

# **Curraghinalt Project County Tyrone**

Prepared for Dalradian Gold Limited

**Environmental Statement - Volume 3**

**C21 Subsidence**

November 2017

**DALRADIAN**  
**GOLD**

## Subsidence

---

<b>To:</b>	John Merry, SRK Consulting (UK) Inc. Jane Joughin, SRK Consulting (UK) Inc.	<b>Client:</b>	Dalradian Resources Inc.
<b>From:</b>	Bruce Murphy Choong E. Lee	<b>Project No:</b>	3CD016.000
<b>Cc:</b>		<b>Date:</b>	October 20, 2017
<b>Subject:</b>	Review of Subsidence - Dalradian's Curraghinalt Project		

---

### 1 Introduction

This section provides a review of subsidence as a result of proposed underground mining at Dalradian's Curraghinalt Project. Based on the mining and backfill method to be employed, and empirical and 3-D numerical modelling assessments of the mining plan down to 400m (April 2016 plan), SRK concludes that there will be limited, if any, surface subsidence above the evaluated mine extraction area. Micro seismic events induced by mining could be expected in the deeper sections of the mine. The magnitude of these events is typically too small to be felt on surface.

### 2 Background

SRK has carried out a geotechnical site investigation, and a laboratory testing program to characterize the geotechnical conditions, and provide analysis of the data for use in underground mine and infrastructure design. Rock core from 20 (15 surface and 5 underground) boreholes were geotechnically logged in detail, and 5 of these were surveyed in places using optical and acoustic televiewers for assessment of the rock mass. Structural mapping of existing underground workings was also conducted to verify rock mass conditions and assess excavation performance. To facilitate the geotechnical study, a 3-D structural geology model was developed using the available orientation data.

As part of this geotechnical study, SRK reviewed the stability of the region of rock left between the upper limits of the proposed mining openings and lower limits of the overburden soil known as the crown pillar.

### 3 Geological Description

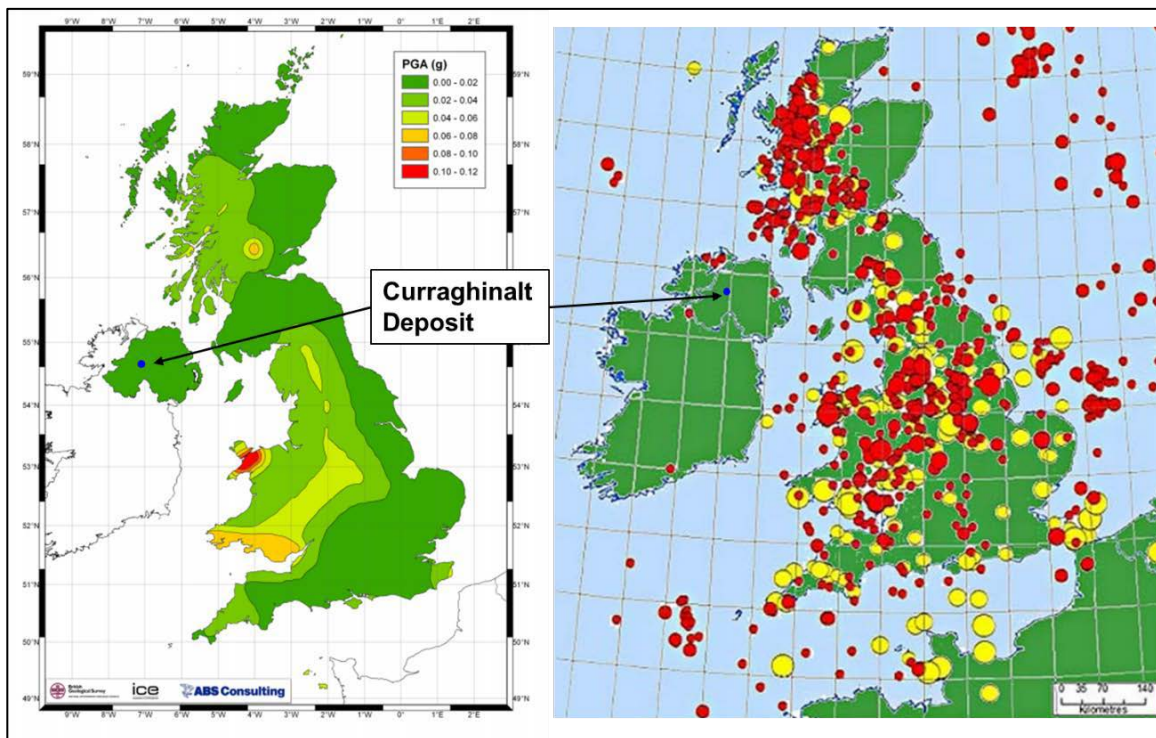
The geological description is summarized from sources including Tully Technical Review (2005), the Micon Mineral Resources Estimate (2012) and the 2016 SRK NI 43-101 resource estimate.

