Difficult mining conditions in 153 Orebody at a depth of 4550 ft at Vale Inco's Coleman Mine

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ABSTRACT: Vale Inco's Coleman Mine 153 Orebody is a narrow vein deposit with a dip that varies from 30 to 70 degrees. It has a strike length of 1200-feet and the current mining extends from the 4250 level to 5100 level. The primary mining method is mechanized cut-and-fill although drift-and-fill is also used in wider sections of the ore zone. The ore body is divided into six main mining horizons with an average of three mining blocks on each cut.

There are some interesting rock mechanics challenges related to mining upward from the 4550 level and these challenges are increasing as the mining front progresses toward the 4400 level. The mining of the 4550 block is currently at cut 13 whereby the crown pillar thickness is approximately 60-feet. Significant factors including increased stress levels in the crown pillar, the change in the orebody dip at this level and a recently indentified geological structure in the footwall, have all combined to introduce seismic activity in the footwall of 4550 level. Closer studies revealed a consistent trend of seismicity that was further examined with core logging and Acoustic TeleViewer technology. The data from these assessment tools disclosed a geological structure that is influencing the mining environment.

This paper reviews the seismic analysis for the 4550 level mining zone and the subsequent procedures used to locate the new geological structure. The paper also discusses the key mining practices used to successfully mine cut 13 of 4550 level and briefly reviews the studies that are underway to up-date the mine design for continued extraction of high-grade ore in a safe and productive manner.

1 GENERAL INFORMATION

1.1 *153 Orebody*

Vale Inco's Coleman Mine is located on the North Range of the Sudbury basin, approximately 28 miles north-west of the city of Sudbury and 3 miles east of the town of Levack, (Figure 1).

Coleman Mine's 153 Orebody is located 2500 feet west of and 1000 feet north of the Main orebody in the North range felsic footwall gneisses and breccias. The 153 Orebody consists of a complex system of copper-nickel-precious metal veins and stringers within an east west striking, southerly dipping sequence consisting of felsic gneiss, granite, and Sudbury breccia.

The 153 Orebody has a strike length of 1200 feet and has been defined from 3600 level to 5100 level (a vertical distance of 1500 feet). The ore zone has been divided into six horizons: 4250, 4400, 4550, 4700, 4810, and 4945 levels.

Additional mining is occurring in Coleman Mine in adjacent mining zones to the 153 Orebody – these mining areas are not part of this discussion, since this paper primarily concentrates on the seismicity trend and a new structure identified in the 4550 level of 153 orebody.

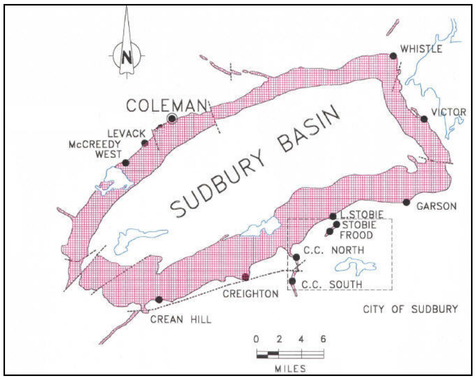

Figure 1. Sudbury basin map and location of Coleman Mine

The primary mining method in the 153 Orebody is mechanized cut-and-fill. Cut-and-fill production headings are mined to the width of the ore vein, up to a maximum width of 24 feet and with a cut height of 9 feet. Ore veins wider than 24 feet are mined in multiple passes using drift-and-fill mining and using unique ground support systems for the first and second passes.

With six mining horizons in the 153 Orebody, each cut-and-fill level successively mines upward, in individual cuts (each 9-ft high), creating a diminishing crown pillar, Figure 2. Cut-and-fill mining may eventually be converted to bulk recovery for the crown pillars where more challenging mining conditions are expected. To some extent, more difficult mining conditions are being encountered in the footwall of 4550 level at cut 13.

