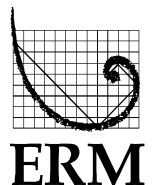


**BRUCEJACK GOLD MINE PROJECT**  
Application for an Environmental Assessment Certificate /  
Environmental Impact Statement

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## **Appendix 11-B**

Preliminary Assessment of Subsidence Potential for the  
Brucejack Project





**BGC ENGINEERING INC.**  
**AN APPLIED EARTH SCIENCES COMPANY**

234 St. Paul Street  
Kamloops, BC Canada V2C 6G4  
Telephone (250) 374-8600  
Fax (250) 374-8606

October 10, 2013  
Project No.: 1008-010  
Document: BJ-2013-11

Ian Chang, Vice President, Project Development  
Pretium Resources Inc.  
#1600 – 570 Granville Street  
Vancouver, B.C., V6C 3P1

Dear Mr. Chang,

**Re: Preliminary Assessment of Subsidence Potential for the Brucejack Project - FINAL**

## **1.0 INTRODUCTION**

BGC Engineering Inc. (BGC) is pleased to provide you with the following preliminary assessment regarding the potential for surface subsidence due to excavation of the proposed Brucejack Project mine workings.

This discussion is intended to support the Environmental Assessment (EA) phase of the project, currently being undertaken by Pretium and their environmental consultant Rescan.

A review of the site specific conditions and factors affecting the potential for subsidence at the Brucejack property indicates a very low probability that significant subsidence will occur.

## **2.0 BACKGROUND**

### **2.1. Definition of Subsidence**

Subsidence is a natural and man-made phenomena associated with a variety of processes including compaction of natural sediments, groundwater dewatering, wetting, melting of permafrost, liquefaction and crustal deformation, withdrawal of petroleum and geothermal fluids, and mining of coal, limestone, salt, and metallic ores. Most subsidence is either created or accelerated by human activity.

Mine subsidence can be defined as ground surface movements that occur due to the collapse of overlying or adjacent strata into mined out voids, which expresses itself in cracks, fissures, step fractures, pits or sinkholes, troughs, or sags.

Subsidence is an inevitable consequence of underground mining – it may be virtually undetectable, of significant magnitude but localized, or gradual, continuous and extensive over very large areas. Subsidence may occur immediately following mining, or be delayed for decades due to a variety of factors.

## 2.2. Subsidence Mechanisms and Controlling Factors

(Note: The following discussion is sourced primarily from SME, 1986; Marcus, 1997).

A number of geologic and mining parameters can affect the magnitude and extent of subsidence. These include the thickness of extracted materials; overlying mining areas; depth of mining; dip of mining zone; competence and nature of mined and surrounding rock masses; near surface geology; structural characteristics and geologic discontinuities; faults, fractures and lineaments; in-situ stresses; degree of extraction; surface topography; groundwater (including water elevation and fluctuation); method of mining; rate of advance; backfilling; and time.

These factors have been recognized and examined in detail in the literature. Included below is a brief discussion of some of those factors, with particular emphasis on those that are more typical of hard-rock mining-related subsidence.

- **Ore Thickness:** There is a direct relationship between the thickness of the extracted materials and the amount of surface subsidence that may result, making it an important factor in subsidence predictions. A greater ore thickness generally results in a greater amount of surface subsidence.
- **Multiple Ore Zones:** Where multiple mining horizons exist, subsidence which occurs in one area increases the likelihood of similar events in other areas, because the strata have been disturbed.
- **Ore Zone Depth:** A general consensus among industry experts is that subsidence is often *independent* of depth, refuting the previously held notion that surface subsidence can be prevented by leaving sufficient thicknesses of overburden. While this may prolong the time period before subsidence effects are observed at the surface, the possibility for subsidence is generally not changed. Bulking / swelling of material failing into mined out voids may impact the magnitude of subsidence, but will not prevent it entirely, regardless of depth.
- **Dip of Ore Zone:** Where the mining horizon is inclined, subsidence becomes skewed and mitigation measures such as pillars become less effective.
- **Competence of Mine Floors and Roofs / Stope Footwalls and Hanging walls:** The competence of mine excavation surfaces is critical in the initiation of subsidence events, since they propagate from these areas. Weak poor quality rock permits the fall of overlying strata, and may compact more easily, resulting in a greater likelihood and severity of subsidence. Conversely, **good quality rock around the periphery of an excavation limits the failure of overlying strata, resulting in a lower likelihood and severity subsidence.**
- **Nature of Overlying Rock and Overburden:** The strength of the overlying strata above the mining horizon is a factor in the timing and extent of subsidence.
- **Surface and Near-Surface Geology:** Surface and near-surface soils and unconsolidated materials tend to emphasize subsidence effects, because they behave in an inconsistent manner. They are an important factor relative to hydrologic

impacts of subsidence because they affect the exchange of surface water and groundwater.