Dalradian's Curraghinalt deposit is hosted in the Mullaghcarn Formation of the Dalradian Supergroup in Northern Ireland. The Dalradian Supergroup was pushed on top of the Ordovician aged Tyrone

Volcanic Group by the north-east to south-west striking Omagh Thrust Fault. The Curraghinalt deposit is located 3 km north of the thrust fault; the formation was related to the closing of the Laprus Ocean in the Ordovician.

The Mullaghcarn formation is one of the three formations present in the Dalradian Supergroup; it is composed of pelite, semi-pelite, and psammite that are striking north-east to south-west with a moderate dip to the north-west. The complexity of the geology made it impossible to develop a lithological model based on the known lithological contacts. The topography above the proposed mining area is rolling hills and broad valleys that gently dips to the north. The overburden material consists of glacial deposits and peat with a typical thickness of 3 – 5 m.

SLR Consulting has conducted a review of the historical earthquake and recent instrumental data (by British Geological Survey and Dublin Institute for Advanced Studies): see Section 2.3 of their report: EIA Baseline Data Collection: Soils and Geology. This concludes that Northern Ireland is virtually aseismic and that there have been no earthquake events recorded in the vicinity of the proposed development at Curraghinalt, or along any of the main fault structures in the vicinity of the site. In addition, the project is located in a low seismicity region as indicated by a low peak ground acceleration (PGA) value range of 0.00 g to 0.02 g. For comparison, a PGA value in more earthquake prone area such as Victoria, BC, Canada is 0.61 g based on return period of 2,475 years (National Building Code of Canada, 2010). In Northern Ontario regions where Scaled Span Crown Pillar Design Method (Carter et al., 2008) was developed, the PGA value varies from 0.05 g and 0.06 g. Figure 3.1 shows Eurocode 8 PGA hazard map for 2,500 year return period and British Geological Survey's recorded earthquake activities since 1832.



**Figure 3.1: (Left) Eurocode 8 PGA hazard map for 2,500 year return period (Musson and Sargeant, 2007). (Right) Historical seismicity of the UK (yellow) from 1832 to 1970 for earthquakes of magnitude above 3.0 and instrumental seismicity (red) 1970 to present for earthquakes with  $ML > 2.0$  (British Geological Survey website. [www.bgs.ac.uk](http://www.bgs.ac.uk). 2016).**

## 4 Proposed Mining Context

### 4.1 Orebody Geometry

The Curraghinalt deposit comprises orogenic structurally controlled mesothermal gold bearing quartz and quartz-sulphide veins hosted in the Dalradian clastic sedimentary rocks. The gold bearing veins cross-cut the Dalradian sediments with a general strike of 090-135° and 55-75° dip to the north. The sixteen veins forming the deposit and their thicknesses are listed in Table 4.1, and shown in Figure 4.1.

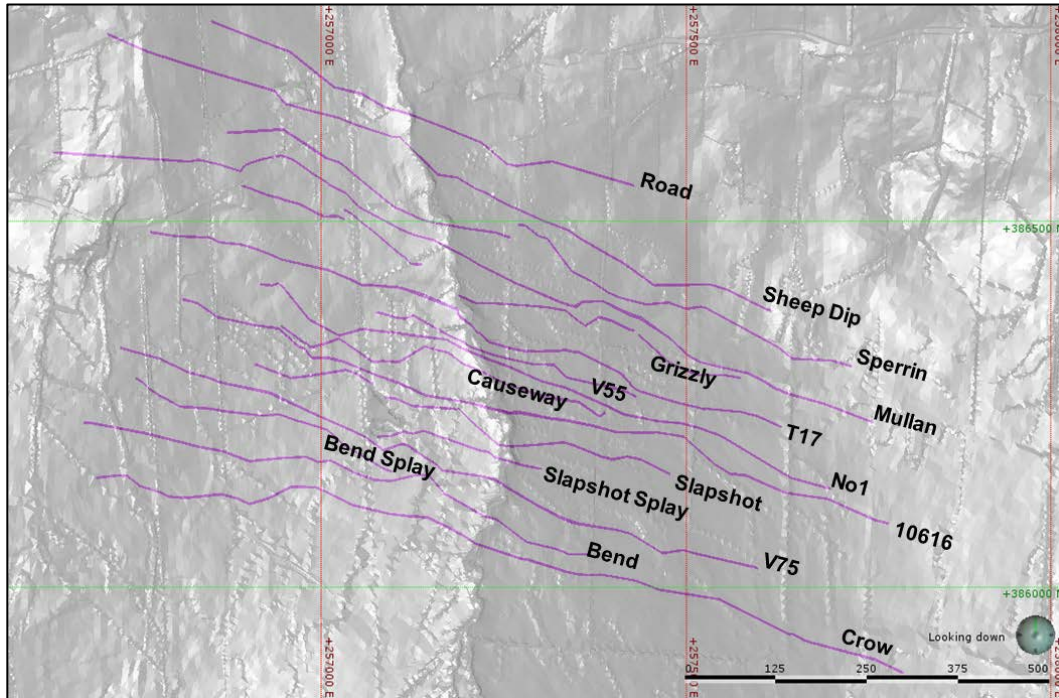


Figure 4.1: Plan view of Curraghinalt deposit.