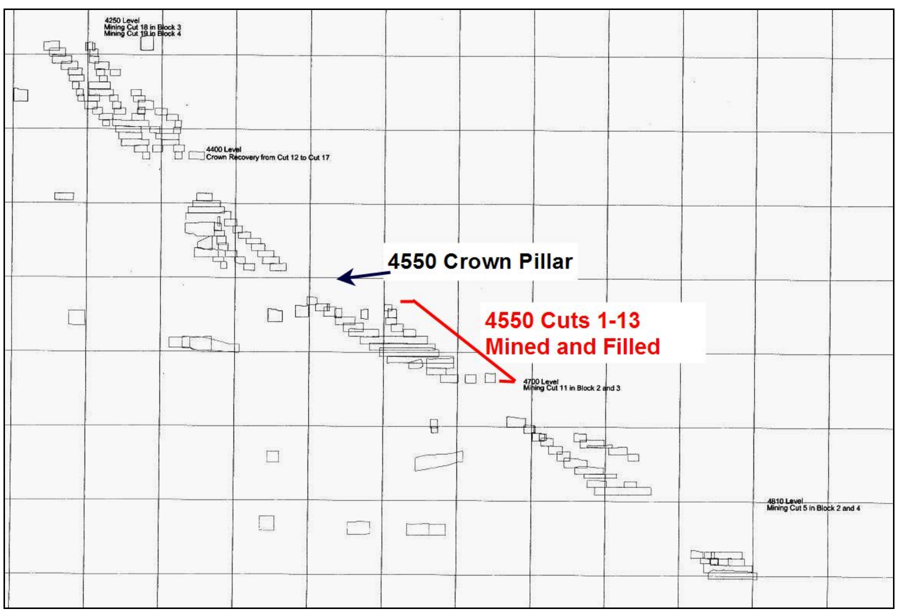

Figure 2. A typical section of 153 orebody, showing the crown of 4550 level

1.2 *Geology Structures*

Main structures in the area and around 153 Orebody include an olivine diabase dyke in the west of the current ore development and Bob's Lake Fault to the east. These major structures are combined with numerous but localized faults and joints at variable dips ranging between 10-80 degrees.

Bob's Lake Fault strikes approximately in the north-south direction (with respect to the mine's north). The fault is basically a sheared zone of highly–choloritized joint surfaces. During formation, the ore zones closer to the fault likely have been dragged down by the fault and these seem to be under tension with seismic conditions. The ground in this area for the most part is relaxed and blocky and requires enhanced ground support systems to stabilize potential wedges and reduce the likelihood of falls of ground.

The diabase dyke dips to the east at 72 degrees and varies in thickness from 20 to 200 feet. This dyke intersects the 153 Orebody between depths of 4,400 to 5,200 feet. To date, there is no evidence that the dyke influences ground stability in the 153 Orebody.

The two major geological structures and their relative orientation and location next to the 153 Orebody zone are shown in Figure 3 (looking north).

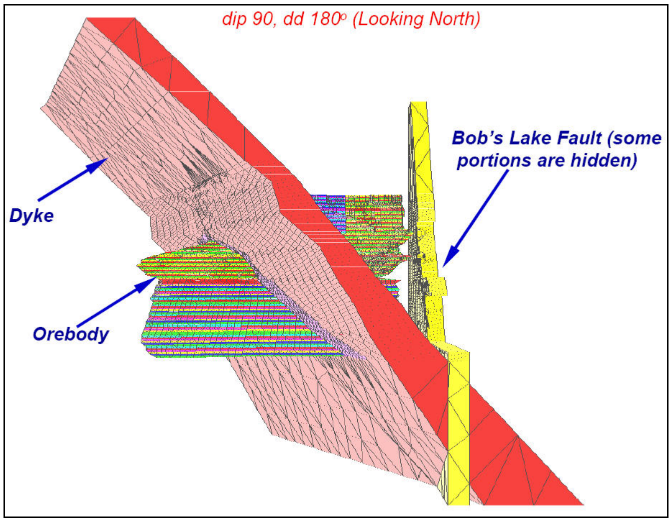

Figure 3. Looking north at 153 Orebody, diabase dyke and Bob's Lake Fault (Mortazavi et al 2000)

1.3 *Principal Stress Directions*

Magnitude and orientations of principal stresses are summarized in Table 1, (Espley et. al. 1996). Orientations are measured relative to Coleman Mine grid north which is 37-degrees west of true north.

