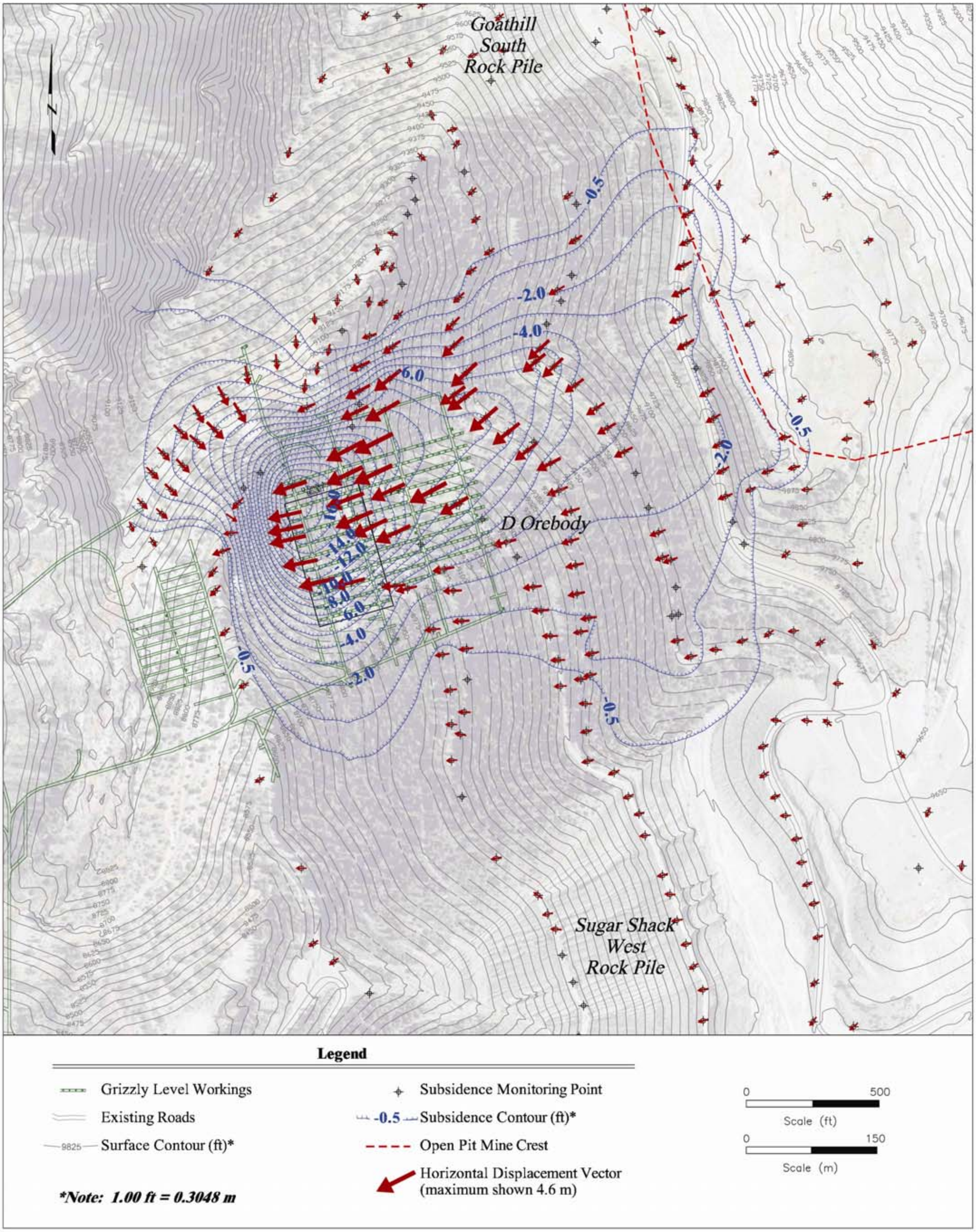

Figure 9. D Orebody Surveyed Subsidence Map—October 2004

characteristics correlate with values reported at other western U.S. caving operations:

Mine	Bulking Factor	Cave Rate (m/day)	Reference
San Manuel (South)	8.9%	0.49	[4]
Lakeshore	9.5%	1.98	[5]
Henderson	9.5%	0.70	[6]

As of the end of 2004, the Block 1 cave was too immature to define the ultimate cave or relaxation angles. Early subsidence, reaching as far as 550 m away from the undercut boundary of Block 1, suggests that relaxation angles will vary locally over a range between about 55° and 85°.

3.3. Hillside Movement

Subsidence over Block 1 initiated large-scale sliding of the west-facing hillside above the D Orebody some time in early 2003. By the end of 2004, the hillside above Block 1 has moved on the order of several feet to the west into the emerging subsidence basin. As much as 1.5 m of total movement has been measured since July 2003 near the top of the slide, located approximately 460 m east of Block 1. The rate of movement averaged about 0.30 cm per day (10.1 cm per month) in 2004. Tensile cracks at the top of the ridge continue to grow with sliding. Three boreholes were drilled and instrumented with time-domain-reflectometry (TDR) cables and inclinometers/extensometers in July 2004 to monitor slope movement as part of a separate study.

4. CAVE-ANGLE MODELING

By conventional practice, subsidence limits are estimated using cave-angle projections from the mining footprint to surface, as illustrated in Figure 10. For most mines, caving typically propagates upward from the extraction level through the rock mass at angles ranging from 75° to 90° from horizontal [7]. Numerical modeling and field observations suggests that a cave angle of 85° best represents conditions in the Goathill and D orebodies. Within this cone, the depth of subsidence at the surface is controlled by the gross swell factor within the cave.

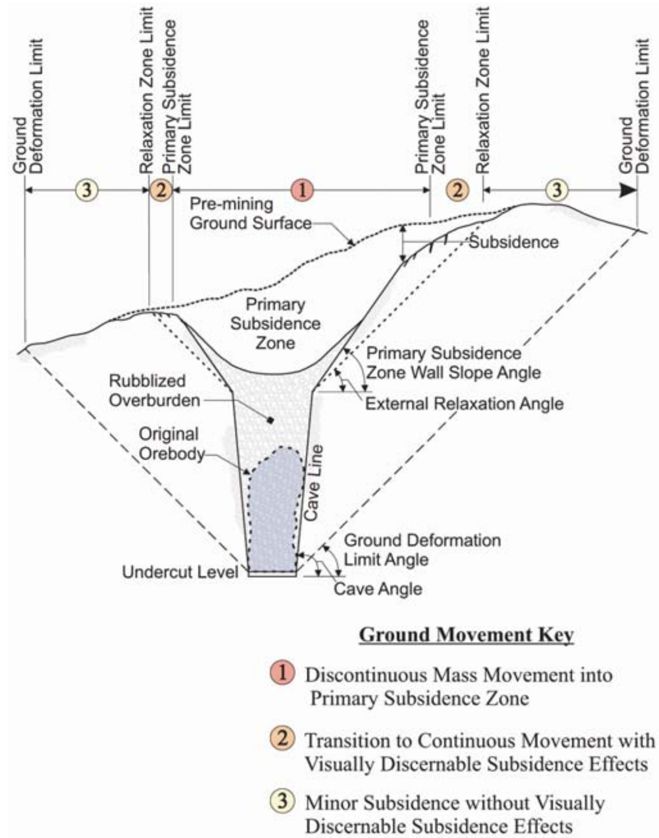

Figure 10. Cave-angle Subsidence Model

Considering a 10% swell factor and an ultimate draw of 190 m of ore in Block 1, the original ground surface is predicted to move downward as much as 150 m. However, the actual depth of the primary subsidence zone is expected to be significantly less because of mass wasting and natural infilling of the glory hole, as evidenced by the relatively shallow 60-m-deep glory hole at Goathill.