Table 4.1: Vein Thickness

Vein	Thickness (m)	
	Average	Maximum
No1	0.82	4.12
10616	0.79	3.45
V75	0.74	2.25
Bend	0.71	2.44
Crow	0.90	3.17
T17	0.76	3.62
Mullan	0.78	3.91
Sheep Dip	0.59	2.17
Road	0.64	1.69
Slapshot	0.61	2.13
V55	0.63	2.40
Sperrin	0.48	2.50
Causeway	0.69	3.12
Grizzly	0.56	1.64
Slapshot Splay	0.47	1.27
Bend	0.55	2.11
<b>Total Averages</b>	<b>0.73</b>	<b>4.12</b>

## 4.2 Rock Mass Conditions

The three major lithological units in the Curraghinalt deposit are psammite, semi-pelite, and pelite. Psammite is the most competent unit, with unconfined compressive strength (UCS) of ~100 MPa. Semi-pelite has intermediate UCS of ~45 MPa. Pelite is the weakest unit with UCS of 10 to 20 MPa. The rock mass forming the crown pillar of Curraghinalt deposit is consisted of moderately to highly fractured semi-pelite and pelite. The corresponding geotechnical domains are Yellow Domain (upper limit) and Pink Domain (lower limit) listed in Table 4.2.

The main foliation that dips moderately to the northwest (45°/325°) and an orthogonal sub-vertical joint set (85°/055°) are the two-dominant discontinuity sets that exists throughout the deposit in all lithology units.

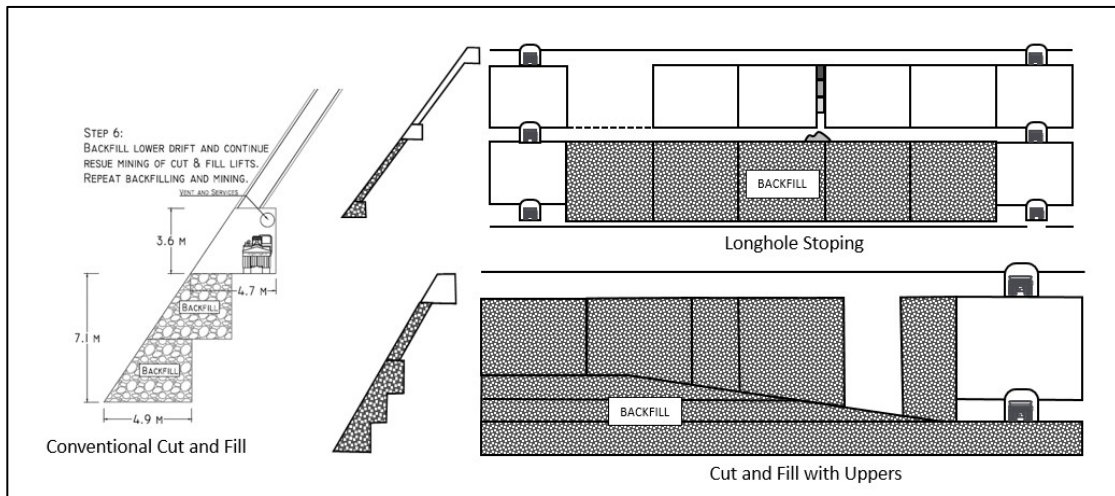
**Table 4.2: Geotechnical Parameters by Domains**

Domain	Intact Rock Strength (MPa)	Q'		RMR <sub>90</sub>		Percentage of Total Mined Vein Area
		Low	High	Low	High	
Green Domain	100	3.33	8.33	55	65	38%
Yellow Domain	45	2.50	3.33	50	55	23%
Pink Domain: Weak Domain (Semi-Pelite)	45	1.67	2.50	45	50	11%
Pink Domain: Weak Domain (Pelite)	20	2.50	3.33	45	50	
Red Domain: Very Weak Domain	20	0.83	1.67	40	45	27%