Table 1. Major In Situ Stress Components at Coleman Mine.

Stress Component	Magnitude (psi)	Trend*	Plunge	Stress Ratio
Major Principal Stress (σ_1)	1575 + 1.8 × depth (ft)	127°	0°	1
Intermediate Principal Stress (σ_2)	1260 + 1.44 × depth (ft)	217°	0°	0.8
Minor Principal Stress (σ_3)	1.29 × depth (ft)	0°	0°	0.58

1.4 *Seismicity in 4550 Level*

During the early stages of mining cut 13, an unrelenting seismicity trend was identified in a north-south direction, Figure 4. This trend is in the opposite direction of the principal stress as shown in Table 1.

An assessment of the seismicity data showed that this trend has been consistent and repeatedly encountered in and around the same areas of the ore zone with the past mining activity. In addition, a study of the locations of rock bursts showed that a group of previous rock bursts also plots in close proximity to this trend. Many of these rock bursts occurred in the first cuts of the 4400 level, above the 4550 level, Figure 5.

To better identify the reason behind this persistent trend, a diamond drill program was planned and subsequently four holes were drilled in and around the area of interest, Table 2. The cores and holes were analyzed by geotechnical core logging techniques in addition to Acoustic TeleViewer probing. Both the logging and probing was done to better define the rockmass properties and to potentially locate any surrounding structures that have not been encountered in the orebody but would be close enough to cause this particular trend of seismicity. The data collection and analysis from each technique is described below.

