Investigation, Design and Development of the Valley Pit Big Bear Pushback at the Teck Highland Valley Copper Mine

S. Fortin  Teck Resources Ltd., Vancouver, Canada
N.D. Rose  Piteau Associates Engineering Ltd., North Vancouver, Canada
A.T. Holmes  Piteau Associates Engineering Ltd., North Vancouver, Canada

Abstract

The expansion plan for the Valley pit at the Teck Highland Valley Copper (THVC) mine, BC, Canada involves a pushback on the east wall through a 225m thick sequence of glacial overburden sediments (Big Bear). This slope has historically experienced a significant amount of deformation along weak, pre-sheared glaciolacustrine clay horizons. This paper summarizes the integrated approach undertaken by THVC to rally engineering design, mine planning and operational practice to execute controlled excavation and placement of a seven million tonne waste rock stabilization buttress using slot-cut mining methods. The long-term performance of the Big Bear slope in-turn relies on controlling piezometric levels within the lacustrine clay units by operating a dedicated depressurization system.

A comprehensive field investigation program was carried out to define the engineering geology and hydrogeological conditions in the slope. A hydrogeological model was developed to assist the design of a depressurization system comprised of 77 active wells and 27 one-meter diameter passive vertical drains. Detailed design assessments were conducted to define a stable slope configuration and predict slope deformation using a combination of limit equilibrium and numerical modelling methods. At the early stage of this project, Teck Resources performed a risk assessment to identify and manage the risks associated with the Big Bear mining phase. A trigger action response plan was created and mine planning and scheduling decisions were made through continuous assessment of risk to personnel, equipment and ore reserves. This resulted in the optimization of buttress dimensions, the slope depressurization system design and completion of a final mining plan in late 2010. The Big Bear mining phase is forecasted to be completed in mid 2011.

1 Introduction

Teck Resources Ltd. (Teck) operates the Highland Valley Copper (THVC) mine, located 55 km southwest of Kamloops, in the Thompson Nicola Region of British Columbia. Mining operations at THVC are conducted through three open pits, the Valley, Lornex and Highmont pits, with total annual output on the order of 300,000 dry metric tonnes (dmt) copper concentrate and 5,000 dmt of molybdenum concentrate. THVC is currently mining an ultimate mining phase on the east wall of the Valley Pit comprised of the Big Bear mine plan in overburden and the Phase 8E mine plan in bedrock. In mid 2009, THVC began a pushback of the east wall of the Valley Pit (Fig. 1), which involves 75 million tonnes (Mt) of mostly overburden waste and 85 Mt of ore.

The Big Bear pushback was required to provide adequate stability of a 225m high overburden slope that will expose a low shear strength lacustrine clay unit (Unit 10B) between about the 1000 and 1027m levels on the central portion of the east wall. A 36 to 62m high by 30m wide waste rock buttress, comprising approximately 7 Mt, will be constructed using a slot cut and fill mining approach to stabilize the overall overburden slope. A smaller 30m high by 20m wide buttress comprising approximately 1.3 Mt was constructed on the 1100m level to provide stability for exposure of a weak clayey silt unit in the mid to upper slope. The combined Big Bear and Phase 8E mining phases are part of an ultimate pit plan to 2022. Current pit dimensions define an almost equal length and width of about 2100m at the main pit crest. Wall heights range from 495 to 670m and are projected to reach 840m on the ultimate west wall.
Detailed design of the Big Bear mine plan followed an integrated approach between the geotechnical and mine engineering groups and Piteau Associates, with constant consideration of mine operations and overall risk management aspects. This paper presents an overview of the geotechnical and hydrogeological investigations, laboratory testing and stability assessments. Development of the mine plan required the construction of an effective depressurization system to allow development of stable slopes. Comprehensive standard operating procedures and an extensive slope monitoring network were required to allow safe mining operations.