The ultimate angle of the primary subsidence basin walls depend upon the in situ and residual strength of the host rock and the steepness of the surrounding natural slopes. Good agreement with the glory hole geometry at Goathill was achieved using an 85° average cave angle and a 55° primary subsidence basin sidewall angle for estimating the limit of the glory hole (Figure 10). A 45° relaxation angle, suggested by Nickson et al. [8], proved realistic for describing the limit of the relaxation zone. Figure 6 shows reasonable agreement between the results of the cave-angle model and field mapping. Some deviation occurs on the northeast and southwest boundaries where a combination of sharp corners in the mine layout and steep topography causes the model to project unusually far beyond the actual limit of surface disturbance.

The limit of ground deformation shown in Figure 6 represents the farthest extent of mining-induced ground movement. Ground strain beyond this limit is not expected to be of sufficient magnitude to damage most mining and civil structures, such as buildings, roadways, and shafts. A 45° angle is generally adopted for conservative design [9] and was used for the original design at the Questa Mine.

The cave-angle model represents a simple, but effective predictive tool. The model, calibrated to conditions at Goathill, is considered a reasonably accurate general predictor of ultimate subsidence above the D Orebody. However, as a geometric construct, the cave-angle model is limited in its simplicity and ability to consider potentially important effects, including variable geology, local structure, ground stress, draw sequence, irregular caving geometries, and less-than-fully-developed glory hole subsidence. PFC3D was adopted for advanced modeling because of the code's ability to simulate these and other effects.

5. DISCONTINUUM MODELING

PFC3D is a 3D computer model capable of simulating continuum- and discontinuum-type ground deformation in response to mining. The host rock mass is represented as a bonded assemblage of rigid spheres. Elastic deformation of the rock mass is controlled by the elastic properties of the bonds. In the event of excess stress, bonds are capable of rupturing, allowing the process of rock mass fracturing and disintegration, and large-scale deformation and material flow, to be simulated. This ability makes PFC3D and other "ball" codes ideally suited for simulating caving mechanics and subsidence associated with block caving. A variety of investigators have made advances applying ball codes to subsurface caving mechanics [10, 11, 12, 13].

While ball codes have enormous potential, geomechanics modelers are faced with the sometimes controversial task of specifying model properties that have no direct physical analog and cannot be measured in the laboratory. Typically, this involves quantifying "artificial" properties on a micro-scale to produce a desired response on a macro-scale. For this reason, ball models are jointly considered phenomenological, where certain physical phenomena are explicitly simulated, and empirical, where abstract functions are calibrated to known responses to predicted behavior.

For subsidence modeling, numerous iterations were require to achieve the desired Hoek-Brown constitutive behavior of the rock mass prior to any attempt to simulate block caving. With a working constitutive model, it was possible to calibrate other "artificial" parameters influential to subsurface mass flow and subsidence.

5.1. Rock Mass Properties

Rock mass properties were assigned spatially according to a 3D block model developed by Molycorp from surface/underground geologic mapping and drill hole data. Blocks were assigned lithology and a geostatistically estimated RQD value. A 3D perspective of the RQD model above Block 1 in the D Orebody is shown in Figure 11.

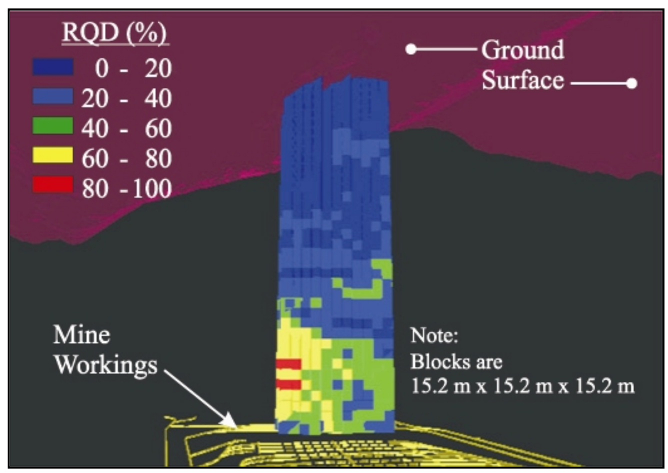

Figure 11. RQD Block Model—D Orebody Block 1

For modeling purposes, the complex geology of the Questa Mine was simplified to four predominant rock types: andesite, felsic dikes, intermediate dikes, and aplite-porphyry rocks. Rock quality at Questa is substantially affected by intense, but variable fracturing spaced as closely as 30 mm. Extensive mapping at the mine shows a range in Q [14] values from 0.002 to 8, which rates the rock mass from "exceptionally poor" to "fair" [15]. Rock mass properties were estimated according to the Geological Strength Index (GSI)

Table 1. Rock Mass Properties

Material		*GSI*	Young's Modulus (MPa)	Poisson's Ratio	Friction Angle (degrees)	Cohesion (MPa)	Rock Mass Strength (MPa)
Rock Type	**RQD (%)**						
Andesite	0 to 20	9	952	0.30	28.2	1.4	4.5
	20 to 40	19	1683	0.30	33.1	2.0	7.4
	40 to 60	24	2193	0.30	35.2	2.4	9.1
	60 to 80	27	2611	0.30	36.7	2.9	11.7
	80 to 100	29	2974	0.30	37.4	3.0	12.3
Felsic Dikes	0 to 20	9	952	0.30	28.2	1.1	3.6
	20 to 40	19	1683	0.30	33.1	1.6	5.9
	40 to 60	24	2193	0.30	35.2	1.9	7.3
	60 to 80	27	2611	0.30	36.7	2.4	9.4
	80 to 100	29	2974	0.30	37.4	2.4	9.8
Intermediate Dikes	0 to 20	9	952	0.30	28.2	1.6	5.4
	20 to 40	19	1683	0.30	33.1	2.4	8.0
	40 to 60	24	2193	0.30	35.2	2.8	11.0
	60 to 80	27	2611	0.30	36.7	3.5	14.1
	80 to 100	29	2974	0.30	37.4	3.6	14.7
Aplite	0 to 20	9	952	0.30	28.2	1.9	6.3
	20 to 40	19	1683	0.30	33.1	2.8	10.3
	40 to 60	24	2193	0.30	35.2	3.3	12.8
	60 to 80	27	2611	0.30	36.7	4.1	16.4
	80 to 100	29	2974	0.30	37.4	4.2	17.2

introduced by Hoek et al. [16] and are summarized in Table 1 according to RQD.

Rock mass properties in Table 1 were translated to micro-properties in PFC3D by reproducing the desired Hoek-Brown properties in synthetic triaxial tests in PFC3D. Triaxial "tests" were conducted at confining pressures up to 21 MPa corresponding to stress conditions in the block cave. Because the properties are highly dependent upon ball diameter, triaxial tests were performed at the same ball size used in the mine-scale models.

The triaxial geometry and a typical model stress-strain curve are shown in Figure 12. Planar octagon symbols in the figure represent individual bond fractures or "micro-cracks" which ultimately govern failure. Testing was repeated with adjustments to model micro-parameters until a satisfactory replication of the Hoek-Brown strength envelope and elastic modulus was achieved. Although many "artificial" micro-parameters exist within PFC3D, calibration was ultimately limited to the following micro-parameters which were determined to dominate the strength and stiffness response of the rock mass:

- Bond elastic modulus, E_c
- Bond normal to shear stiffness ratio, k_n/k_s
- Bond normal strength, *s*
- Bond shear strength, *t*