- **Geologic Discontinuities: Faults, folds, and other inconsistencies in the overlying and surrounding strata may increase subsidence potential.** The disturbance of equilibrium forces by mining can trigger movement along a fault plane. Faults may also weaken the overlying strata and trigger subsidence in materials that may otherwise show desirable properties. Subsidence effects related to faulting may be localized about the fault structure, or may occur as increased subsidence magnitudes over a more regional area. Joints and fissures in the strata also affect subsidence but on a smaller scale.
- **Degree of Extraction:** The amount of pillar support is directly related to the timing and extent of subsidence. Lower extraction ratios result in greater thicknesses of pillars, which tends to delay and decrease subsidence. As the amount of pillar support is decreased, either by mine design or as a result of pillar extraction, subsidence occurs more rapidly and extensively. Complete removal of pillars without backfill is almost always followed by subsidence, with surface manifestations being a function of upward propagation to the surface.
- **Surface Topography:** Sloping ground like hillsides tends to emphasize the surface manifestation of subsidence, while it is less accentuated on flatter ground and in valleys.
- **Groundwater:** Drainage gradients may be altered by disturbance of the strata around mine areas. Rocks may become weakened by saturation, and erosion patterns could change. Where surface water is present, it may migrate more easily to fractures and fissures in the strata and into the mine area and may induce subsidence. Subsidence may also occur as a result of dewatering to facilitate underground mining in some rock types.
- **Mining Method:** The extent and magnitude of subsidence is dependent on the mining method(s) used to extract the ore. **The inclusion of appropriately designed crown, sill, and rib pillars into the geometry may significantly limit the effective extent and magnitude of subsidence.**
- **Backfilling: Partial or complete mine backfilling reduces subsidence and is dependent upon the type and extent of backfilling. However, it is important to note that backfilling does not necessarily eliminate subsidence entirely.**
- **Time:** The amount of subsidence has been observed as a direct function of time. Surface effects are delayed in room-and-pillar mining for some time, unless the pillars are removed. In block caving mines, surface effects are often noticeable soon after the initiation of caving.

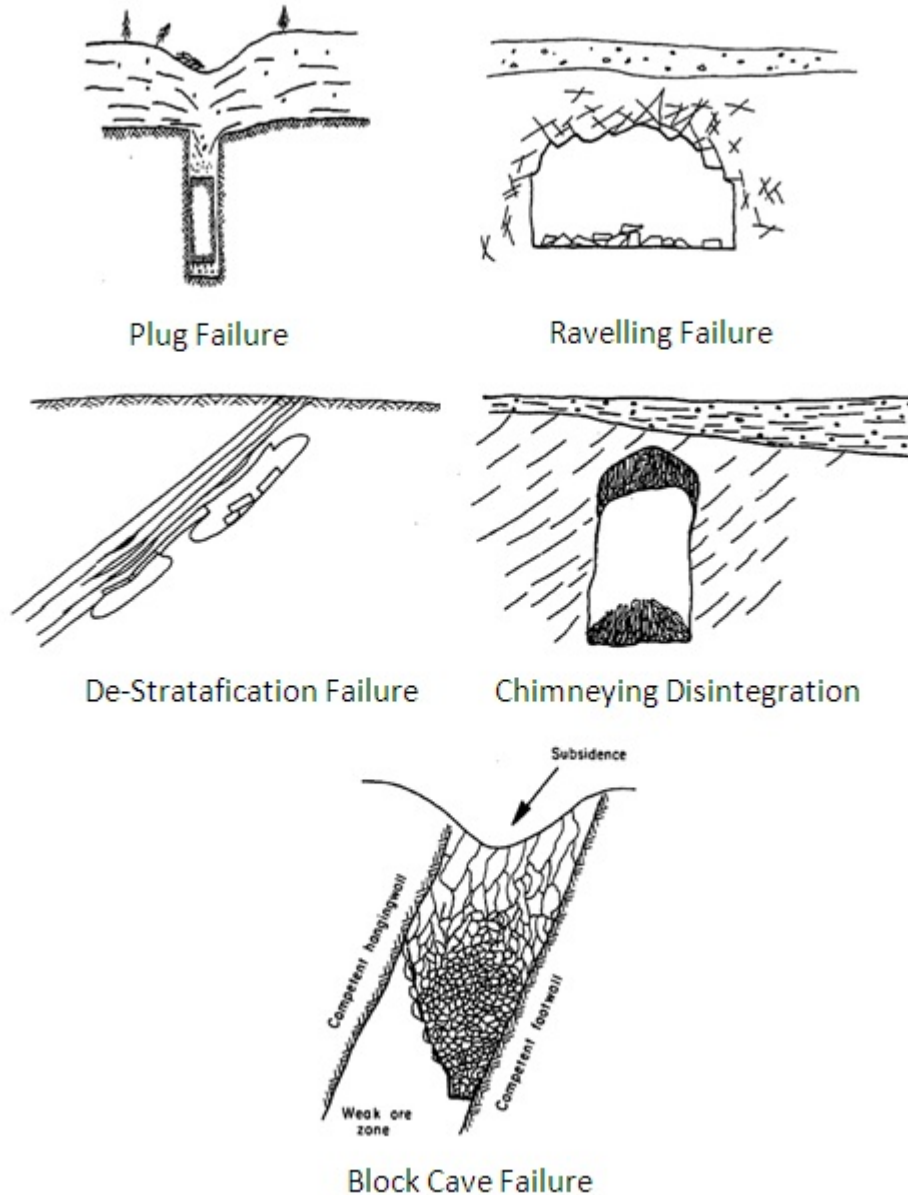
As noted above, the geologic configuration of an ore deposit directly influences the nature and magnitude of potential surface subsidence. Shallow mining operations within flat layers of relatively weak sedimentary or evaporite deposits (e.g. coal, salt, potash) typically represent the most unfavorable configuration in terms of subsidence magnitudes and zone of