2 Field investigation

A substantial field investigation program was completed along the Valley pit east wall, which focussed mainly on characterizing the glacial sediments across the Big Bear slope with geotechnical and hydrogeological drilling. It also included confirmatory drilling, window mapping and photogrammetry of the exposed bedrock slopes. Close attention was paid to the delineation of the Lornex Fault Zone (orange unit on Figs. 1 and 2) and the clay-rich units occurring in the lower portions of the overburden strata, due to their adverse influence on slope deformation and stability of the east and southeast walls. Hydrogeological investigations focused on defining the groundwater distribution and flow regimes for the various overburden and bedrock units as well as dewatering potential in the overburden. The following discussion pertains exclusively to results of the overburden investigations.

2.1 Engineering geology

2.1.1 Lithology

The east wall slope in the Valley Pit is comprised of a 350m thick sequence of glacial valley sediments that occur along the Highland Valley (Fig. 1), exposing an overburden slope up to about 225m high below the crest of the ultimate east wall. The glacial overburden units consist of pro-glacial outwash and glacifluvial deposits, glacial outwash sands and gravels interbedded with till, and alluvial fans consisting of cross-bedded sands and sandy-gravels. Lacustrine sediments occur within the mid to lower portion of the glacial sequence.
The upper portion of the lacustrine sediments on the east wall consist of approximately 100m of sub-horizontally bedded silts to fine sands containing organics throughout (Unit 10A). Shallow water glaciolacustrine sediments grade into alluvial deltaic fans in the upper portion of the unit defining discontinuous sand and gravel layers. Upper Unit 10A exhibits higher plasticity clayey-silt laminae that define low residual shear strengths that have been identified between the 1100 and 1130m levels in the 2005 North Lubeland and 2008 South Lubeland slope failures on the east wall (Fortin et al., 2009). Thin discontinuous sand layers occur within generally low plasticity silts in the Mid and Lower Unit 10A.

Lacustrine Unit 10B comprises an approximately 3 to 25m thick sequence that is indicated to daylight between approximately the 1000 to 1025m elevations on the central east wall. Unit 10B comprises an interbedded sequence of high plasticity, low shear strength silty clays that grade downwards to clayey silts with thin silt laminae throughout. As shown on Figure 2, bedding is interpreted to dip shallowly to the east/northeast, to flat in the centre of the paleo-valley, then slightly west/southwest near the eastern margin. Pre-sheared, fine-grained bedding horizons in overburden have been mapped on the pit walls and in core within the 10A and 10B lacustrine units on the southeast and east walls.

Lacustrine Unit 10C consists of inter-bedded clayey silts grading downward to silts and sands into the Basal Aquifer. The Basal Aquifer consists of silty sands, sands, gravels and sandy gravels originating from pro-glacial and sub-glacial outwash and alluvial deposits. Unit 10C was identified as a suitable foundation material for the 10B Buttress due to its texture and drainage characteristics (Piteau 2010).

### 2.2.2 Engineering material properties and shear strength

Due to the large slope heights to be developed in overburden on the east wall it was necessary to establish a thorough understanding of the material properties and shear strengths within the various overburden units. A comprehensive laboratory testing program was carried out on selected drilling samples with two primary objectives: (i) define shear strengths for the weaker units, and (ii) confirm shear strengths for the stronger foundation units. Primary laboratory testing methods included grain size analysis, hydrometer tests, Atterberg Limits, X-ray diffraction, C-U triaxial tests with pore pressure measurements and C-D direct shear tests.

Figure 3 presents material relationships developed for plastic index (PI), liquid limit (LL), clay content and angle of shearing resistance ($\phi'$). As seen from this figure, low shear strengths (i.e., $\phi' < 12^\circ$) are indicated for clay contents greater than 50%. Some of the direct shear tests were observed to define higher shear strengths, but these results were explained by the observation of shearing through silt laminae between adjacent clay varves. These observations supported a $\phi'$ of 25° for cross-bedding in low shear strength clay materials.

An important field observation that was associated with low shear strength bedding was the presence of slickensides in the Upper 10A and 10B units, and a clear absence of slickensides in the underlying Unit 10C.