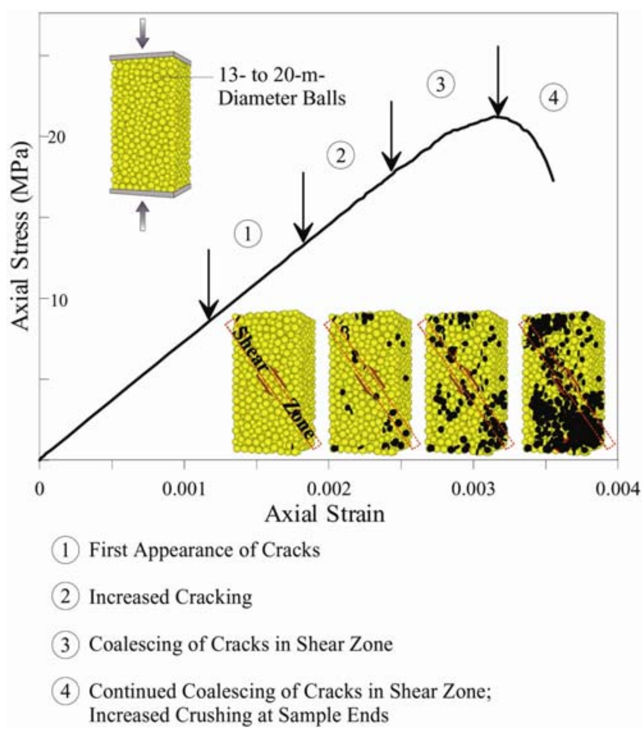

Figure 12. Synthetic Rock Mass Triaxial Test

5.2. Model Geometry and Mining Sequence

Separate models were constructed for the Goathill and D orebodies. Figure 13 illustrates the geometry of the Goathill model. Color banding is shown in the figure as a visual aid to highlight the variable surface topography. The volumetric extents of the models and mesh resolution, i.e., ball size, were practically constrained by computational run time. Every effort was made to limit the volume of the models so that ball diameters could be made as small as possible in the belief that smaller-diameter balls add more degrees of freedom and the ability to simulate smaller-scale phenomena, thus affording better accuracy. Ultimately, it proved necessary to limit the models to a maximum of 125,000 balls with diameters ranging from 13 to 20 m. Model run-times averaged 15 to 20 days on a Pentium 4, 2.4-GHz personal computer.

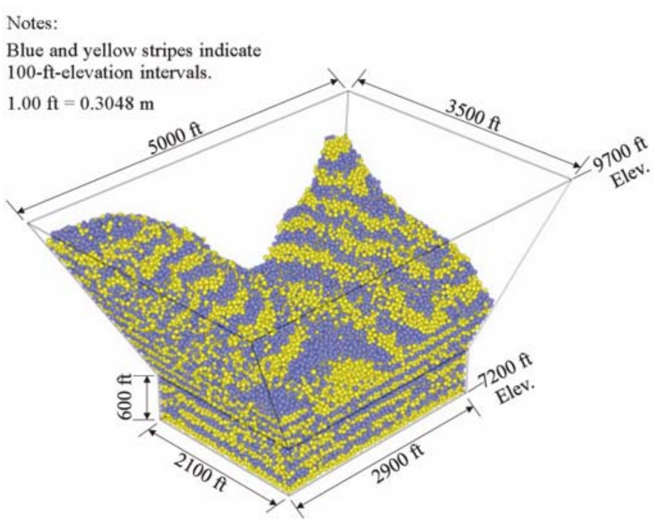

Figure 13. Goathill Orebody Subsidence Model

The undercut levels defined the base elevations of the models. Draw was simulated by eliminating balls at multiple, individual drawpoints at the base of the models. Balls were removed according to mine records in monthly steps to simulate the actual draw. Detailed records for individual draw windows were incorporated in the D Orebodymodel. The Goathill model assumed uniform draw per block because of less complete records; however the gravity, LHD, and front-cave blocks were mined in their historical sequence.

Balls drawn from the model initiated the step-wise process of stress redistribution, ball-to-ball bond fracturing, and mass movement into the void. A cross section of the D Orebody model in Figure 14 illustrates the pattern of mass movement resulting from complete draw of the ore column in Blocks 1–3. Mass flow in the cave is apparent by the disturbance of the originally horizontal color bands in part (a) of the figure. Displacement vectors of individual balls, shown in part (b) of the figure, highlight zones of active mass flow. The model indicates a stress-relaxation zone peripheral to the cave where ball-to-ball bonds are broken, but movement into the cave is retarded by frictional forces.

5.3. Model Results

Although the completeness of mine records prevented a direct comparison of the PFC3D model with the staged evolution of the Goathill glory hole, the model could be compared with several important features of the relatively mature Goathill glory hole in 2004. Figure 15 is a plan view of the PFC3D model surface. The epicenter of mass flow indicated by the area of peak downward movement of surface balls correlates with the center of the existing glory hole.

The model appears most accurate along the east-southeast wall of the glory hole where the glory hole edge coincides with the limits mapped in 2004. The model also indicates shallow-seated slope movement on this wall consistent with field observations. To the north and west, the model shows considerably more basement movement and hillside sliding into the glory hole than observed to date. The model predicted a final glory hole close in size to the much larger relaxation zone limit mapped in 2004, suggesting that rock mass strength is underestimated, at least near the surface, in the model.

Because the model does not account for time-dependent rock mass behavior, the model results represent long-term subsidence. Some potential exists for the glory hole to grow beyond its current limit and more closely resemble the model results. This appears imminent to the northwest along the base of Goat Hill where the base of Goat Hill is continuing to slide into the glory hole per the mechanism predicted in the model.

The same model properties used in the Goathill model were applied to the D Orebody, Block 1 model. While the Goathill model provided calibration with the large-scale features of late-stage surface subsidence, the D Orebody model

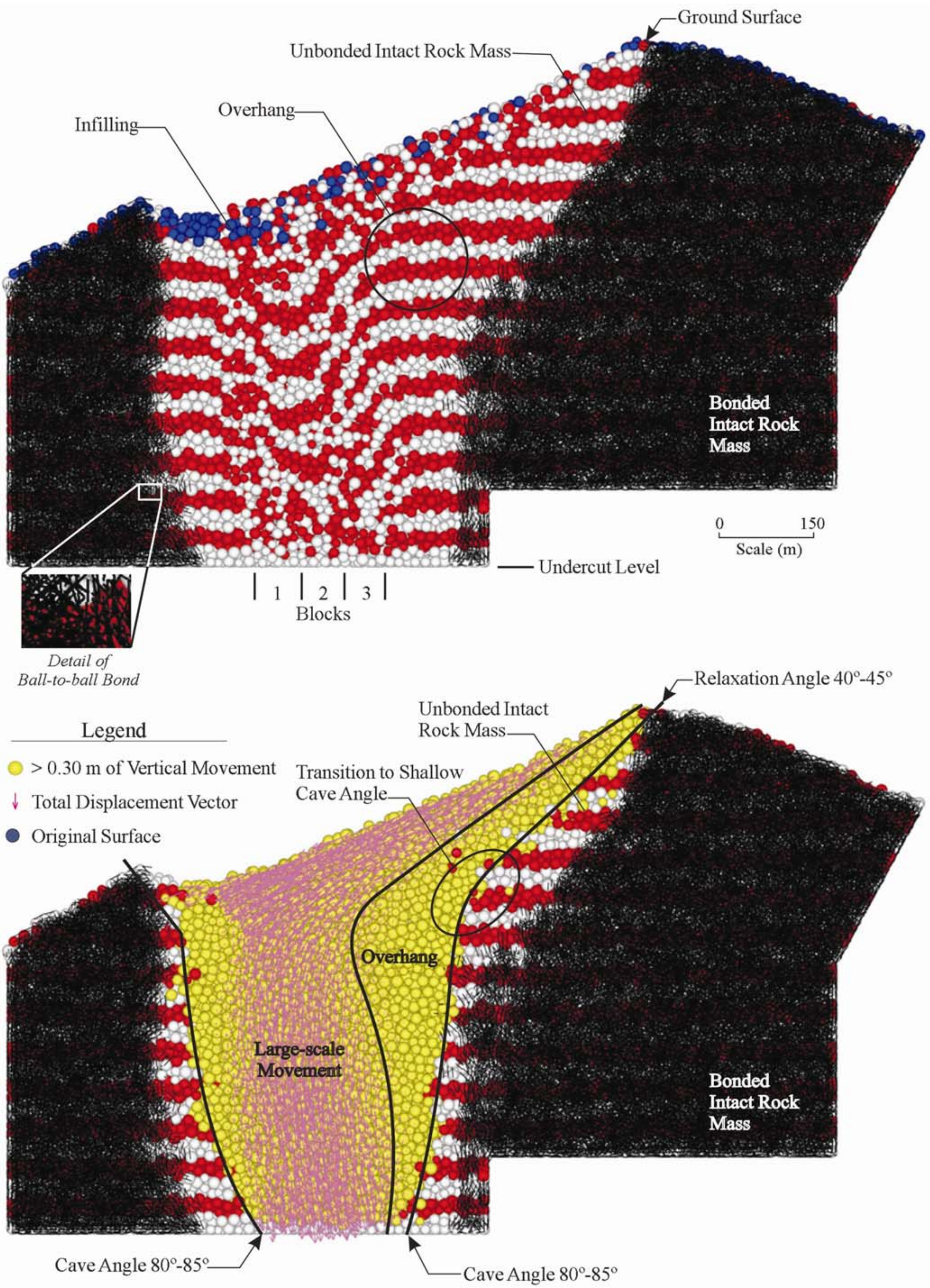

Figure 14. Cross Section of Subsidence Mass Movement from Block Caving—D Orebody Model