influence. In contrast, vein-type deposits typically have relatively limited ore thicknesses, are relatively steeply dipping, and typically have a strong host rock mass. **The principal risks for the safety of people and property located at surface above vein-type deposits is often concentrated above crown pillars and represents a relatively limited zone of influence at surface.**

The potential for mine induced subsidence is strongly related to the mining method and resultant mine geometry. The selection of the mining method mainly depends on the configuration of the deposit (e.g. size, depth, extent, orientation). Stope mining techniques like those proposed for the Brucejack Project, combined with the development of adits, drifts, and shafts, have historically been the most prolific form of hard-rock metals mining and has been done at both large and small scales. Stope mining is applicable to most vein-type ore bodies typical of base and precious metals deposits. The subsidence created by stope mining is usually the result of unintended cave-ins, inadequate support, pillar robbing, mining too close to the surface, and eventual collapse of the workings over time as the inevitable consolidation of the strata takes place. **Most often subsidence occurring as a result of stope mining techniques is limited to the hanging wall side of underlying stopes. In many cases, the degree of surface subsidence that occurs from stope mining is both isolated and relatively minor.** However, in some cases, particularly where extensive mining by this technique has been employed (e.g. Butte Mine, Montana; Hollinger Mine, Ontario), the resulting subsidence can result in significant surface impacts.

Subsidence above underground mines can be categorized into two distinct types: continuous and discontinuous. Continuous subsidence is characterized by a usually slow, smooth, and flexible readjustment of the ground surface that has no abrupt changes. This well-known and generally well understood phenomenon induces topographical depressions without major failures, leading to a dish-shaped feature on surface. In most cases the maximum amplitude in the centre of the depression is on a decimetric to metric scale. Continuous subsidence typically occurs in mining operations within flat layers of relatively weak sedimentary or evaporite deposits (e.g. coal, salt, potash).

Discontinuous subsidence is characterized by the gradual to sudden appearance of a generally irregularly-shaped depression or collapse crater at surface, resulting in localized large surface displacements, on the order of metres to tens of metres. Subsidence resulting from failures or caving of stopes is commonly discontinuous. As shown in Figure 2-1, failure modes that result in discontinuous subsidence include plug failures, progressive block raveling due to lack of adequate confinement / in-situ stress, de-stratification, chimneying disintegration, and block caving.



**Figure 2-1. Common Failure Mechanisms of Shallow Stopes in Hard Rock Mines (after Bétournay, 1995)**

The deposit and rock mass properties also have a significant influence on subsidence potential. Displacements within the rock mass at the periphery of underground workings can be discontinuous, sudden, and irregular. **A strong rock mass above vein-type deposit mine workings will tend to prevent any underground instabilities progressing towards the surface if the mining depth is sufficient.**

Active mine stability is generally studied for short-term projects. In contrast, subsidence can occur over very long time scales (i.e. decades to centuries). Time is therefore a fundamental factor in subsidence development. Time related factors effecting subsidence include the long term reduction in rock strength due to micro-fracturing under continuous loading conditions.

Some rock types are very sensitive to this effect (salt, gypsum, clay) while some exhibit less sensitivity (granite, quartzite). Strength reductions typically range from 20% to 50%, based on laboratory testing. The ageing of a rock mass also can affect its long term strength characteristics. Ageing is a chemical process that modifies the rock mass properties due to imposed variations in environmental conditions. In particular, the introduction of changes to the water and oxygen can have a significant impact of the quality and competency of a rock mass over time.

### **2.3. Subsidence Monitoring**

Subsidence monitoring should be carried out over the life of the mine, including post-closure. Pre-mining high-resolution topographic surveys are useful in establishing base case conditions to be evaluated against as mining progresses.

Subsidence monitoring measurements are based upon a survey of the vertical and horizontal displacements that take place at known reference points on the ground surface. A variety of specific methods may be used depending on the objectives, site, density of monitoring points, duration and cost. Automatic data acquisition systems have been utilized and are gaining acceptance. The actual range of subsidence varies between a few feet to as much as several hundred feet vertically; horizontal displacement may occur as well. It is important in monitoring subsidence that full coordinates (x, y, z) are measured in order to track the progress of ground movements.