Based on the laboratory testing results, low shear strength units are indicated to exhibit all of the following characteristics:

- clay content greater than 50%;
- PI > 20% and LL > 55% defining high plasticity silt to clay (MH to CH); and
- slickensides, indicating pre-shearing.

X-ray diffraction testing was carried out on selected 10B samples to confirm the clay mineralogy of this unit. The test results indicate that unit 10B is comprised of 36-42% of clays from the smectite group, which are swelling clays. These materials can be prone to strain softening related to unloading and hydration upon exposure; however, these effects can be mitigated with stabilization measures such as waste rock buttressing, provided that exposure time is minimized.
2.2 Hydrogeology

Recharge occurs to the Valley pit groundwater flow regime primarily as infiltrating precipitation over the surrounding catchments. The Valley Pit is the principal discharge area for the catchments, as illustrated by the indicated groundwater flow directions (Fig. 4a). Normal annual precipitation is 387mm per year, and recharge to the groundwater flow regime is estimated to vary between about 40 and 60 mm/year.
The principal aquifers in the east wall include the Basal Aquifer that underlies the lacustrine sediments, the Main Aquifer that overlies the lacustrine sediments (Fig. 2) and three alluvial fans. The three alluvial fans on the east wall include the West Fan that was deposited into the Highland Valley basin from the northwest; the Trojan Fan deposited from the Trojan Valley to the northeast; and the Bethsaida Fan deposited from the southeast (Fig. 4a).

![Groundwater flow path map](image1)

### Figure 4. Groundwater flow path map (a) and depressurization system (b) comprised of 77 pumping wells and 27 passive vertical drains. Area of Fig. 4b referenced by the inset white box on Fig. 4a.

The Bethsaida Fan sediments are prominent in exposures across the southeast and east walls of the pit. These sediments comprise an interbedded sequence of generally coarse-grained sediments, with a complete absence of silt in many of the sand or sandy gravel interbeds. The Trojan and West fans are not readily observed in exposures, but are not considered to be as permeable as the Bethsaida Fan. Fan sediments are distinctly interbedded with the lacustrine sediments to varying degrees across both lateral and vertical facies changes.

The predominant groundwater flow directions beneath the valley bottom are interpreted to be along the northwest-southeast trending axis of the main valley, and to a lesser extent the northeast trending Trojan valley, directly towards the pit. Most of the groundwater flow is interpreted to enter the pit area via the Basal Aquifer from both the northwest and southeast, the Bethsaida Fan aquifer from the south, and the Main and West Fan aquifers from the north. Dewatering within these areas of the pit will therefore exhibit response typical of unconfined to semi-confined aquifers. Well influence zones will be quite large and the rate of drawdown will be relatively slow. In central areas of the east wall that are distant to the alluvial fans, pore pressures in the permeable 10A/B horizon exhibit a more confined response, with drawdown achieved over a much shorter time frame.

Stratigraphy and attendant facies changes, vertical and horizontal location in the pit and proximity to the alluvial fans control the highly variable groundwater levels observed in the lacustrine units across the Big Bear slope. Piezometers installed in the lacustrine units generally exhibited a downward gradient, with maximum pressure heads ranging from 14 to 26m at the Unit 10A/10B interface prior to implementation of the depressurization measures. Unit 10B and silty clay layers in the Unit 10A sediments act as aquitards, which generally result in a high downward gradient in the flow regime (i.e. non hydrostatic), and high pressure heads along the top of these aquitard layers. Negative pore pressures were measured in the lower Unit 10B and 10C layers, due to flow to the...
underlying Basal Aquifer which is partially dewatered. Measured hydraulic heads in Unit 10B were highly variable, depending on proximity to alluvial fans and associated recharge, and the distribution of very low hydraulic conductivity lamina in the unit.

The objective of the dewatering/depressurization system design was to achieve a low head in the 10A/B layer immediately above Unit 10B, and to reduce pore pressures in Unit 10B.