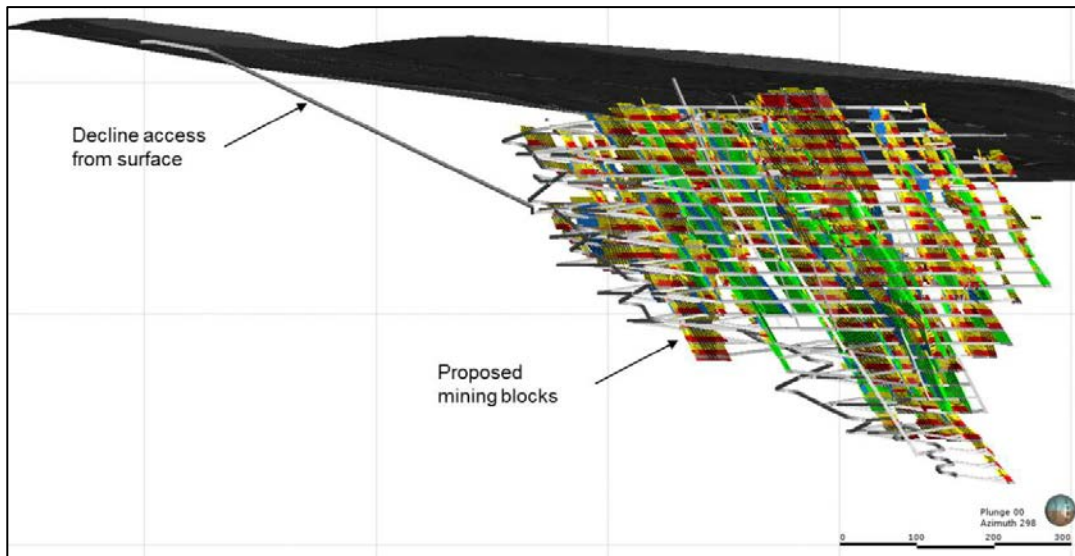
## 4.3 Mining Methods

The mining method for Curraghinalt Project is selected based on the quality of the rock mass that forms the hanging wall and footwall of the mineralized vein. Variations of longhole stoping will be utilized in all geotechnical domains with the exception of the Red Domain, where cut-and-fill mining is required to limit the excavation span to maintain stability.

The proposed mining to 50 vertical metres from surface consists of development drives (cross cuts, strike drives), underground infrastructure (backfill chamber), and mining blocks (longhole stoping, cut-and-fill, cut-and-fill and uppers (Figure 4.2 and Figure 4.3). Note that underground infrastructure excavations are considered permanent openings, and therefore will be supported extensively.



**Figure 4.2: Mining methods planned to be employed at Curraghinalt: conventional cut and fill (left), longhole open stoping (top right) and cut and fill with uppers (bottom right). (JDS, 2016).**



**Figure 4.3: Isometric view (looking northwest) of mine design.**

#### 4.4 Crown Pillar Design Approach

In order to assess crown pillar stability, the Scaled Span Crown Pillar design approach (Carter, 1992) was used. This empirical method is widely used in the mining industry and has been regularly updated by the original author and others. This method divides the assessment into a geometric assessment of the crown pillar, the Scaled Crown Span, and a rock mass quality derived component, the Critical Span. Both relationships are defined by the expressions presented below.

Scaled Crown Span:

$$C_S = S \times \sqrt{\frac{\gamma}{t \times (1 + S_R) \cdot (1 - 0.4 \times \cos \theta)}}$$

Where:

- $C_s$  Scaled Crown Span (m)
- Scrown pillar span (m)
- $t$  crown pillar thickness (m)
- $\gamma$  specific gravity of the rock mass
- $S_R$  span ratio = crown pillar span/crown pillar strike length
- $\theta$  dip of the orebody or foliation (degrees)

Critical Span:

$$S_c = 3.3 \times Q^{0.43} \times \sinh^{0.0016} Q$$

Where:

- $S_c$  Critical Span (m)
- $Q$  NGI Q rating value

In cases where the Scaled Crown Span is less than the Critical Span, then the crown pillar would be considered as stable; where this relationship is reversed the pillar would be considered unstable. This relationship defines an initial crown pillar stability factor; however, the rock mass quality significantly influences the ability of this relationship and there will be on-going review and monitoring at the operational stage of the mine to hold true over the long term. The 2008 update of the design approach provides guidelines for levels of risk deemed acceptable for a particular situation.

Rock mass characteristics of the Red Domain were used, and 3 – 5 m were deducted from measured crown thickness to account for overburden soil. Figure 4.4 shows that crown pillars are classified as Class D if no fill is placed within the excavations and the excavations are not supported. The guideline describes Class D as a semi-temporary crown with 5 to 10 year lifespan. All of these areas will have ground support installed for the mine life providing increased stability.

All production excavations will be backfilled tightly without delay to prevent unravelling of the rock mass and any development of instability over the longer term. All crown pillar area excavations will be promptly filled and the upper 15 m with cemented backfill to ensure it stays in place. This is expected to move the crown pillars into the Class F and G categories as the tight fill will prevent the unravelling of the mined excavations, which would require either incidental superficial monitoring or no monitoring at all following mine closure (Table 4.3) depending on the findings of the ongoing review and monitoring.