### **2.4. Subsidence Mitigation**

Post-mining stabilization techniques to mitigate subsidence include backfilling, grouting, excavation and fill placement, and blasting. The extent to which post-mining stabilization techniques can be relied on to mitigate subsidence damage is uncertain, as they require assessment of long-term stability. Current analytical and empirical methods to predict the very long-term stability characteristics of mining districts need significant improvement. This is particularly the case for vein / stope mining methods.

## **3.0 GEOTECHNICAL CONDITIONS AT THE BRUCEJACK PROPERTY**

This section presents a summary of the geotechnical conditions and geologic structure within the footprint of the proposed Brucejack Project excavations, and summarizes the geotechnical model used to assess the potential for surface subsidence. Work completed for the current study focuses on the Brucejack Project's West Zone (WZ) and Valley of Kings (VOK) mineralized zones. The discussion below is sourced largely from BGC (2013).

### **3.1. Overburden**

The overburden in the area of Brucejack Project consists of a veneer of well-graded glacial till over bedrock. Grain size varies from sand to gravel, with some silt and clay, and variable quantities of cobbles and boulders. Clasts are subrounded to rounded, and color varies from

orangey brown to grey. Overburden thickness varies but is generally less than 5 m and often less than 1 m. A thin (often less than 0.5 m, but occasionally up to 3.0 m) layer of sandy organics overlies the overburden.

### 3.2. Rock Mass Conditions

For the purposes of this study, the rock mass has been categorized as “fresh rock” or “weathered rock”. The near-surface weathered rock mass is distinguished from the underlying fresh rock by an increased fracture frequency and a slightly higher degree of alteration characterized by iron oxide staining on joint surfaces (Photograph 1). The interface depth between weathered and fresh rock is estimated to range between 10 and 50 m, based on core logging and underground mapping of existing workings.



**Photograph 1. Typical Weathered Rock Zone (Outlined in Red)**

The fresh rock at Brucejack has an average Geological Strength Index (GSI) rating that typically ranges from 70 to 85, and average unconfined compressive strength (UCS) of approximately 100 MPa. The fresh rock is classified using standard terminology as 'Good' to 'Very Good' and 'Strong to Very Strong'. The weathered rock at Brucejack has an average GSI ranging from 60 to 65, and an average UCS of 40 to 50 MPa. The weathered rock is classified as 'Good' and 'Medium Strong'. Additional details on the geotechnical properties for Brucejack rock mass can be found in BGC (2013).



### **3.3. Geologic Structure**

#### **3.3.1. Major Faults and Regional Structure**

The Brucejack Project area includes a number of major faults and corresponding surface lineaments. These are summarized in BGC (2013), and on Table 2-1.

The major regional lineaments near the Brucejack Project are the Brucejack Fault lineament, the Upper Treaty Glacier lineament and the Treaty Creek lineament.

The Brucejack Fault Zone truncates several site-scale faults at the western extent of the Brucejack Project, and thus has been interpreted as post-dating site-scale deformation events. Structural orientations parallel to the inferred Brucejack Fault lineament were commonly observed in downhole structural measurements across the property. All interpreted structural domains include sets oriented along the Brucejack Fault Zone with dips ranging from 56° to vertical.

The Upper Treaty Glacier lineament is a prominent high angle topographic lineament north of the Brucejack Project area. Although not associated with a specific fault set, similarities in regional topography and drainages make it likely that parallel structures will be prevalent throughout the study area. The Upper Treaty Glacier lineament appears in drill hole and underground mapping data in the northern regions of the property, and appears locally as a moderately strong shear and joint set.

The Treaty Creek lineament strikes east-southeast and extends north to the Iskut River Fault. The lineament marks the contact between the Hazleton Group and Bowser Lake Group rocks to the north of the property, and is a common orientation for valleys and drainages in the region. It is expected that lineament-parallel steep structures will be prevalent throughout the study area.

The level of knowledge with respect to site-scale faulting is greater for the WZ than the VOK. The VOK mineralized zone is bound to the west by the Brucejack Fault Zone, is surrounded to the north and south by northeasterly-trending fault traces, and is crossed by a southeasterly-plunging syncline. Oriented core measurements from a geotechnical drill hole drilled less than 100 m away from, and parallel to, the Brucejack Fault Zone showed significantly higher variability than other geotechnical drill holes in the VOK, indicating a potential zone of fault-related structural disturbance in the westerly extents of the mineralization.