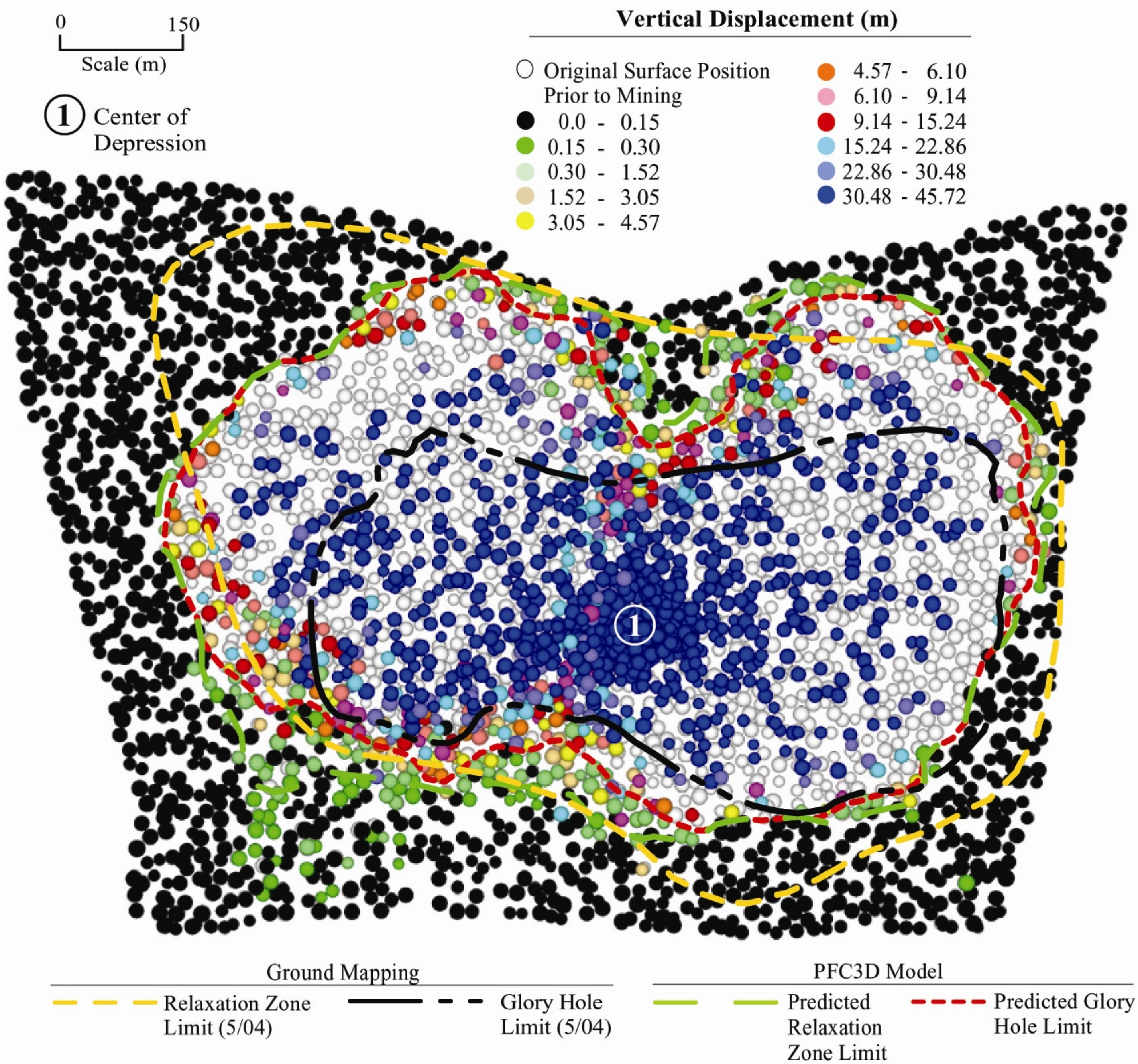

Figure 15. Plan View Map of Surface Movement and Subsidence Limits—Goathill Orebody Model

allowed model response to be calibrated with detailed chronological records of early-stage subsidence.

Figure 16 compares modeled and measured subsidence at the epicenter of the Block 1 subsidence basin since the beginning of surveying. The figure plots subsidence and subsidence rate against time. The plot shows that the PFC3D model lags the actual time that measurable subsidence began on surface by approximately 12 months. Because minor subsidence may have occurred prior to the first survey, the lag time may actually exceed 12 months.

The lag is attributed to a slow propagation of the cave to surface in the model. The large ball diameters showed resistance to small volumetric changes in the early stages of draw. Special provisions were made to decrease ball interface friction as a function of downward movement in the cave to accelerate cave propagation to surface, and to simulate the effects of comminution and densification. However, a friction angle less than about 5° promoted excessive lateral growth of the cave and could not maintain the relatively steep (80°–85°) cave angles thought to exist in practice.

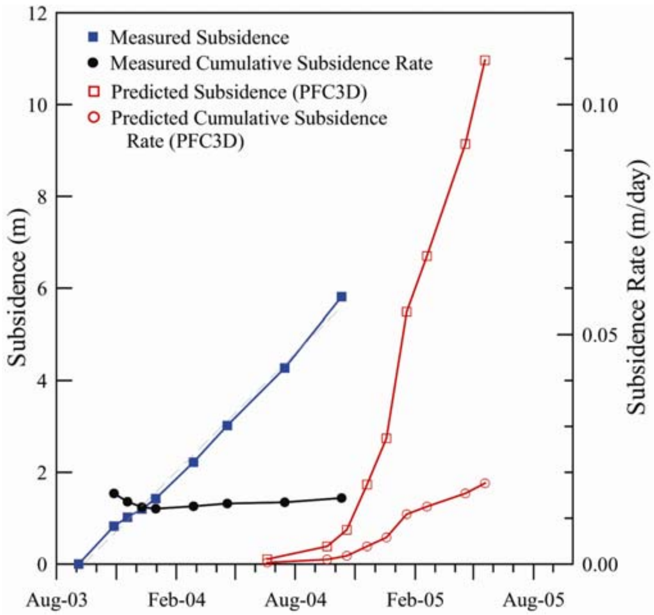

Figure 16. Modeled and Measured Subsidence Histories—D Orebody Block 1 Model

Once a large enough volume of ore was eventually drawn in the model, the "hang-up" of the large balls was overcome and caving progressed relatively smoothly. Figure 16 shows closure of the modeled-measured time lag and a trend toward the converging magnitudes and rates of subsidence in more recent months. Once the cave became more mature, the model was able to reproduce the observed 10% gross bulking factor in the cave.

6. CONCLUSIONS

Block caving subsidence is a complex combination of highly discontinuous rock mass flow surrounded by a zone of minor discontinuous/continuous ground relaxation. The true advantage of a ball code for modeling this type of environment lies in a ball code's ability to simulate large-displacement mass flow simultaneous with elastic- and small-strain, inelastic deformation. This capability offers enormous potential for advancing predictive accuracy.