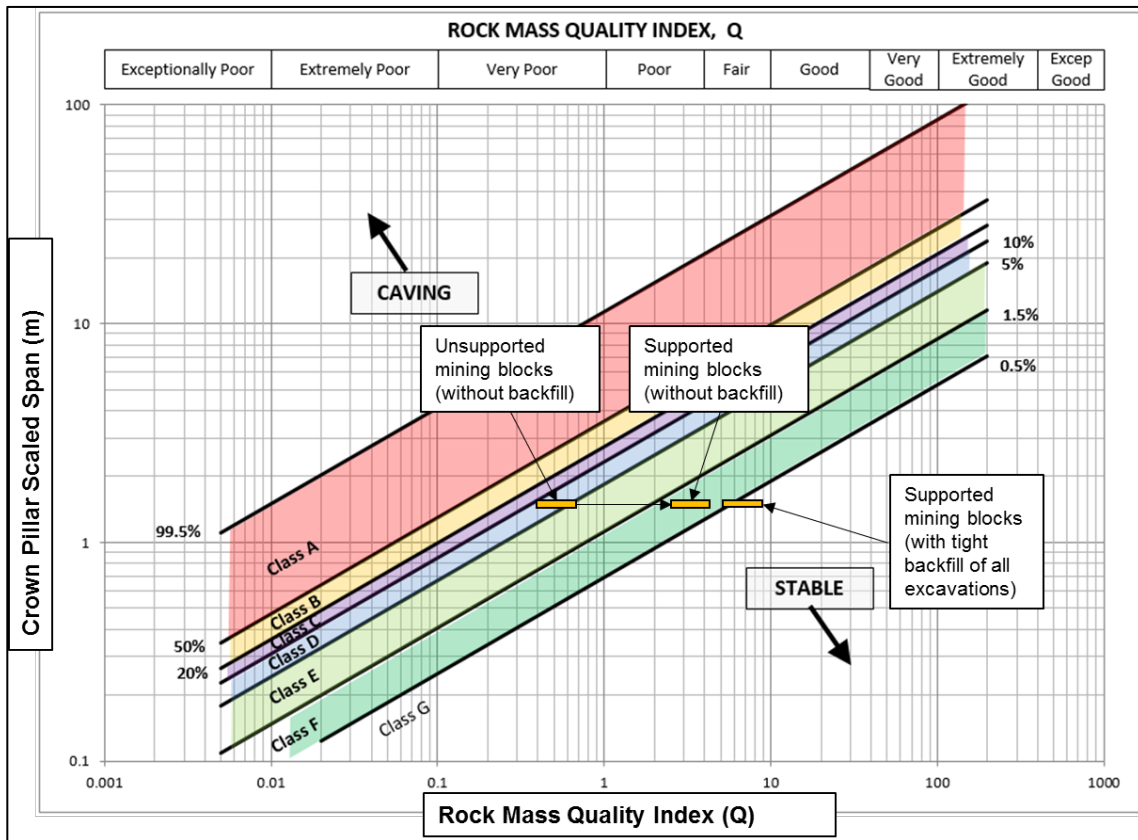


Figure 4.4: Scaled Span plot of the excavations in the crown pillar areas showing unsupported, supported without backfill, supported with tight cemented backfill of all excavations.

Table 4.3: Acceptable risk exposure guidelines (Carter et al., 2008)

Class	Probability of Failure %	Minimum Factor of Safety	Maximum Scaled Span, $C_s (= S_c)$	ESR (Barton et al. 1974)	Design Guidelines for Pillar Acceptability/Serviceable Life of Crown Pillar				
					Expectancy	Years	Public Access	Regulatory position on closure	Operating Surveillance Required
A	50 – 100	<1	$11.31Q^{0.44}$	>5	Effectively zero	< 0.5	Forbidden	Totally unacceptable	Ineffective
B	20 – 50	1.0	$3.58Q^{0.44}$	3	Very, very short-term (temporary mining purposes only ; unacceptable risk of failure for temporary civil tunnel portals)	1.0	Forcibly Prevented	Not acceptable	Continuous sophisticated monitoring
C	10 – 20	1.2	$2.74Q^{0.44}$	1.6	Very short-term (quasi-temporary stope crowns ; undesirable risk of failure for temporary civil works)	2 – 5	Actively prevented	High level of concern	Continuous monitoring with instruments
D	5 – 10	1.5	$2.33Q^{0.44}$	1.4	Short-term (semi-temporary crowns, e.g. under non-sensitive mine infrastructure)	5 – 10	Prevented	Moderate level of concern	Continuous simple monitoring
E	1.5 – 5	1.8	$1.84Q^{0.44}$	1.3	Medium-term (semi-permanent crowns, possibly under structures)	15–20	Discouraged	Low to moderate level of concern	Conscious superficial monitoring
F	0.5 – 1.5	2	$1.12Q^{0.44}$	1	Long-term (quasi-permanent crowns, civil portals, near-surface sewer tunnels)	50–100	Allowed	Of limited concern	Incidental superficial monitoring
G	<0.5	>>2	$0.69Q^{0.44}$	0.8	Very long-term (permanent crowns over civil tunnels)	>100	Free	Of no concern	None required