**Table 2-1. Major Geologic Structure in the Brucejack Project Area (BGC, 2013)**

Scale	Structure	Strike (°)	Dip (°)	Orientation Source
Regional	Treaty Creek Lineament	291 or 111	-	ERSi, 2010
	Upper Treaty Glacier Lineament	310 or 130	-	ERSi, 2010
	Brucejack Lineament Fault	355	-	ERSi, 2010
		176	60-90	Newhawk, 1990
356		60	Margolis, 1993	
Site	Lancaster Fault	330	74	BGC Mapping, 2012
		023	80-85	Newhawk, 1990
	Sutcliffe Fault	036	86	Newhawk, 1990
		038	73	BGC Mapping, 2012
	Jaz Fault	204	40	BGC Mapping, 2012
		191	-	Newhawk, 1990
	Zorzi Fault	212	74	BGC Mapping, 2012
		200	-	Newhawk, 1990
	Babics Fault	141	83	BGC Mapping, 2012
		125	-	Newhawk, 1990
		122	75	Roach, 1991
	Ryne Fault	246	71	BGC Mapping, 2012
		213	-	Newhawk, 1990
	Maddux Fault	059	69	BGC Mapping, 2012 - 1350 Level Ore Drive
		048	73	BGC Mapping, 2012 - Ramp-Exploration Drift Intersection
		020	72	Roach, 1991
		020	-	Newhawk, 1990
	Not My Fault	312	-	Newhawk, 1990
	Kovacic Fault	124	-	Newhawk, 1990
	SW Fault	151	-	Newhawk, 1990
Bruce Fault	291	60-70	Newhawk, 1990, SSR NI 43-101	
Wobbegone Fault	237	-	Newhawk, 1990	
Grace Shear Zone	321	-	Newhawk, 1990	

### 3.3.2. Structural Domains and Design Discontinuity Sets

Structural domains for the Brucejack Project have been previously defined in BGC (2013). In general, the geologic structure across the property is highly variable in both dip and dip direction. Dominant fabrics include moderately to steeply-dipping southeast-striking structures, moderately-dipping southwest to northwest-striking structures, moderately to

steeply-dipping easterly-striking shear sets, and vertical north to north-northwest striking structures. Shallowly dipping ( $<20^\circ$ ) sets are less common but have been identified due to their potential for adverse failure geometries in the backs of underground excavations. Vein-parallel structures, including faults, should be assumed to be present in the walls of the stopes.

#### **4.0 MINING METHOD AND PROPOSED CROWN PILLAR**

The Brucejack Project Feasibility Study mine plan is shown in plan view in Figure 4-1 and in isometric view in Figure 4-2. The total width of the mining footprint will range from 650 m (east to west) to 1125 m (north to south). This footprint area includes both the Valley of Kings and West Zone proposed underground workings, and the main access decline between them. Topography varies considerably in the project area, but the estimated maximum depth of mining is approximately 600 m below ground surface. Dewatering is currently proposed to occur through a sump and pump system as mining proceeds (i.e. no dewatering wells are planned).