However, as a state-of-the-art technology, ball codes are relatively immature and, before more universal favor is found, will continue to pose two types of important challenges to analysts. First is the usual practical challenge of achieving computational efficiency, i.e., fast model run-times with ball diameters small enough to ensure realistic behavior. Because the rock mass cannot disintegrate smaller than individual balls, the minimum ball size within the model will control the scale of physical phenomena that can be simulated.

Shortcomings of the Molycorp PFC3D models are attributed to the large ball diameters more so than any other model parameter. It is likely that the large diameters prevented some potentially influential smaller-scale deformation mechanisms from developing in the cave and near the surface. For this reason, and that material properties must be scaled to ball size, ball codes are inherently more "mesh dependent" than comparable continuum models. In the authors' experience with mine-scale subsidence models, a ball size that is "too small" has yet to be attained.

The other major challenge facing analysts is justification of the "artificial" properties required for ball code modeling. Although a concern, justification of these "artificial" parameters is expected to be forthcoming with research focused on sensitivity analysis of parameters at the macroscopic scale. Although the use of a ball code to simulate subsidence is substantially a pioneering effort, the model results are considered to be reasonably realistic and correlate surprisingly well with observed phenomena.

For subsidence modeling in the future, little question exists as to the value of ball code modeling; the challenge is in "coming to grips" with model predictions based exclusively on non-physical properties that can simulate real physical phenomena.

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APPENDIX III
LORAX REPORT

TECHNICAL MEMORANDUM

To: Holger Hartmaier, BGC Engineering, Calgary, Canada

From: Al Martin, Lorax Environmental Services Ltd.

Date: September 8, 2009

Subject: Polaris Mine – Garrow Lake Water Quality Review

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1. Introduction

The Polaris Mine, situated on Little Cornwallis Island, Nunavut, ceased operation in September of 2002. At that time, reclamation activities commenced in accordance with a Decommissioning and Reclamation Plan (DRP) approved by the Nunavut Water Board and Indian and Northern Affairs Canada (INAC). In accordance with the DRP and Water License, water quality monitoring of Garrow Lake is required during three time periods on an annual basis (at mid-winter, at maximum ice thickness, and at maximum ice melt). Reporting of work and monitoring activities is provided to agencies on both a quarterly and annual basis.

As part of the review of the Abandonment and Reclamation work currently being undertaken by Teck Cominco Ltd., the Standing Offer Agreement 01-09-6007 was awarded by INAC to BGC Engineering to provide an evaluation of several aspects of the post-closure programs at Polaris Mine. As per the scope of work outlined in the Standing Offer Agreement, discussion is requested with regards to "*Teck's conclusion that elevated zinc levels in the mid depth range in Garrow Lake are due to a thin layer of bacteriological tissue*".

The following memorandum, prepared by Lorax Environmental Services Ltd. (Vancouver, Canada) for BGC Engineering provides an assessment of the distribution of total zinc (T-Zn) in the water column of Garrow Lake, and in doing so, assesses the validity of the statement provided in the 2007 4th Quarter & 2007 Annual Report (Teck Cominco, 2008a):

> *"At the top of the pycnocline it is postulated that due to a thin accumulated layer of bacterial tissue that zinc concentrations are sharply higher. As the layer is very thin, if water samples are collected from even slightly different depths, the resulting measured zinc concentrations change significantly. This would explain the more scattered nature of the zinc data at about the 10 m depth."*

The analysis considers data for Zn and other parameters measured in the water column of Garrow Lake to explain the likely mechanisms governing both the distribution and behavior of Zn in the lake system. Recommendations are also made for on-going monitoring.

2. Assessment

As shown in Figures 1A and 2A of the 3rd quarter report for 2008 (Teck Cominco, 2008b), vertical profiles of T-Zn in Garrow Lake show a fair degree of uniformity both temporally and spatially. For all sampling episodes, T-Zn profiles show pronounced maxima at depths of approximately 10 m. The peaks occur at the upper boundary of the pycnocline that separates saline bottom waters from relatively-fresh surface waters.

In highly stratified lacustrine systems such as Garrow Lake, the water column can be characterized by pronounced chemical and physical gradients. In such settings, narrow lenses of heterotrophic and/or autotrophic bacteria can develop that may take advantage of specific salinity or redox regimes. Although such bacterial assemblages can have a pronounced effect on the distribution and behavior of trace elements, there are several conditions that must be satisfied to support the notion that the Zn peaks in the water column of Garrow Lake are associated with bacterial biomass. Specifically, for Zn to be associated with bacteriological tissue implies:

1) T-Zn must be associated with particulate (bacterial) phases in the horizons of maximum concentration. This aspect could be effectively examined through the collection of both dissolved and total Zn profiles to determine the relative proportions of dissolved and particulate phases. The vast proportion of bacteria will be effectively screened by filtration through a 0.1 or 0.2 micron membrane, and therefore the absence of particulate phases would preclude the notion of bacterial assimilation; and

2) Dissolved Zn must be removed from solution and concentrated by bacteria either as complexes sorbed to bacterial membranes or through active cellular uptake. Although possible, it is unlikely such mechanisms could concentrate Zn to the levels observed.

There are other arguments to account for the vertical distribution of Zn in the water column of Garrow Lake. Specifically, there is evidence to suggest that the distribution and behavior of Zn relates to the history of mine-related inputs, the origin of meromixis, and the resulting vertical variations of the water column as they relate to both physical structure and redox-related processes. These topics are explored in the following paragraphs.

In order to elucidate the vertical distribution, and ultimately the source, of T-Zn in the water column of Garrow Lake, it is first important to understand the nature and origin of the physical structure of the lake. The water column of Garrow Lake is naturally meromictic (permanently stratified), whereby relatively saline and dense bottom waters are overlain by more dilute and less dense surface waters (Ouellet *et al.,* 1989). Meromixis is sustained in Garrow Lake as a result of the strong density differences between the upper layer (mixolimnion) and lower layer (monimolimnion). Density contrasts are governed largely by differences in salinity, with temperature variations contributing a relatively minor influence to the density structure. In Garrow Lake, the development of meromixis reflects a combination of several factors, including the natural input of brines to the basin, the continual re-supply of freshwater to the lake surface (through seasonal snow melt and runoff), lake morphometry (relatively deep depth), and the long-period of seasonal ice coverage which limits the potential for wind mixing of the water column. The historic input of saline effluents (tailings supernatant) to the lake has also likely contributed to the density structure.

The physical structure of the water column is clearly illustrated by the profiles of conductivity and temperature (Figure 1). The vertical profiles of conductivity at Stations 262-3 (central site) and 262-3A (southern site) show a pronounced increase in salinity below a depth of 10 m. Conductivity profiles across the pycnocline increase to over 80 mS/cm and remain relatively constant to lake bottom. The naturally anoxic and saline bottom waters are nearly three times (90‰) as salty as normal sea water (Ouellet et al., 1989).

The input of Zn-rich effluents to the lake during the period of active tailings discharge would have represented a source of dissolved Zn to the water column. The behavior of effluent within the lake would have depended upon the flow and density characteristics of the slurry and supernatant. Although no salinity data for the effluent are available, it can be assumed that effluents were likely denser than pre-mining lake surface waters, and probably less dense than the natural saline bottom waters of the lake. Given these considerations, the T-Zn peaks in Garrow Lake may represent a relict signature from the period of tailing discharge. This tenet relies on the assumption that the peaks in T-Zn are represented by dissolved phases, and that the dissolved Zn levels in the tailings discharge were at least greater than the highest T-Zn values ever recorded in the water column. The maximum recorded value in the water column to date is 1.6 mg/L (March, 2002). This value should be checked against historical records to verify that dissolved Zn levels in tailings discharges were greater than this value. Profiling for both total and filterable fractions could be used to verify the importance of dissolved Zn species.