## 4.5 Backfill Approach

The selected mining methods, variations of longhole stoping and cut-and-fill, require backfill to manage stability and achieve the planned extraction. The primary backfill product is paste-fill produced from the processing tailings to which binding agents (e.g. cement) are added to achieve the required strength. The required paste-fill strength was determined based on the potential mode of fill failure and excavation dimensions:

- **Longitudinal stopes:** Paste-fill placed in narrow stopes (1.2 – 2.4 m) is most likely to fail at the stope ends. Vertical ends (18 m high) are exposed when the adjacent stopes are mined potentially allowing the backfill to fail into the newly excavated void. The required backfill strength to mitigate this effect is relatively low at 150 – 200 kPa.
- **Closure areas:** The mining sequence between main levels is overhand (bottom – up) but overall mining progresses from the shallow areas to deeper mineralisation. This approach results in closure areas as lower levels mine towards previously mined areas. With this approach it is unavoidable to expose the bottom of previously mined and backfilled drift/stopes. In these scenarios the backfill strength is dictated by the exposed span and beam thickness. The general approach is to place a higher strength plug or slab of backfill where it will be undermined and placing regular backfill in the rest of the stope. Based on the planned development excavation geometry (3.5 m wide and 3.0 m high) and adopting a robust and conservative approach, higher strength backfill (400 – 500 kPa) will be used in all closure areas.

Waste rock produced from underground development is a secondary source of backfill for placement in certain production excavations. Uncemented waste rock does not have the same initial strength as paste fill and will only be used in very specific areas: these being cut-and-fill excavations that will not be undermined and isolated longhole stopes. Waste rock can also be mixed with paste fill to improve its strength where appropriate.

The general mining approach requires filling of a mined stope/drift before mining the excavation above. The generalization does not apply in closure areas but as detailed above, a robust approach of tight backfilling (including cemented backfilling) will be adopted.

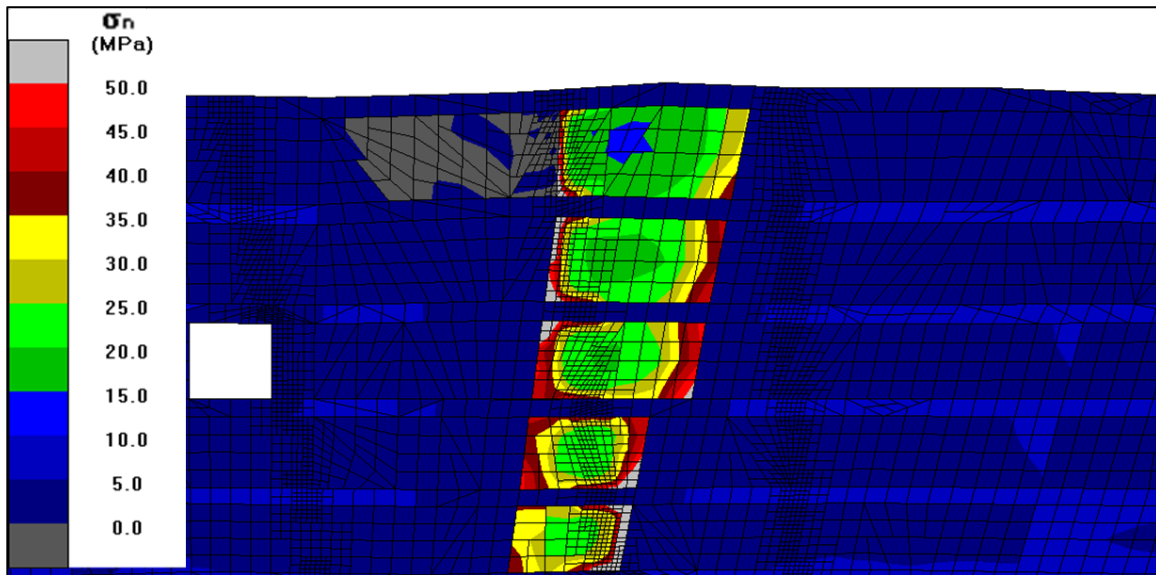
In the stoping areas close to the crown pillar cemented fill will be placed in the upper 15 m to ensure the integrity of the crown pillar area following completion of stoping and following mine closure.

Careful monitoring is also recommended, both underground and on surface, so that mitigation measures can be implemented in a timely fashion. There will be a system of surface monitoring stations to monitor any potential surface movement prior to the start of underground mining operations.