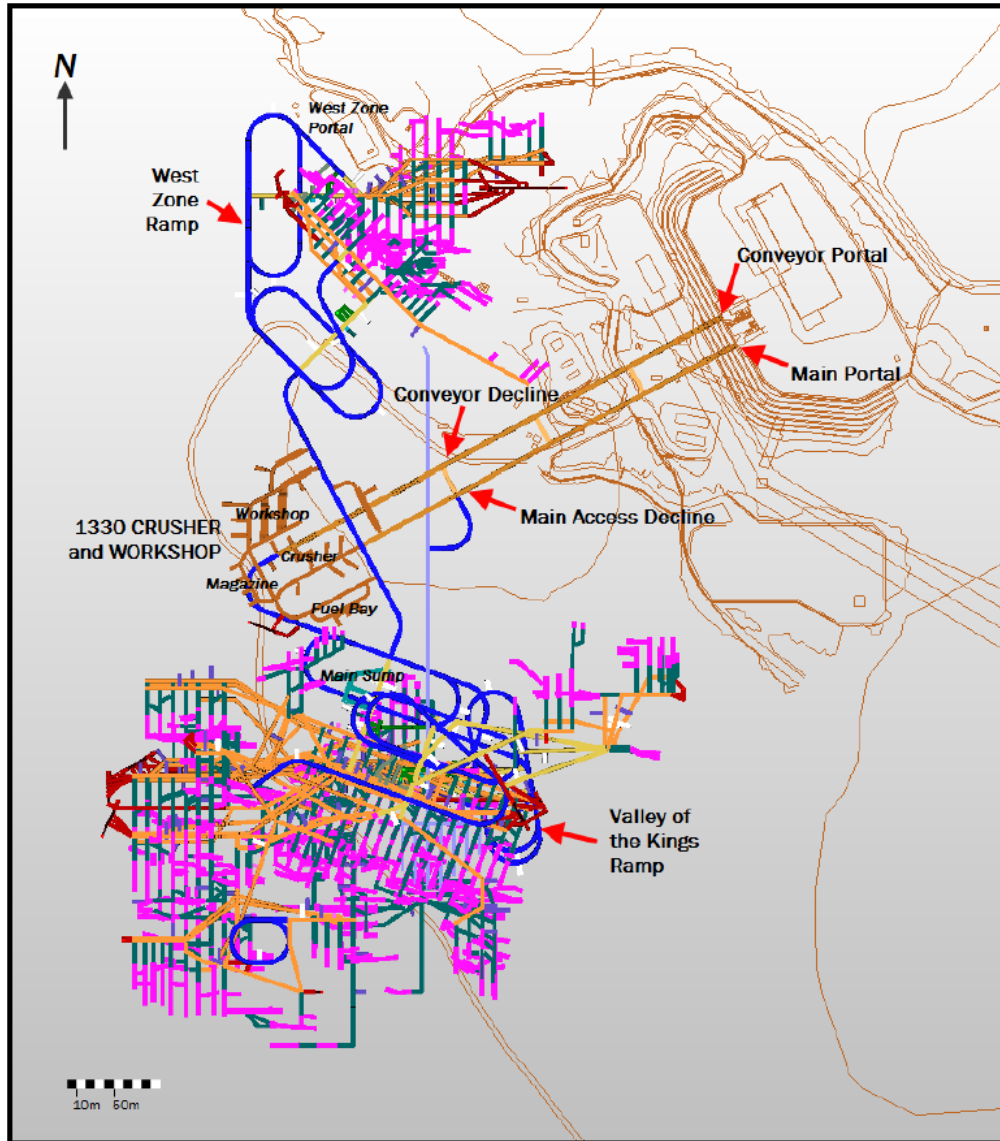
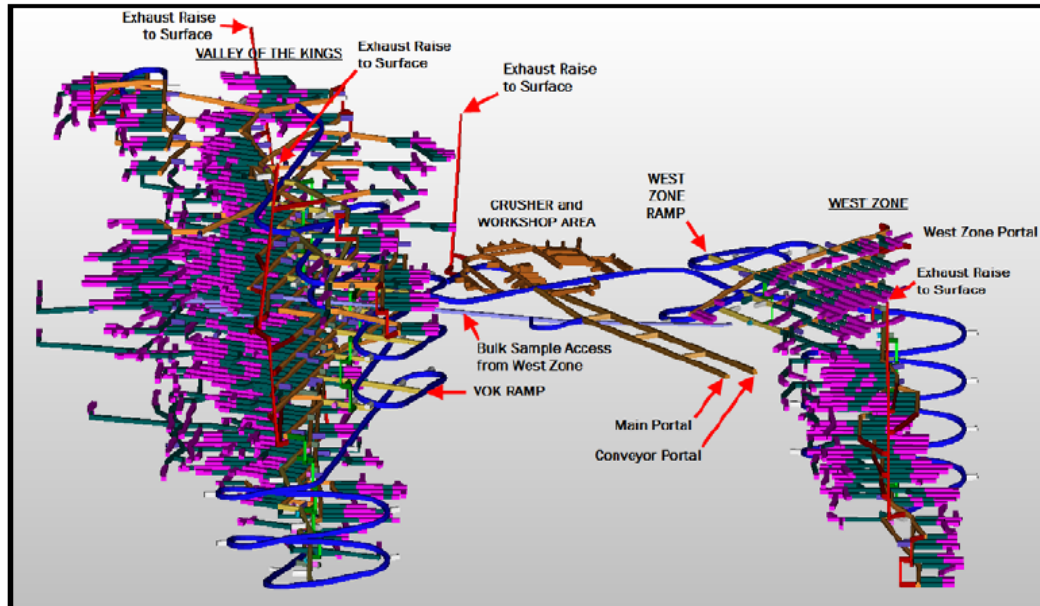
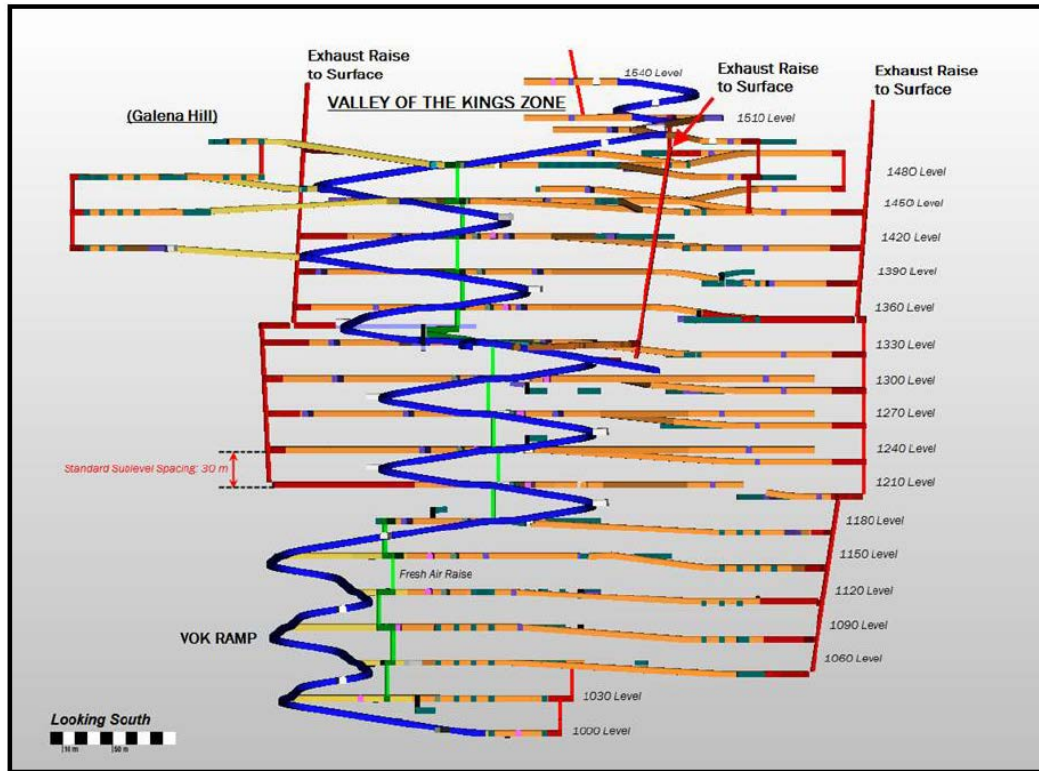