3 Big Bear slope design

3.1 Past slope performance

Prior to 2004, the east wall overburden slope was indicated to have been stable, other than local bench scale instability. In January 2004, observed acceleration in prism monitoring data led to a decision to stop mining on the 1055m working level and implement remedial designs that incorporated an offloading cut at the crest of the pit and subsequently the Phase 6 expansion. A borehole camera survey was carried out in standpipe piezometers and vertical drains located on the 1070m bench and on the 1055m bench near the toe of the Phase 5 pushback. Most of the installations showed signs of deflection near the top of Unit 10B, which was interpreted as discrete translational shearing movement related to mining induced stress relief. Deflections appeared to be greatest towards the south end of the slope, where mining of the 1055m bench had progressed back to the design toe.

In 2005 and 2008, instability developed in the upper overburden slopes in Upper Unit 10A above approximately the 1115m bench, referred to as the Lubeland instability. A documented account of the slot cut excavation and construction of a 20m wide by 30m high waste rock buttress stabilize the 2005 and 2008 Lubeland slope failures is provided by Fortin et al. (2009). Peak 3-day average movement rates in 13 different slot cuts ranged from 8 to 122 mm/day during slot cut mining and buttress construction. These values provide an important historical basis for selecting movement rate thresholds for the construction of the 10A Buttress (Fig. 1b) along the same stratigraphic horizon on the Big Bear pushback.

3.2 Groundwater depressurization targets

Objectives for the dewatering measures are two-fold: (i) reduce recharge from alluvial fans (dewatering) and (ii) reduce pressure heads in the 10A/B and 10B layers. Interpreted 10A/B and 10B piezometric surfaces prior to dewatering are presented in section on Fig. 2, by the solid red and blue lines, respectively.

Practicable depressurization targets were developed for the east wall, to provide a basis for stability analyses and design of the slope. The November 2009 piezometric levels were selected as the targets for the Main Aquifer and Middle/Upper 10A, as no dewatering measures were designed to specifically target those areas. The piezometric surfaces interpreted from November 2009 data for the Main Aquifer, a pore pressure ratio (\(r_u\)) of 0.1 or a pressure head of about 10m, were the recommended groundwater conditions for stability analyses. Piezometric surfaces interpreted from actual monitoring data for the lower 10A, 10A/B and 10B Units when the GWE wells (first phase of the dewatering wells implemented in 2005/2006) were previously in operation, were selected as the targets for the stability analyses in the area where these wells had been in operation. Depressurization targets that were judged to be attainable were defined for those areas not previously serviced with dewatering wells. Target 10A/B and 10B piezometric surfaces are shown by the dashed red and blue lines on Fig. 2.

To verify that the selected piezometric targets were feasible, a 3D finite-element groundwater flow model was developed using the FEFLOW™ modeling code. Model geometry was based on HVC’s 3D GEMCOM™ stratigraphic surfaces, and the model was calibrated against observed well yields and piezometric responses. Once an acceptable calibration was achieved, the model was used to forecast response to the dewatering system. The model was modified a number of times, to reflect response to the dewatering system as it was progressively implemented, and revised mining and dewatering implementation schedules. Pore pressures simulated by the model were incorporated in the stability analyses, and the most current analyses were then used to modify short range mining plans to maintain an adequate factor of safety (FOS) in the design.
3.3 Slope stability analysis

3.3.1 Design approach

Following comprehensive field investigations and design, execution of the Big Bear mine plan follows an observational approach where the slope is excavated under controlled conditions such that any failures that do occur are caught and effectively controlled on benches while preventing the development of overall slope instability. This approach provides for adequate safety at minimal cost, although special design or remedial measures may be required to ensure the stability of haulroads and critical infrastructure.

Two-dimensional (2D) limit equilibrium analyses were used to define preliminary interramp and overall slope angles in overburden, including stepout widths and buttress dimensions, to define a stable slope configuration for the Big Bear pushback. Mine plan revisions were made by HVC mine planning, which subsequently led to the development of the Big Bear mine plan in late 2009. Subsequent stability analyses and design optimization of the Big Bear mine plan were carried out using 2D and 3D limit equilibrium methods, as well as detailed numerical modelling with UDEC™.