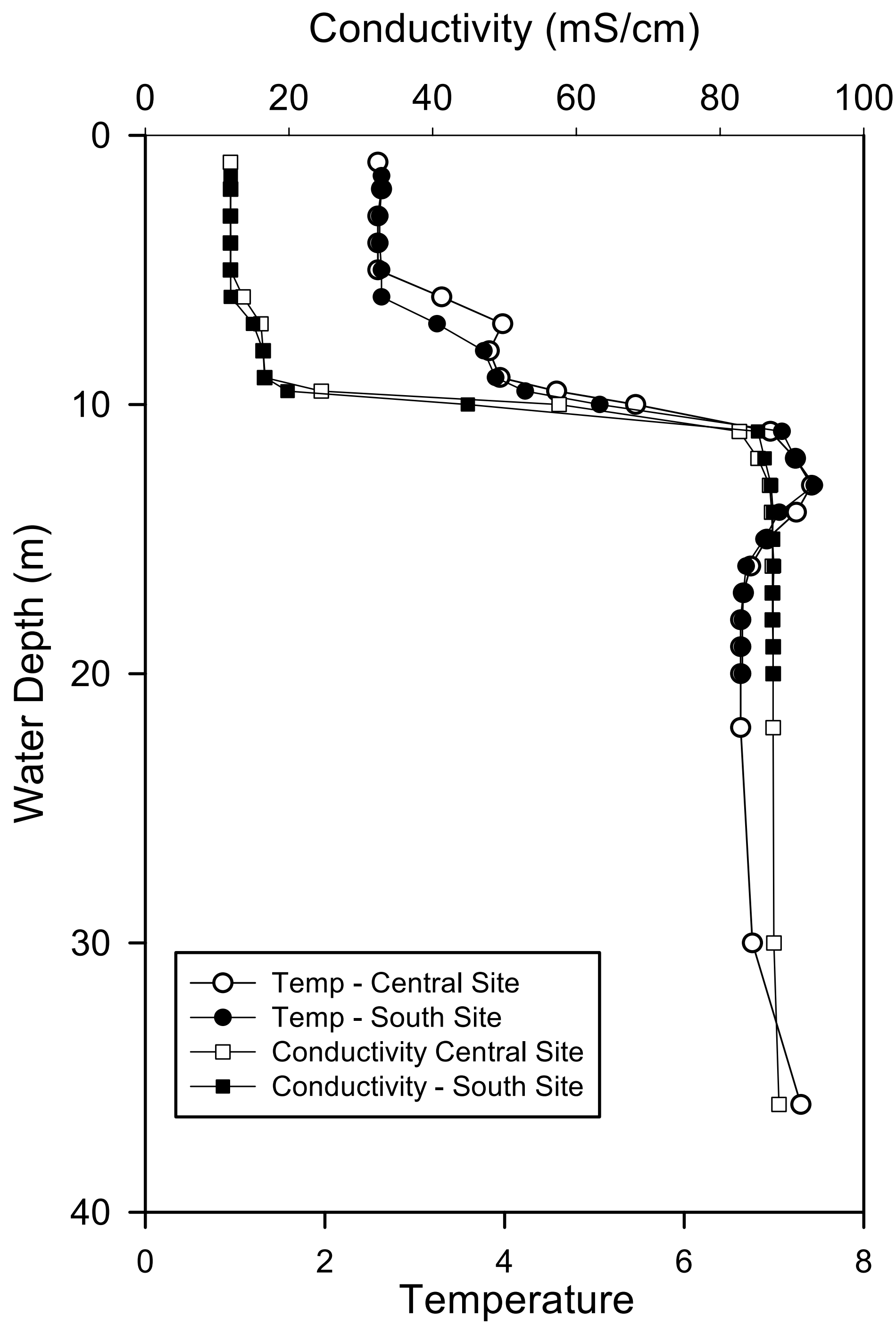

Figure 1: Vertical distribution of conductivity and temperature in Garrow Lake at stations 262-3 (central site) and 262-3A (southern site) for data collected August 29, 2008.

A critical piece of the "relict tailings effluent" argument is to explain the relative absence of Zn in lake bottom waters. Above the 10 m horizon, T-Zn concentrations have remained relatively invariant since 2004, with mean values in surface waters (upper 5 m of water column) at the central site ranging from 0.17 to 0.25 mg/L (Figure 2). The relatively constant values in the surface layer imply that the mixolimnion has approached a pseudo steady-state condition. Elevated levels of T-Zn are presumably sustained through continued mine-related loadings derived from surface water and/or groundwater inputs. Within a given year, the lowest values in the lake surface have been observed in August which is consistent with the period of maximum freshwater input. In contrast, T-Zn concentrations in the lower water column have exhibited a pronounced decrease during the closure period. Between 2002 and 2005, T-Zn levels below 15 m at the central station have decreased from approximately 0.5 mg/L to <0.05 mg/L (Figure 2). In order to explain this decrease, it is necessary to under the nature of reduction-oxidation (redox) conditions in the water column. This topic is explored below.

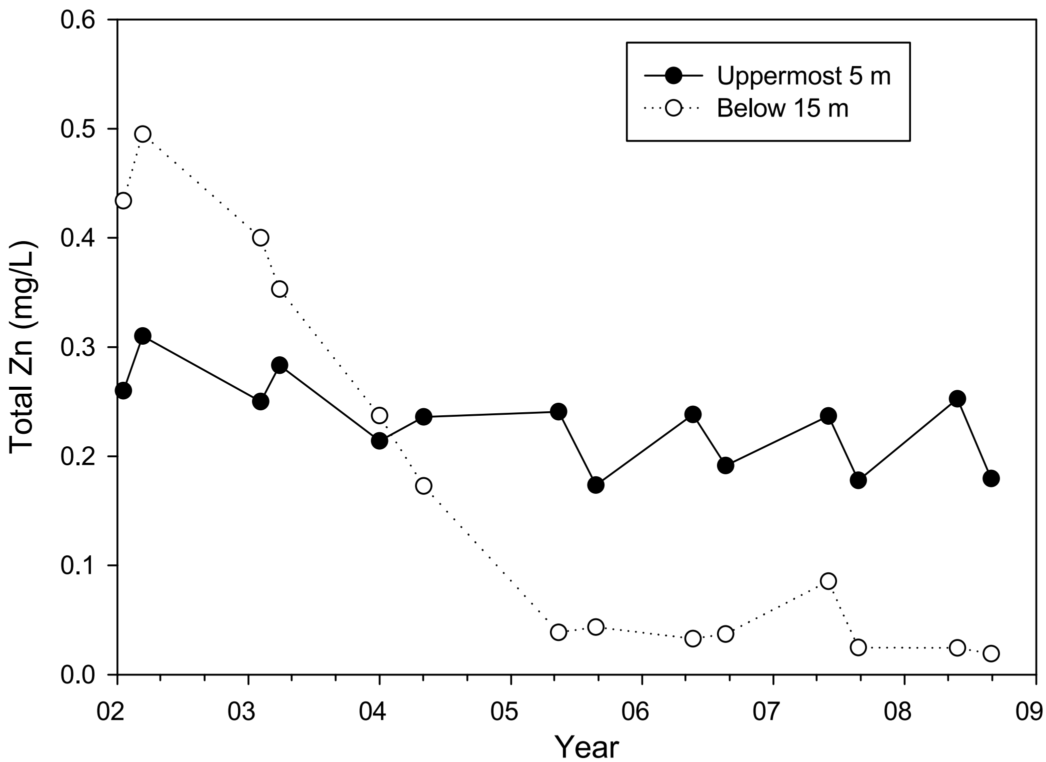

Figure 2: Time series of total zinc at the central station in Garrow Lake. Values for surface waters (average of values in uppermost 5 m) and bottom waters (average of values below 15 m) are presented.