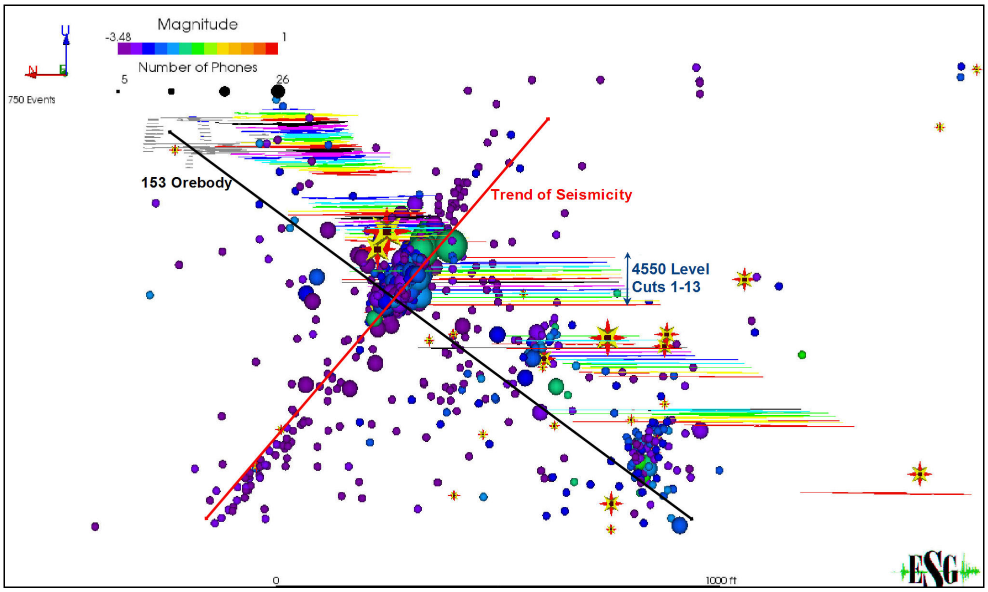

Figure 4. 153 orebody levels, looking east, showing the trend of seismicity

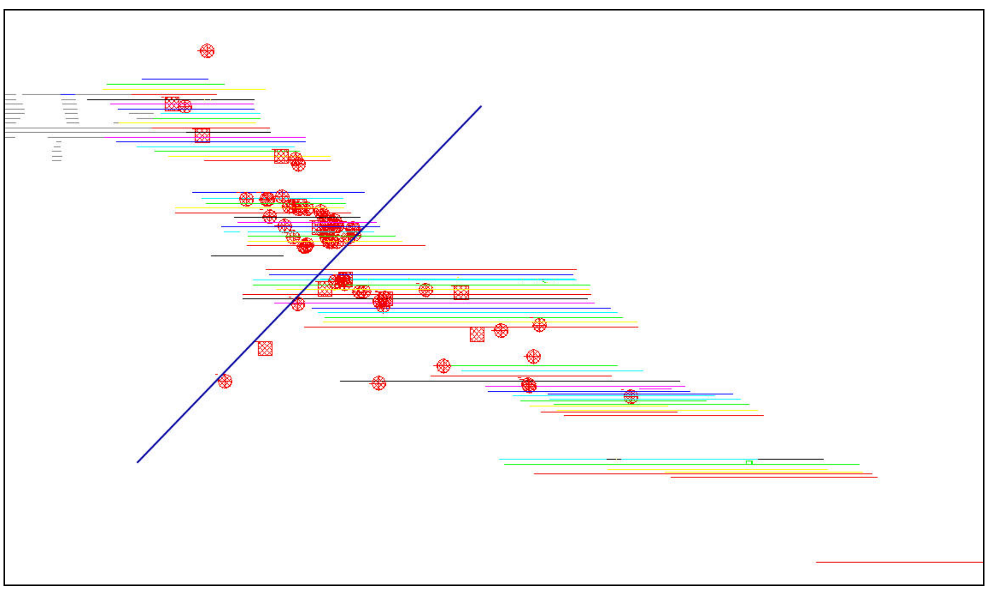

Figure 5. The location of rock bursts over the mining history; these are plotting near the seismicity trend.

Table 2. Location and direction of diamond drill holes

B.H.#	E	N	Z	AZI	DIP	LENGTH
1252210	15435	10545	8690	126	-40	125
1252220	15435	10545	8690	142	0	210
1252230	15435	10545	8690	166	0	155
1252240	15431	10544	8690	201	-40	400

2 DATA COLLECTION AND ANALYSIS

2.1 *Geotechnical Core Logging*

Structural data was collected from 4 holes that were drilled through the 4550 level. The locations of these holes are shown in Figure 6.