## 4.6 Mining Induced Seismicity

The Curraghinalt Project is located in a low *in situ* stress environment with the detailed mine design currently extending from near surface to a depth of approximately 400 m, but the deposit is open at depth. The major stress is orientated NNW – SSE and the k-ratio is estimated to be approximately 1.5. The intermediate stress is orientated ENE – WSW and approximately equal to the vertical stress. The maximum virgin in-situ stress based on the initial mine design is estimated to be 11 – 16

MPa depending on the orientation. The planned mining will extract the mineralized veins while retreating towards the cross cuts. The sequence and extent of the mining will result in the development of higher induced stresses ahead of the advancing mining. These will reach a maximum as the mining closes on the cross cuts and previously mined sills. As a risk mitigation measure, protection pillars will be left along the cross cuts. These pillars minimize mining induced damage to the cross cuts and maximize safe extraction of the mineral resource. These pillars will be extracted as the mine approaches the end of its life on retreat from the hanging wall towards the footwall. Numerical modelling of the initial mine design confirms that these protection pillars will experience the greatest increase in stress, Figure 4.5, and as such is an area where mining induced seismicity is possible.



**Figure 4.5: Numerical modelling indicated that the protection pillars will be subjected to elevated stress levels.**

An assessment of the seismic risk has considered both the induced stress and the rock mass properties. The rock mass in the Curraghinalt deposit ranges from a weak (10 – 20 MPa) and foliated pelite to moderately strong (100 MPa) and jointed psammite. The semi-pelite and pelite is not expected to fail in a brittle manner due to the well-developed foliation and low rock mass strength. These rock types are expected to unravel around the excavations and transfer load to other areas. The psammite is a more competent rock mass. The higher rock mass strength and lack of foliation makes it more susceptible to sudden brittle failure and thus mining induced seismicity.

For the purpose of this assessment it is assumed that the protection pillars in the numerical model (Figure 4.5) consist of psammite. The unconfined rock along the excavation surface is exposed to increased stress (~ 50 MPa) which will lead to localized failure on the pillars. This would include spalling in open stopes and cross cuts. The stress in the core of the pillar (< 25 MPa or 25% of the UCS) is not sufficient to exceed the strength of the confined rock mass required for a sudden failure of the pillar. As noted above, these pillars are planned to be extracted on retreat back to the accesses.

Micro seismic events could be expected along open excavations in the deeper sections of the mine

but larger seismic events are unlikely to occur. Micro seismic events typically have a local magnitude of less than zero and are too small to be felt on surface.

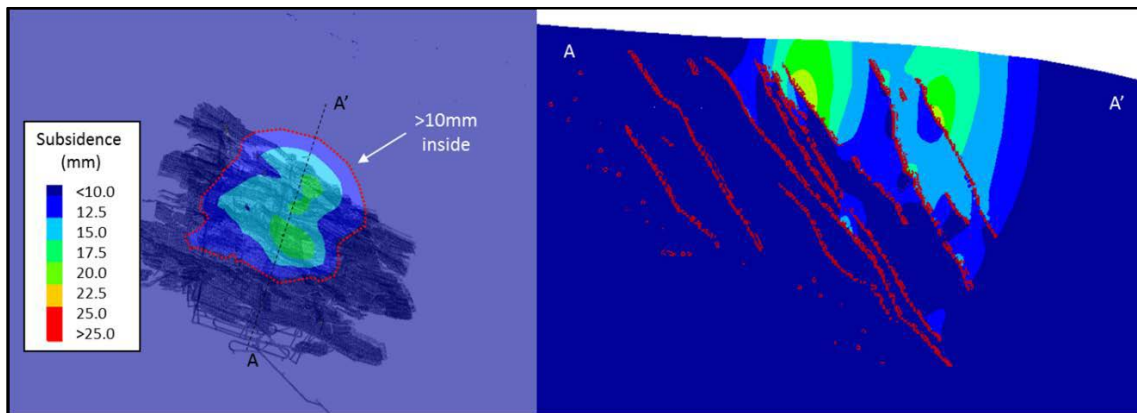
The seismic risk associated with additional extraction beyond the evaluated mine plan down to 400m, within the proposed future mineral extraction area is likely to be similar to that predicted above. Notwithstanding this assessment, the seismic risk will be the subject of on-going monitoring and evaluation to confirm this assessment of the risk and if required mining extraction plans will need to be modified to mitigate against risks related to mining induced seismicity. A micro-seismic monitoring system will be installed at the start of mining and the system expanded as the mine develops.

## 5 Subsidence Modelling

Numerical modelling was completed with FLAC3D continuum software to assess the influence of underground excavations on crown pillar stability, hanging wall stability and the potential for subsidence. Due to uncertainty related to complexity of geology, a sensitivity analysis was also carried out by varying the strength parameters of the rock mass. Figure 5.1 shows the model result on plan view, and a vertical section through the area with highest extraction.

The main findings from the assessment are:

- The extent of subsidence changes with rock strength and 3-D nature of stope interaction.
- Minimal non-damaging horizontal strains are expected at surface.
- The rock is of moderate strength and minimal subsidence can be expected at surface (less than 20 mm). This is largely based on the dipping nature of the orebody and the fact that all production excavations will be tightly backfilled.