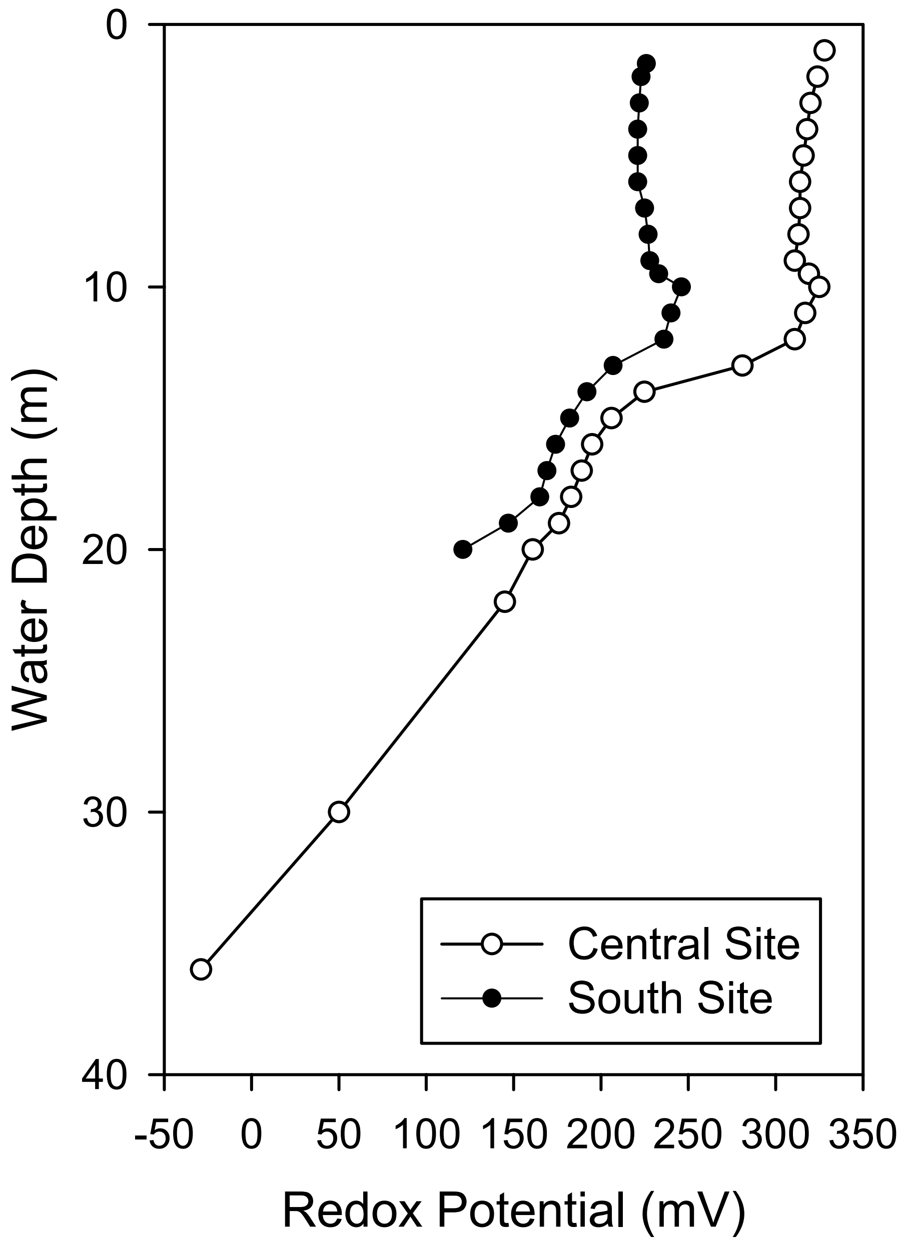

Figure 3: Profiles of redox potential in the water column of Garrow Lake (August 29, 2008 data).

The meromictic nature of Garrow Lake has allowed the development of a redox gradient in the water column, with progressively lower redox potentials observed with depth below the mixed layer (Figure 3). In this system, the rate of oxygen consumption in lake bottom waters exceeds the rate of oxygen supply from atmospheric sources, resulting in the development of an anoxic monimolimnion. Organic matter represents the “fuel” which drives oxygen consuming reactions, and may be in the form of phytoplankton/bacterial detritus, algae, or residual organic-based milling reagents often used in flotation circuits (pine oil, frothers, collectors, surfactants, *etc*.).

The remineralization (oxidation) of organic matter occurs through microbially-mediated reactions which liberate energy from the oxidation of organic molecules. In the oxidation process, microbes facilitate the reduction of various electron acceptors and take advantage of the energy gained in these reactions (Van der Weijden, 1992). In the oxidation process, microbial assemblages will preferentially utilize electron acceptors in order of their free energy yield. In the presence of dissolved oxygen, aerobic bacteria will utilize O_2 as a terminal electron acceptor since this redox reaction affords the greatest free energy. However, when oxygen is not available, as is the case for the monimolimnion of Garrow Lake, other secondary oxidants will be utilized. These, in order of their free energy yield, include nitrate, Fe^{III}-oxides, Mn^{IV}-oxides and sulfate (Table 1).

Table 1:
Oxidation/reduction reactions associated with the oxidation of organic matter, represented as $(CH_2O)_{106}\,(NH_3)_{16}\,(H_3PO_4)$. From Van der Weijden (1992).

1. Oxygen (O_2) Consumption:

$(CH_2O)_{106}\,(NH_3)_{16}\,(H_3PO_4) + \underline{138\ O_2} \Rightarrow 106\ CO_2 + 16\ NO_3^- + HPO_4^{2-} + 18\ H^+ + 122\ H_2O$

2. Nitrate (NO_3^-) Reduction (Denitrification):

$(CH_2O)_{106}\,(NH_3)_{16}\,(H_3PO_4) + \underline{84.8NO_3^-} \Rightarrow 7.2\ CO_2 + 98.8\ HCO_3^- + 16\ NH_4^+ + 42.4\ N_2 + HPO_4^{2-} + 49.6\ H_2O$

3. Manganese Oxide (MnO_2) Reduction:

$(CH_2O)_{106}\,(NH_3)_{16}\,(H_3PO_4) + \underline{236\ MnO_2} + 364\ CO_2 + 104\ H_2O \Rightarrow 470\ HCO_3^- + 8N_2 + 236\ Mn^{2+} + HPO_4^{2-}$

4. Fe Oxide (FeOOH) Reduction:

$(CH_2O)_{106}\,(NH_3)_{16}\,(H_3PO_4) + \underline{424\ FeOOH} + 756\ CO_2 \Rightarrow 862\ HCO_3^- + 16\ NH_4^+ + 424\ Fe^{2+} + HPO_4^{2-} + 120\ H_2O$

5. Sulfate (SO_4^{2-}) Reduction:

$(CH_2O)_{106}\,(NH_3)_{16}\,(H_3PO_4) + \underline{53\ SO_4^{2-}} \Rightarrow 39\ CO_2 + 67\ HCO_3^- + 16\ NH_4^+ + HPO_4^{2-} + 53\ HS^- + 39\ H_2O$

The characterization of redox zonation in a water column of Garrow Lake can be achieved through the examination of various redox-sensitive parameters including dissolved oxygen, manganese, iron, sulfate and hydrogen sulfide ($\Sigma H_2S = S^{2-}$, HS^- and H_2S). The profiles of these parameters in Garrow Lake yield a predictable sequence consistent with the thermodynamic principles described above (Figure 4). Dissolved oxygen (DO) shows a precipitous decline in concentration at approximately 10 m, with complete oxygen depletion encountered by 15 m. Manganese concentrations increase at a depth commensurate with oxygen depletion, and is predicted to reflect the reductive dissolution of Mn oxides in suboxic horizons and release of dissolved Mn^{2+} to solution (Davison, 1993). The profile for total Fe follows a similar pattern to that of Mn. Iron values increase to over 0.4 mg/L within the zone of oxygen depletion and likely represent the addition of dissolved ferrous iron (Fe^{2+}) to solution through the reductive dissolution of Fe oxides that settle through the surface layer. Sulfate data are not available, however, the presence of free sulfide in the lower part of the water column provides conclusive evidence of sulfate reduction in lake bottom waters (Figure 4).