3.3.2 Limit equilibrium analysis

Two-dimensional limit equilibrium analyses were carried out for areas on the Big Bear mine plans where slope dimensions are adequately long in the out of plane direction to satisfy a 2D approach. 3D limit equilibrium (Clara-W™) analyses were used to analyze the stability of the slot cut mining during 10B Buttress placement. Shear strength anisotropy was used to define potential shearing along bedding with either discontinuity planes in Clara-W or anisotropic functions in Slide™. Design acceptability criteria included a minimum FOS of 1.2 for interramp and overall slopes in slope areas where critical infrastructure does not exist, compared to 1.25 to 1.3 in areas of infrastructure and critical haulroads. The effects of dynamic loading (earthquake and blasting) were also considered with respect to the Big Bear slope design.

Parametric sensitivity analyses using ranges of piezometric conditions, interramp slope angles (IRAs), mining levels, etc., confirmed the following measures are required to develop a stable Big Bear slope configuration:

- 10A Buttress: a 20m wide by 30m high waste rock buttress between the 1100 to 1130m levels to prevent shearing along weak bedding horizons in Upper Unit 10A;
- 10B Buttress: a 30 to 40m wide by 45 to 62m high waste rock buttress between the 1001 and 1070m levels to prevent shearing within Unit 10B;
- IRAs of 22 to 33° between the 1001 and 1205m levels defining and overall slope angle of 20°; and
- controlling piezometric pressures within lacustrine units and recharge from water bearing aquifers.

3D stability analyses of the interramp and overall slopes (Fig. 5) indicated that slot cut methods would be required along the western edge of the pushback to minimize the exposed length of the 10B clays along the strike of the pit wall. To allow full development of the 1037 bench and slot cut accesses prior to slot cut mining on the east and northeast walls, Big Bear target depressurization levels (Fig. 2) needed to be achieved prior to beginning slot cut mining, while full development of the 1037m bench and slot cut accesses were prepared.

Stability analyses were also carried out to investigate the shear strengths that are required to define a minimum FOS of 1.2 for 10B Buttress foundation conditions in Unit 10C. Assuming an active Rankine angle (i.e., 45° + $\phi'/2$) for potential shearing through the waste rock buttress into the Unit 10C foundation, a minimum $\phi'$ of 17° is required along bedding, but no change in the required cross-bedding shear strength, for an assumed $r_e$ of 0.05. If undrained conditions are assumed, a minimum undrained shear strength ($c_u$) of 140 kPa is required. Based on the results of laboratory testing, FOSs of greater than 1.2 are expected for a 30m wide buttress based on both drained and undrained conditions.
3.3.3 Deformation modeling

A numerical model of the Big Bear slope (Section NE3) was developed using UDEC to assess the potential for complex large-scale deformations and progressive failure development in bedrock and overburden related to mining. The code is well suited for the Big Bear slope stability conditions that are influenced by complex structural conditions in bedrock and the interaction with discrete shearing along weak clay-rich bedding layers in lacustrine Units 10A and 10B. The modelling methodology used to analyze the east wall is similar to that presented in Rose and Scholz (2009). The primary objective to evaluate slope stability and forecast slope deformations in overburden on the east wall related to potential shearing in Units 10A and 10B. In particular, the potential for shearing was investigated to determine the potential for loss of enhanced depressurization measures (i.e., pumping wells and vertical drains) that are critical to the stability of the overall slope.

Calibration of the UDEC models was achieved through a comparison of actual monitored slope displacements (based on prism and inclinometer monitoring data) and model response with movement histories placed at the same location in the model as the actual prisms or inclinometers on the slope. The fabric of geologic structure and the shear strength of Units 10A, 10B were varied to achieve model calibration. Forward analysis was carried out to assess the overall stability and predicted displacements related to proposed Big Bear mining.