Figure 4-1. Mine Development and Infrastructure, Plan View (Tetra Tech, 2013)



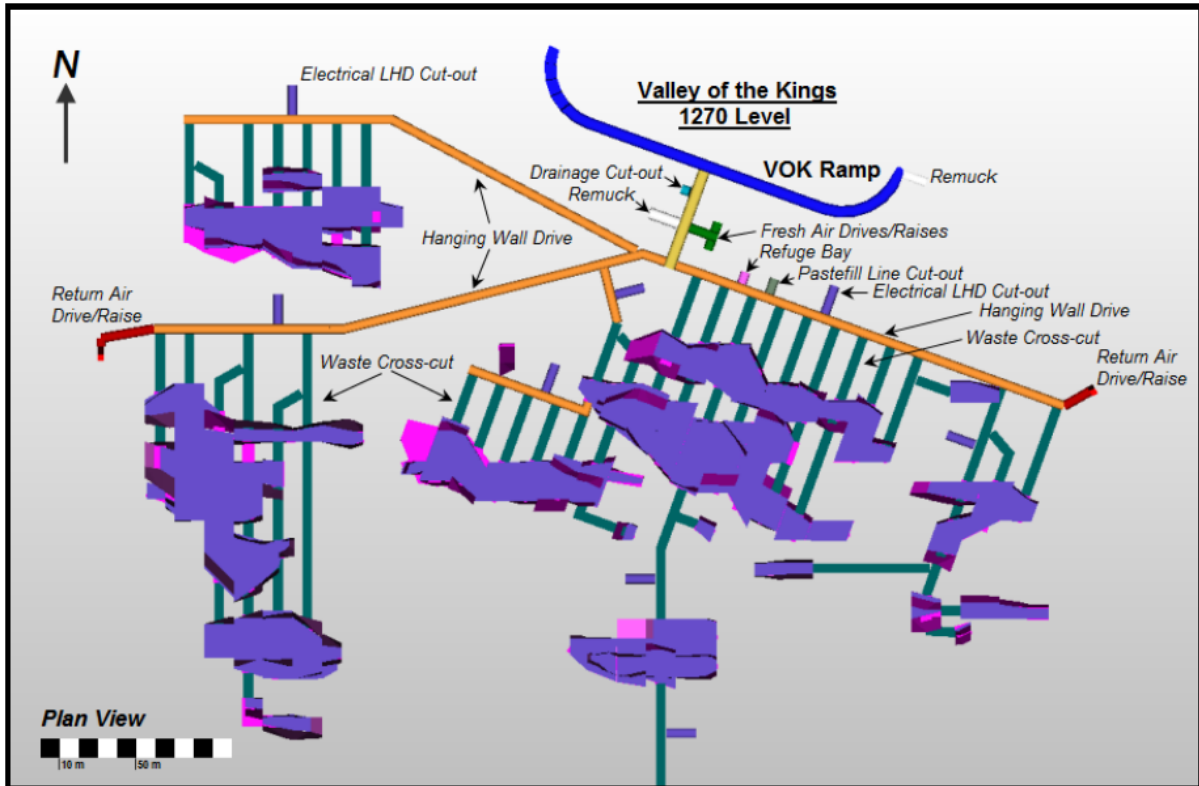
**Figure 4-2. Mine Development and Infrastructure, Isometric View (Tetra Tech, 2013)**

The proposed underground mine design supports the extraction of 2,700 t/d of ore through a combination of transverse 'Long Hole Open Stopping' (LHOS) and longitudinal LHOS. Paste backfilling of stopes is integral to the mine plan to maximize orebody recovery and mining productivity. Sublevels will be accessed from the main ramps on a 30 m vertical interval that is defined by the planned stoping heights (Figure 4-3).