Collectively, the profiles of DO, Fe, Mn and sulfide are indicative of reducing conditions in the water column below the pycnocline. The presence of free sulfide has particular relevance to the behavior of Zn. In the presence of dissolved HS^-, Zn precipitates from solution as secondary sulfide phases (ZnS, *i.e.* sphalerite). ZnS is highly insoluble, and will form before other competing sulfide phases such as FeS (Stumm and Morgan, 1981). The formation of ZnS presents the leading hypothesis to explain the depletion of Zn in the bottom waters of Garrow Lake. The formation of ZnS will only be possible in horizons where there is commensurate sulfate reduction. In the zone at the upper boundary of the pycnocline where conditions are only mildly suboxic, sulfate reduction and therefore Zn removal is not predicted to occur. Therefore, the relict Zn signature from historic effluent inputs in this region could persist over yearly time scales.

Sulfate reduction and concomitant Zn removal can be viewed as a form of passive bioremediation that represents a biogeochemical analogue to other forms of active anaerobic treatment systems that take advantage of sulfate reducing bacteria. Zinc sulfide precipitation has also been put forth as a mechanism to control Zn concentrations in the water columns of other stratified lakes that have received mine-related loadings (Suits and Wilkin, 1998; Ramstedt *et al.,* 2003).

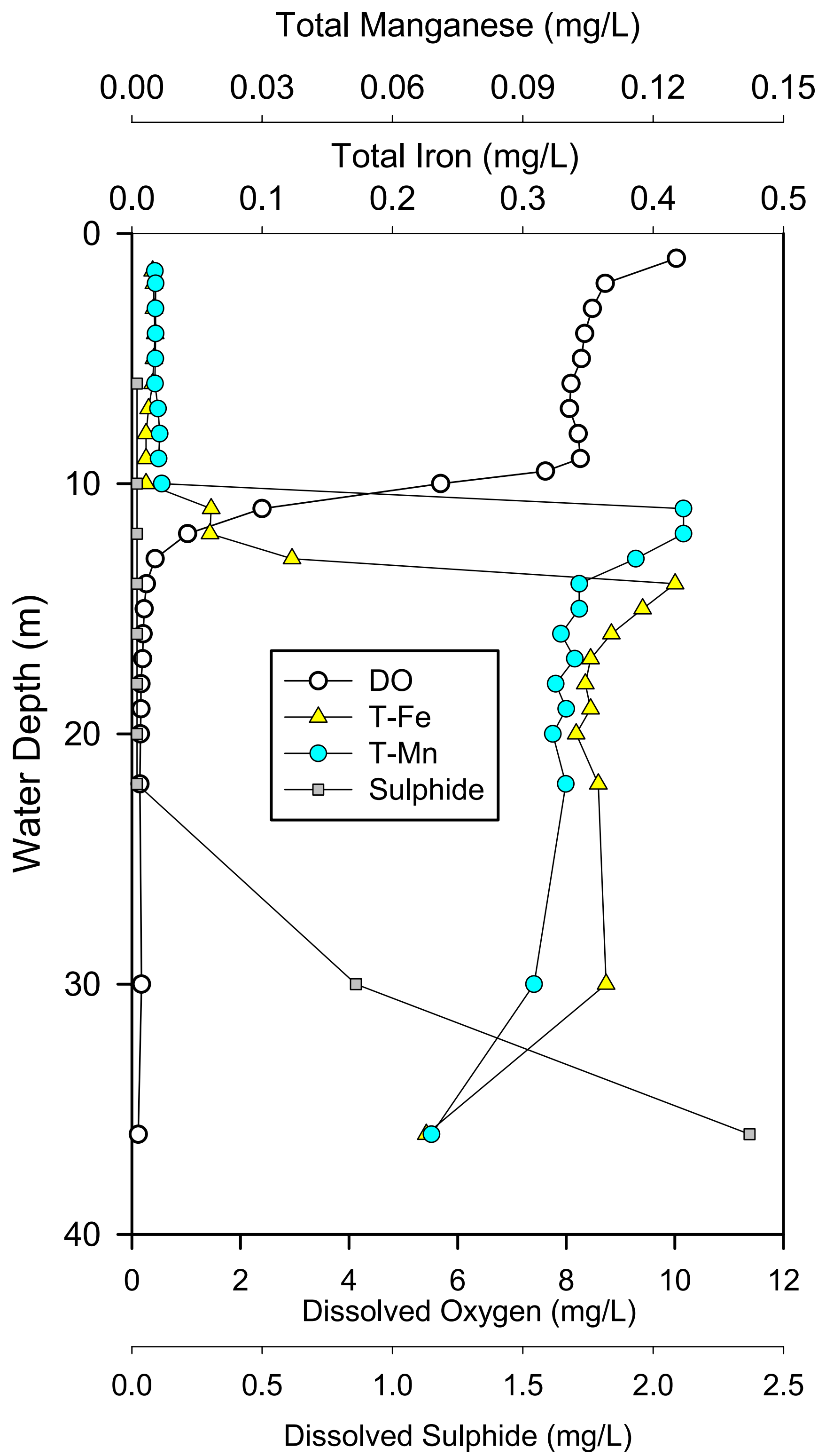

Figure 4: Profiles of redox-sensitive parameters in the water column of Garrow Lake (August 29, 2008 data for central station). Data are provided for dissolved oxygen (DO), total iron (T-Fe), total manganese (T-Mn) and sulfide.

3. Summary and Recommendations

3.1 Summary

In summary, it appears less plausible that the Zn maxima in the water column of Garrow lake are associated with bacterial tissues. Rather, it is more likely that the Zn peaks are represented by dissolved fractions that reflect a relict signature of Zn inputs associated with historic tailings discharges. Above the zone of maximum Zn concentration, T-Zn levels appear to have reached near-steady-state conditions, in which Zn levels are governed by a combination of continued Zn loadings to surface waters in conjunction with periodic incursions of summer melt waters. Below the Zn maxima, it is possible that levels of dissolved Zn are being naturally attenuated through the precipitation of secondary Zn sulfide minerals.

3.2 Recommendations

There are several, and relatively low-cost, measures that can be added to the monitoring program to support or negate the arguments presented in this report. First, the measurement of both dissolved and total metal fractions will be critical for evaluating the potential influence of bacterial assemblages. As discussed, Zn hosted with bacteria will be effectively removed through filtration through a 0.1 or 0.2 micron filter. The addition of dissolved metals to the monitoring program will be important for verifying the nature of the redox conditions in the water column (through analysis of dissolved Fe and Mn). The addition of dissolved measurements should be conducted on one sampling campaign only, the results of which would be used to assess the merits of this component for subsequent surveys.

The addition of sulfate to the analyte list will also be important for assessing the magnitude of sulfate reduction in lake bottom waters. Sulfide should be measured as dissolved forms only. The methods for preservation and analysis of sulfide were not presented as part of the quarterly/annual reports. However, given that sulfide is extremely reactive, preservation with zinc acetate (or equivalent) should occur immediately (within a minute) upon sample collection.

If dissolved parameters are collected, it is critical that appropriate field methods are used to minimize the potential for oxidation artifacts. Specifically, parameters such as dissolved ferrous iron (Fe^{2+}) are unstable in the presence of molecular oxygen, and will rapidly oxidize within minutes to produce hydrous ferric oxides. The precipitation of such phases prior to filtration can result in the scavenging of other metals that have a high affinity for oxide surfaces (e.g., Zn). A recommended means to minimize the potential for such artifacts is to collect samples using a peristaltic pump with in-line filters. In this way, sample exposure to atmospheric influences is greatly reduced.

In conclusion, Teck Cominco Ltd. should consider the above and undertake the following in order to negate or support the findings of this analysis:

1. Collect measurements of both total and dissolved trace metals in the water column for one survey. A filter size of 0.1 or 0.2 microns should be used to filter out bacteria;
2. Add sulfate to the analyte list;
3. Collect measurements of dissolved sulfide (if not already being done) and use appropriate preservation methods;
4. Minimize the potential for oxidation artifacts during the collection of water samples through the use of a peristaltic pump and in-line filtration; and
5. Compare maximum T-Zn levels in Garrow Lake with those of historic effluent discharges to aid in assessing whether the Zn peaks in the water column represent a relict signature of historic tailings deposition.

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