Sensitivity analyses were carried out to investigate potential slope conditions that could be encountered during mining of the Big Bear slope, which include a range of groundwater levels (non-depressurized vs. at target depressurization levels) and a range of slope deformation conditions (open slot vs. buttressed). Forecasted slope displacements are illustrated on Fig. 6. Predicted slope movements are highly sensitive to buttressing and groundwater conditions. Horizontal displacements for the slot open condition are significantly higher than for buttressed conditions below the 1190m level. Similarly, horizontal displacements are predicted to be significantly higher under non-depressurized conditions compared with Big Bear target water conditions. As shown on the plots for slope inclinometers in the area of PVDs on the 1055m level (Fig. 6), displacements at the end of Big Bear mining indicate slope displacements related to discrete shearing along the upper Unit 10B contact. For Big Bear groundwater conditions, approximately 0.3m of displacement is indicated near the Unit 10B contact for buttressed conditions, as compared to 0.9m under the slot open conditions. These results indicate that provided Big Bear target depressurization conditions are achieved and maintained, the one-metre diameter PVDs below the 1055m level should remain functional. As the BBW wells do not penetrate through Unit 10B, potential shearing loss of these installations is not indicated based on observation of small negative tilt of about 100 to 210mm over hole lengths of 60 to 110m.
3.4 Depressurization system

The design and long-term, safe operation of the Big Bear slope relies on a comprehensive system to dewater/depressurize the east wall of the Valley Pit. The groundwater control system is comprised of the following elements (Fig. 4b):

- 77 BBW wells targeting the sediments at the Unit 10A/B contact that overlie the 10B clay;
- 27 passive vertical drains (PVDs) drilled near the toe of the wall, to provide continuous, passive dewatering in the area where mining activity will preclude maintenance of operating wells in the period leading up to the slot cut construction.
- Perimeter interception wells to intercept water in the Main and Fan aquifers;
- Five wells located on the southeast wall of the pit to intercept Bethsaida Fan water; and
- Deep wells to intercept groundwater from the Basal Aquifer and maintain strong downward hydraulic gradients through the lacustrine sediments.

The BBW wells are drilled to the top of Unit 10B and target the permeable 10A/B stratum at the contact between Units 10A and 10B. The 10A/B layer varied from a silty sand to a gravelly sand with some silt, depending on the degree of interbedding with alluvial fans. All BBW wells were constructed with a 150mm wire wound screen.
installed in a 300mm diameter hole with an annular filter pack. A vacuum was applied to the filter pack via a 25mm slotted PVC pipe. BBW wells were screened from the base of the well to about El. 1050m. The upper elevation of the screened interval was adjusted depending on water occurrence depths in each well. The total flow from the fully implemented BBW well field was approximately 540 USgpm in early May, 2011.

The 27 PVDs were constructed in the summer of 2010, along the alignment of the final 1055 or 1037m levels, to dewater/depressurize the 10A/B layer where the largest ground deformation is expected. These 1m diameter rock-filled columns are intended to maintain hydraulic connection between the 10A/B sediments and the underlying Basal Aquifer, for shear deformation of up to 1m in the intervening 10B clay layer (Fig. 7).

Figure 7. PVD drilling, design and construction.

The PVDs were drilled using Kelly drilling methods with a BG36 rig. The upper portion of each PVD was typically drilled by advancing temporary casing, to maintain an open hole in the near surface lacustrine sediments and granular interbeds. Below the cased portion, a biodegradable mud slurry with a half life of about 40 days, was used to maintain an open hole during construction, and to provide a permeable interface with the Basal Aquifer to maintain a drained condition in the PVD. Boreholes were advanced using a telescoping Kelly bar and a variety of auger buckets, which were changed to match the character of the various soil strata intersected in each hole. A casing oscillator was employed to support the rotary technique, as required (Fig. 7).

Completion depths of up to 115m were achieved, with an average production rate of approximately 25m penetration per day. Operating heads in the PVDs were all below El 1000m prior to the start of slot cut mining, indicating they were effective.