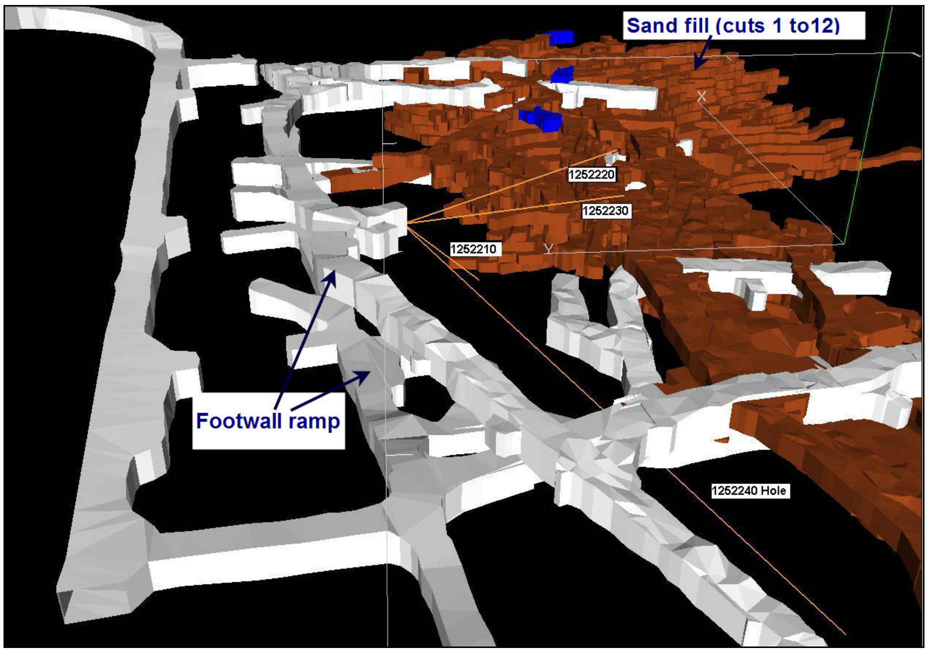

Figure 6. Location of 4 diamond drill holes, drilled from the ramp toward the orebody

Holes 1252220 and 1252230 were drilled flat and were aimed at the zone of high seismicity that was identified during the early stages of mining cut 13. The other two holes, 1252210 and 1252240, were drilled at dips of 40 degrees into the footwall of 4550 level. The holes were logged and the ground conditions were further assessed using the Acoustic TeleViewer.

The data collected from core logging includes:

- Joints
- Joint Sets
- Fault Zones
- Shear Zones

Types of detailed data collected, includes:

- Joint Roughness
- Angle of the Joint
- Joint Surface Alterations
- Detail description of broken core zones
- Areas with core discing

Table 3 shows the average values for Rock Tunneling Quality Index, Q, and Rock Quality Designation, RQD, for three of the holes.

Table 3. Average Q and RQD values for three of the cores

Core	Q	RQD	Comments
DDH 1252210	60	97	Micro Fractures from 0-30 ft
DDH 1252220	8	80	From 80-130 ft- very poor RQD
DDH 1252240	79	98	Major Joint Sets appear to be at 45, 60 & 70^ range

The flat holes, 1252220 and 1252230, were found to be situated in significantly fractured ground. This was expected due to the seismic activity and bursting that had been encountered in this area during the mining of cuts 12 and early cut 13. Figure 7 shows a portion of 1252220 hole.

Figure 7. Core from hole # 1252220.

The logging of the inclined holes, 1252210 and 1252240, showed that the footwall rocks are in good condition with no major structures present. However, a zone of jointed ground was noticed in hole 1252240 at a depth of 57-ft and this feature was further defined as a shear zone. This zone is aligned with the direction of the seismicity trend as shown previously in Figure 4.

In addition to the core logging assessment, the identification of the shear zone in the hole 1252240 was later confirmed by Acoustic TeleViewer probing. Table 4 summarizes the description of joints for the hole 1252240 at the depth of 57 ft, obtained from core logging.

Table 4. Geotechnical core logging data for 1252240 hole. ** Grey data shows the properties of the shear zone defined from the cores that matches the dip of the seismic data trend

6 7 8	Hole Number	Depth (feet)	Feature	Orientation Dip	Orientation Ref. Code	Core Scale Desc. Waviness Code	Core Scale Desc. Smoothness Code	Alteration/Filling	Comments
145	1252240	54.2	JN - Joint	50	NOC	Stepped	Rough (30)	Minor chlorite	
146	1252240	54.8	JN - Joint	40	NOC	Planar	Rough (30)	epidote	epidote covering joint face
147	1252240	55.3	CJN - Cross JN	62	NOC	Planar	Rough (30)	epidote	epidote covering joint face
148	1252240	55.4	CJN - Cross JN	63	NOC	Planar	Smooth (220)	epidote	some chlorite also present
149	1252240	55.5	JN - Joint	63	NOC	Planar	Smooth (220)	epidote	some chlorite also present
150	1252240	57.1	JN - Joint	45	NOC	Planar	Smooth (220)	Minor chlorite	
151	1252240	57.2	SH - Shear	45	NOC	Planar	Slickensided	Minor chlorite	looks to be loose chlorite powder
152	1252240	57.3	JN - Joint	45	NOC	Planar	Smooth (220)	Minor chlorite	
153	1252240	58.1	JN - Joint	72	NOC	Undulating	Rough (30)	None	
154	1252240	58.9	JN - Joint	59	NOC	Irregular	Rough (30)	None	
155	1252240	59.6	JN - Joint	70	NOC	Undulating	Rough (30)	None	
156	1252240	61.4	JN - Joint	55	NOC	Undulating	Rough (30)	None	
157	1252240	64.8	JN - Joint	20	NOC	Undulating	Rough (30)	None	