**Figure 5.1: Predicted subsidence (section and plan) over the proposed underground mining down to 400m (April 2016 mine plan). Subsidence is expected to be very limited, in the order of 0 – 20 mm.**

With a predicted subsidence of less than 20 mm the impact is expected to be limited to a continuous extremely shallow depression that would be undetectable without the use of accurate levelling referenced to stable Ordnance Survey of Northern Ireland benchmarks well outside the mining footprint. The maximum subsidence is expected to occur at the centre of the settlement area but

localized zones of ground settlement could occur based on local variability of geological features.

## 6 Conclusion

The assessment of crown pillar stability, mining induced seismicity and the potential for subsidence above the higher extraction areas down to 400m (April 2016 Mine Plan) was carried out using representative rock mass characteristics. Both empirical and numerical analyses suggest that limited subsidence will occur based on the narrow mining widths, the mining methods used, and the placement of tight backfill.

The subsidence boundary (Figure 5.1) should be considered an estimate, and further geotechnical data acquisition and evaluation, and ground surface monitoring information will be collected as the mine is developed in order to refine the subsidence model. Mining extraction and backfill plans will then be adjusted to ensure that subsidence remains within acceptable levels.

As mining extents increase along strike, micro seismic events are expected to have local impacts on underground excavations. The events are expected to be small in magnitude and are not expected to affect the integrity of surface infrastructure either within or outside of the reviewed mineral extraction area. Increased depth of mining will impact the local underground seismic risk and this will need to be reviewed on an ongoing basis as the mine is developed.

Additional extraction along strike of the analysed mine plan can be expected to result in similar subsidence to that predicted, provided that vein geometries and levels of extraction are similar. Impacts to surface will likely reduce as the depth of mining increases.

If levels of measured subsidence are greater than that of the estimates, suitable amelioration measures such as stiffer backfill (cemented rock fill) or the retention of pillars within the mining horizons (reduced extraction), will be used to maintain the subsidence to acceptable levels.

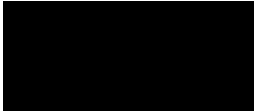
### 6.1 Recommendations

As underground mining progresses, it is recommended that the impacts of mining will be regularly monitored through instrumentation, surface surveys, and by visual inspections on surface and of underground excavations. These could include surface monitoring such as high- resolution satellite radar interferometry imagery (InSAR) or aerial drone Lidar mapping.

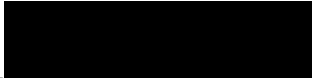
Although the predicted subsidence of the proposed Curraghinalt mine workings evaluated is low, and over limited areas of the mine, SRK recommends the installation of permanent subsidence survey monuments over the proposed mine workings prior to the commencement of mining operations. An annual high precision subsidence survey to monitor subsidence should be undertaken. An east-west and north-south subsidence transit, would provide confirmation of the anticipated subsidence, and provide evidence of minimal subsidence effects to local stakeholders

SRK Consulting (Canada) Inc.

Prepared by:

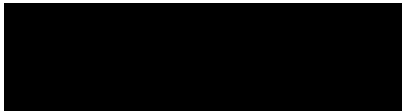


Choong E. Lee, MEng, EIT  
Consultant, Rock Mechanics



Bruce Murphy, PEng, FSAIMM  
Principal Consultant, Rock Mechanics

and reviewed by:



Tim Coleman, PEng, B.Eng (Hons) ACSM M.Sc. DIC  
Principal Consultant, Rock Mechanics

**Disclaimer**—SRK Consulting (Canada) Inc. has prepared this document for Dalradian Resources Inc.. Any use or decisions by which a third party makes of this document are the responsibility of such third parties. In no circumstance does SRK accept any consequential liability arising from commercial decisions or actions resulting from the use of this report by a third party.

The opinions expressed in this document have been based on the information available to SRK at the time of preparation. SRK has exercised all due care in reviewing information supplied by others for use on this project. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information, except to the extent that SRK was hired to verify the data.

## 7 References

- Carter, T.G., Cottrell, B.E., Carvalho, J.L., and Steed, C.M.. 2008. Logistic Regression improvements to the Scaled Span Method for dimensioning Surface Crown Pillars over civil or mining openings.
- Micon International Ltd. 2012. A Preliminary Economic Assessment of the Curraghinalt Gold Deposit, Tyrone Project, Northern Ireland.
- Musson, RMW and Sargeant, SL. 2007. Eurocode 8 seismic hazard zoning maps for the UK. British Geological Survey Technical Report.
- National Coal Board – Mining Department. 1975. Subsidence Engineers' Handbook. National Research Council Canada. 2010. National Building Code of Canada.
- Tully, J. 2005. Technical Review Report on the Curraghinalt Gold Property – Exploration License UM-1/02 (UM-11/96), County Tyrone, Northern Ireland.