Perimeter interception wells are operating in the Main Aquifer, and the West, Trojan and Bethsaida fans. There are also five active wells in the north area of the Basal Aquifer and three active wells in the southeast area. Total flow from the perimeter and Basal Aquifer wells is approximately 2,750 USgpm.
3.5 Mine plan

Significant ore reserves are contained in the Phase 8 mine plan in the bedrock slope below the 10B Buttress at 1001m level. The mining sequence set forth to gain access to these reserves commenced in August 2009 with the initiation of the Big Bear pushback, which required stripping of 75 Mt of overburden waste. HVC’s mining fleet had to be enlarged to respond to the demand of the mine plan.

A total of 42-each, 45m wide slot cuts were designed along two 18m benches (compared to regular 15m high benches) at the 1001m and 1019m levels to reduce exposure of the 10B clays (Fig. 8) and maintain stability. The development of accesses for slot cut mining in turn had to consider the progress of the depressurization system, i.e. meeting target criteria prior to day-lighting Unit 10B. The Big Bear mine plan also had to consider the production of approximately 7 Mt of waste rock for backfill material in the buttress, as well as the development of long-term storage capacity at the Jurassic waste dump. The full construction of the 10B stabilization buttress was scheduled to take about 20 weeks to completion by mid 2011 to release access to Phase 8 ore.

3.6 Monitoring plan

Perhaps the most critical aspect of the slot excavation process is to confirm the suitability of the foundation material to support the 10B stabilization buttress. This is achieved through a three-stage process comprised of visual confirmation from test pits excavated in each slot, laboratory testing of test pit samples and results from shear vane and/or dynamic cone penetrometers (DCPT).

Visual inspection is carried out by the geotechnical group on a daily basis and/or for any new excavated “slot” and backfilled area. The objective of the visual inspection is three-fold: (i) ensure that the guidelines set per the Execution Plan are met; (ii) confirm presence of shear surfaces and required extent (vertical and lateral) of buttress fill and foundation soils; and (iii) identify potential areas of ground instability (e.g., tension cracks).

A dedicated monitoring system and related plan was developed to continually assess the performance of the Big Bear slope to ensure safe mining operations. The Big Bear instrumentation network consists of slope monitoring prisms, wireline extensometers, portable GPS antennas, TDR cables, nested vibrating-wire piezometers and a
slope stability radar (SSR). Data collection for the Big Bear instrumentation network is automated by a combination of data loggers and desktop computers. The raw data is transferred via radio communication using the HVC mesh network. The SSR data is accessed and processed via the SSR viewer software (GroundProbe™). All other data are managed and processed by the MS3 software integrated platform (ACA Monitoring Ltd.).

Threshold values and corresponding alarm criteria were established for the various instruments monitoring the Big Bear slope. These values were derived following review of monitoring data collected during placement of the 10B Buttress and correlated against visual field observations. The thresholds are consistent with UDEC deformation modelling predictions and are subject to revision with ongoing evaluation of slope performance.

4 Big Bear implementation

A comprehensive manual of Standard Operating Procedures (SOPs) was developed ahead of commencing slot cut mining to provide a framework of instructions to support safe and controlled mining operations that fully meet design requirements for the Big Bear slope. The following aspects are covered within the document: (i) Roles & responsibilities; (ii) Execution Plan; (iii) Monitoring Plan; (iv) Communication Plan; (v) Trigger Action Response Plan (TARP, as presented by Read and Stacey 2009); and (vi) Contingency Plan.

The roll-out of the SOP manual required training of mine engineering and operations staff, particularly dispatch operators to whom monitoring alarms are conveyed. Buttress construction activities are carried out under full time supervision of geotechnical inspectors in the field on a 24/7 schedule.

The timing and sequence for the development of slot cut access was routinely adjusted to account for the status of actual depressurization levels compared to target. The south end of the 10B Buttress was the first area to meet target depressurization levels, as a result of implementing an interim dewatering strategy during mining development. Empirical estimates and groundwater flow modeling were subsequently used to predict and confirm that the depressurization schedule met the mining schedule.