**Figure 4-3. Mine Development and Infrastructure, VOK Long Section (Tetra Tech, 2013)**

Level development will follow the general strike of the various lenses (Figure 4-4), providing access to the mineralized zones in a manner that promotes transverse mining wherever possible. Level development will generally be in the hanging wall, with hanging wall drives typically including excavations for sumps, refuges, transformers, remucks, paste fill line, and raise accesses. Stope access crosscuts will be on 15 m spacings, with the exception of those levels where sill extraction or near-surface weathered ore will be recovered in smaller units that are designed on 10 m spacings.



**Figure 4-4. Mine Development and Infrastructure, VOK 1270 Level (Tetra Tech, 2013)**

Transverse LHOS is a non-entry method, with remote mucking of blasted ore required once the drawpoint brow is open to the extent where the operator may be exposed to uncontrolled sloughing from the stope cavity. Once emptied of ore, the stope will be remotely surveyed with cavity monitoring equipment. A barricade will be constructed in the drawpoint and the stope backfilled to just below the floor elevation of the top level. Crushed aggregate or ROM waste may be spread over the fill surface to reduce backfill dilution and increase trafficability of mucking equipment for the next lift of the stope.

The primary means of backfilling at the property will be paste fill, which will be generated from unclassified mill tailings mixed with adequate cementitious binder to meet the strength requirements. Regular strength paste fill is commonly required where there will be re-exposure of vertical stope walls. Stopes that will not be re-exposed by adjacent mining are proposed to be backfilled with unconsolidated waste and/or by paste fill with sufficient binder to remove any risk of future liquefaction (low-strength paste fill). High-strength paste fill will be required in the lower portion of all primary and secondary stopes that will be undercut by sill extraction from below.

The minimum recommended crown pillar thickness for the Brucejack mine is 15 m, determined using a number of industry standard geotechnical methods and techniques (BGC, 2013). The maximum recommended transverse stope span is 10 m for all stopes immediately below the crown pillar. Transverse stopes immediately below the crown must be



tight-filled as much as practicable to reduce the potential for crown pillar collapse. The crown pillars are also to be supported with 5.0 m long single strand bulbed cable bolts on 2.5 m spacing, to assist with enhancing stability conditions and preventing the onset of subsidence mechanisms.

## **5.0 POTENTIAL FOR SURFACE SUBSIDENCE AT THE BRUCEJACK PROJECT**

A preliminary review of the site specific conditions and factors affecting the potential for subsidence at the Brucejack Project indicates a very low probability that significant subsidence will occur. This conclusion is based primarily on the following facts:

- Because the overburden is thin (< 5 m) and generally has a low clay content, dewatering of the project area is not anticipated to cause consolidation and subsidence in the overburden.
- The rock mass at Brucejack is classified as Good to Very Good and Medium Strong to Strong, using industry standard classification systems. Rock of this quality around the periphery of an excavation limits the failure of overlying strata, resulting in a lower likelihood and severity of subsidence.
- The Brucejack deposit is a steeply-dipping vein-type deposit. The principal risks for the safety of people and property located at surface above vein-type deposits is often concentrated above crown pillars and represents a relatively limited zone of influence at surface.
- The proposed mine footprint, while substantial, is not on the scale of other vein-type mining districts where significant subsidence has typically been recorded (e.g. tens to hundreds of hectares vs. thousands to tens of thousands of hectares).
- The proposed mining method of long hole open stoping with complete paste backfilling significantly reduces post-mining void volumes. Most often subsidence occurring as a result of stope mining techniques is limited to the hanging wall side of underlying stopes. In many cases, the degree of surface subsidence that occurs from stope mining is both isolated and relatively minor. Complete mine backfilling further reduces subsidence potential, often to virtually undetectable levels.
- To improve near-surface stability conditions at the Brucejack Project, a minimum recommended crown pillar thickness of 15 m has been determined using a number of industry standard geotechnical methods and techniques. The crown pillars are also to be supported with cable bolts to assist with enhancing stability conditions and preventing the onset of subsidence mechanisms.

Notwithstanding the above, the presence of a number of significant regional geologic structures in the Brucejack Project area may negatively influence rock mass stability and increase the potential for mining induced subsidence. Continuous subsidence monitoring and



further study of these structures will improve the level of understanding with respect to this potential.

## **6.0 CLOSURE**

BGC Engineering Inc. (BGC) prepared this document for the account of Pretium Resources Inc. 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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We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

**BGC ENGINEERING INC.**  
**per:**

Catherine Schmid, M.Sc, P.Eng.  
Senior Geotechnical Engineer

Reviewed by:

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

Michael Porter, M.Eng., P.Eng., LEG  
Senior Geological Engineer

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