2.2 *Acoustic TeleViewer*

Two of the diamond drill holes, 1252210 and 1252240, were drilled with a dip of 40 degrees for the added purpose of assessing the condition of the footwall rocks using the Acoustic TeleViewer probe. This was done in addition to the geotechnical core logging conducted for these boreholes. Figure 8 shows the 3D representation of the ground conditions in the two holes based on the results of the Acoustic TeleViewer. There are no major fault/shear structures causing ground problems, however, in hole 1252240, at a depth of 57-ft, a joint set with a dip of 55 degrees and dip-direction of 290 degrees is noticeable. This data aligns with the results of coring and also fits with the observed trend of seismicity.

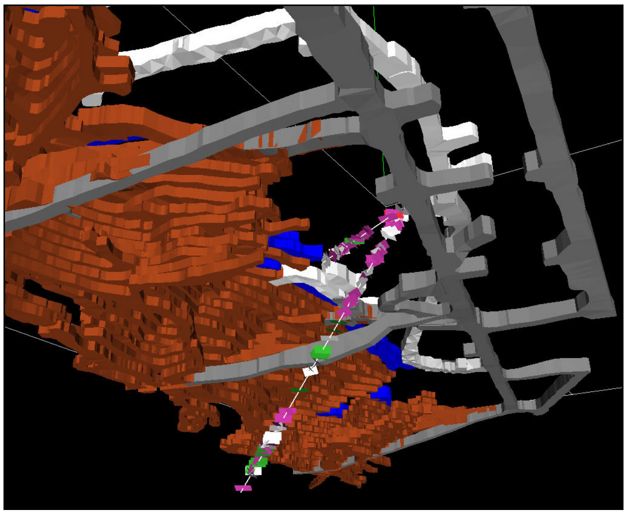

Figure 8. Visual results from Acoustic TeleViewer probing.
Note: Foliation planes (green), jointing (purple), break-outs (white) shown in true dip and dip direction.

Table 5 summarizes joints properties from hole 1252240 which is also represented in a stereonet in Figure 9, indicating the pole of joints between the depths of 55-65 ft.

Table 5. TeleViewer data for 1252240 hole for the depth where the shear zone was identified (Grey area)

BHID	BH_D	Dip	Dip-Direction	Colour	Structure Description
1252240	46.53	58.54	298.77	Purple	Fracture - Joint
1252240	50.25	55.31	319.06	cyan	infilled joint
1252240	53.59	52.7	285.48	Purple	Fracture - Joint
1252240	54.14	14.13	184.37	cyan	infilled joint
1252240	55.13	55.36	294.69	Purple	Fracture - Joint
1252240	55.24	55.8	294.93	Purple	Fracture - Joint
1252240	59.46	51.55	300.85	Purple	Fracture - Joint
1252240	62.81	80.29	50.19	Purple	Fracture - Joint
1252240	63.02	52.07	291.67	Purple	Fracture - Joint

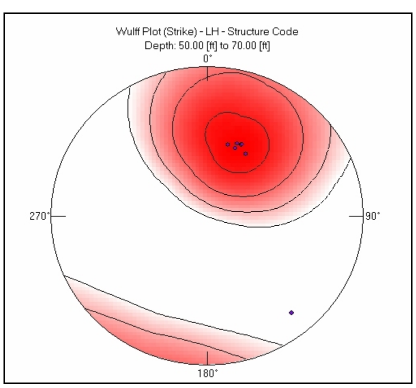

Figure 9. Stereonet showing the joints between depths of 55-65 ft for the 1252240 hole

The shear zone was identified at a depth of 57-ft in the core and at a depth of 55-ft using the Acoustic TeleViewer data. Note that there is a minor difference in depth to the shear zone and this is due to the measuring techniques used. The core logging measures depth starting from the hole collar itself while the TeleViewer starts measuring depth from a cable instrument that is located outside the hole and not at the collar.