The presence of a bedrock ridge defining the western edge of the Highland valley sedimentary basin (Fig. 3) created a particular construction challenge, both from a mining sequencing and from a stability viewpoint. As the Lornex Fault Zone strikes northward sub-parallel to the 10B Buttress on the south end of the pushback, rock of variable hardness values were encountered. Rock hardness ranged from free-dig material near the fault to hard rock requiring controlled blasting methods to minimize disturbance to Unit 10B clays and preserve the existing preferential cross-bedding strength. Blasting of the rock ridge was completed by shooting into a free-face, which limited the options to expedite the excavation process by creating vast amounts of muck inventory.

5 Integrated approach

The Big Bear push-back on the east wall of the Valley pit presented an overall degree of complexity without precedent at THVC. These challenges were positively met by adopting an integrated approach at the initial stage of the project. In the combined interest of time efficiency and risk management, the Big Bear mine plan was essentially developed in parallel to the dynamic geotechnical slope design process. The mine operations group was also involved in the design and planning effort as they would drive the execution stage of 10B Buttress construction. The acquisition of additional mining equipment in turn created additional demand on the mine maintenance group, not only in terms of number of equipment but also on the reliability and availability of the equipment given the schedule set forth for the project. The training of mine operations personnel on SOPs and education of mine personnel and contractors to the importance of a timely completion of the 10B Buttress were determining steps in obtaining buy-in to move the project forward as intended.

6 Conclusions

The current expansion plan for the Valley pit involved a pushback on the east wall of the Valley pit through a thick sequence of glacial sediments. Unit 10B is characterized by pre-sheared, varved glaciolacustrine clays
subject to excess pore pressures. A detailed geotechnical and hydrogeological investigation program was carried out to define the engineering geology of the east wall to support the design of the Big Bear slope. Limit equilibrium methods (2D and 3D) and distinct element deformation analysis modeling were used to design a stable slope configuration which relies on long-term operation of an active/passive depressurization and stabilization rock fill buttresses.

The Big Bear mine plan was developed to release the ore reserves contained below the 10B Buttress during Phase 8 mining while maintaining full production at the mills. Particular challenges involved the sequencing of mining operations to expose pre-existing wells or release ground to install depressurization measures, production of over 7 Mt of rock fill and placement in the stabilization buttress and the excavation/backfill of 42 slot cuts while minimizing exposure time of 10B clays. The construction of the 10B Buttress represents the most critical stage of the Big Bear pushback, which relies on an integrated approach involving all levels of the organization to constantly manage the risks to personnel, equipment and ore reserves. The construction of the 10B Buttress is currently ongoing following well-defined SOPs. Overall slope performance was positive at the time of writing this paper.

7  Acknowledgements

The authors would like to thank Teck Highland Valley Copper for allowing the publication of this paper. The sustained cooperation and assistance of THVC personnel is acknowledged with many thanks. Particular thanks are extended to Messrs. C. Dechert, F. Amon, P. Witt, R. Graden, G. Piwek, J. Sangha, L. Shwydiuk, M. Veillette, S. Tuohy, C. Diederichs, J. Clark, S. Alikhani, I. Dhaliwal, A. Baker, M. Costa, C. Young and J. York whose contributions and support throughout the study were greatly appreciated. Several Piteau Associates personnel were also instrumental to the design and implementation of the Big Bear slope, including A. Stewart, M. Scholz, M. Stewart, J. Burden, A. Pabani, M. Shalka, R. So and J. Mancer. We would like to also acknowledge the support and contribution of J. Scholte and B. Glencross from GAIA Contractors, R. Wilkins at ACA Monitoring Ltd. and Mr. S. Daly. Expressed appreciation is given to the geotechnical review board comprised of Messrs. P. Stacey of Stacey Mining Geotechnical Ltd., R. Smith of Smith Water Management Services Ltd., M. Davies of AMEC Earth & Environmental and S. Anderson of Teck Resources.

8  References