3 DISCUSSION

3.1 *Analysis Summary*

During the mining of block 2 of 4550, seismic activity in a direction opposite to the trend of 153 orebody was noticed. To confirm whether this seismicity trend was mainly due to stress redistributions, or due to an array error, or due to a geological structure in the footwall, a testing campaign was initiated. Both core logging and Acoustic TeleViewer inspections were implemented and assessed.

The results of the TeleViewer and core logging determined that there is a joint-set in the same direction as the trend of seismicity. This structure, even though not extreme in nature, seems to be affecting the ground conditions in 4550 level and this impact seems to be increasing as the mining approaches 4400 level and as the crown pillar is diminished to a critical slenderness.

3.2 *Actions taken to minimize burst hazards*

In a concerted effort to better control and manage seismicity and to minimize bursting while mining cut 13 on the 4550 level, a range of measures were undertaken, such as:

– Development rounds were shortened to 6 or 8 ft in certain areas.
– Destressing techniques were utilized with holes drilled and blasted in the footwall of the mining cuts.
– Ground support was specified based on site conditions. The headings with higher risks were first evaluated for the ore value and, if economical to mine, heavier ground support systems were installed as follow: Shotcrete was used as primary support for certain areas mainly in the wider veins located in the footwall. A 2-inch thick layer of fiber reinforced shotcrete was applied to the unsupported heading after blasting and mucking the rounds. Mechanical bolts were replaced with resin grouted rebars. The walls are supported to the floor with friction set bolts installed over #6 gauge screen.
– Trials with swellex bolts are underway for very broken ground conditions and in high grade cuts, i.e. where the bolt hole diameter cannot be controlled properly for effective use of resin grouted rebar bolts and mechanical anchor bolts.
– Seismicity was monitored constantly by both Mines Technical Services and Operations (shift supervisors) and protocols were followed accordingly. Temporary closure of areas and subsequent re-opening was based on data such as: the number of events, proximity of the events to the mining areas, magnitude of the events, etc.
– Constant monitoring and reporting of the ground conditions and excellent communication between the underground crews and the MTS Ground Control group.

These steps have proven to be effective in the past and were successfully implemented during mining cut 13 of 4550 level to mine the ore in a safe and productive environment.

3.3 *Future mining of 4550 level*

For the future mining of 4550 level, the newly defined geological structure will be monitored closely and the response to mining will be correlated for further design enhancements. Mining that is close to the shear and the mining areas that cut directly through the shear will be examined with recommendations on minimizing stress damage and seismicity.

Some future design considerations include the potential to use pillars, re-sequencing the extraction (footwall areas first), use of ground support enhancements (cables etc.), evaluation of alternative mining methods such as bulk methods, etc.

Numerical stress modelling will also be used to correlate the previous mining and the related ground responses in order to further assist in defining the appropriate mining approach for cut 14 and beyond.

4 CONCLUSIONS

The seismic data was helpful in identifying a geological structure in the footwall of 4550 level in the 153 Orebody. The existence of the structure was confirmed by geotechnical core logging and Acoustic TeleViewer technology. The seismic trend, primarily due to mining induced stress, is aggravated by the geological shear feature in the footwall. A well-developed plan was used to successfully mine 4550 level during cut 13. At this time, future mining in the footwall of the crown pillar is being studied in more detail to choose the most efficient mining sequence and method to ensure a safe and productive mining environment. The results of these studies and the conclusion of the crown pillar extraction will be published in the near future.

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