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Evaluation of Ground Support Requirements for D Orebody Load-Haul-Dump Block, Molycorp

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ABSTRACT: Molycorp, Inc.'s Questa Mine plans to switch from gravity draw in Block 1 to a load-haul-dump (LHD) draw system in the East and West blocks of the D Orebody. Changes in mining method require modifying the support design. This paper summarizes the numerical modeling effort and findings in evaluating abutment stress conditions and ground support requirements for LHD mining. A three-dimensional, elastic-plastic, FLAC^{3D} model was constructed comprising a detailed mesh representing the excavation geometry of the LHD drawlines encapsulated within a coarse, global mesh representing the entire D Orebody. The mining sequence was simulated to output stress changes at the LHD Level during advance of the caving front. The drifts at the LHD Level were mined before or after several key caving steps to represent pre-undercut and post-undercut conditions. A fictitious support pressure was then applied to the walls of the drifts and incrementally relaxed to measure convergence as a function of support pressure. LHD Level support requirements were determined from these ground-support interaction analyses. Conclusions were that a thick shotcrete liner would be required for the drifts in weak andesite, while light shotcrete and rockbolts would be sufficient in areas of strong aplite (granite porphyry).

1. INTRODUCTION

Molybdenum has been mined at Molycorp, Inc.'s Questa Mine, New Mexico for over 80 years. A gravity block-caving method was planned by the end of 1976 because of the well-fractured nature of the rock mass and the size and shape of the deposit [1]. Underground mine development began in 1979, followed by initial production in 1983 from the Goathill Orebody. In its block caving operations, both a manual gravity draw system and a highly-mechanized load-haul-dump (LHD) draw system were selected to remove broken ore from the production level.

By the end of 2000, production began in the D Orebody the east of the original Goathill Orebody [2]. The traditional gravity draw system was adopted to mine Block 1 of the D Orebody (Figure 1). Presently, Molycorp plans to convert to an LHD draw system for the East and West blocks.

The East Block mining sequence was simulated using FLAC^{3D} to estimate stress levels imposed on the LHD lines. Computed convergence within the LHD lines was used to develop ground-support interaction curves for representative locations within the East Block at different stages of mining. The curves, which describe the relationship between entry convergence and passive pressures imparted on the surrounding rock mass by the support system, were ultimately applied to estimate support requirements in the LHD lines.

2. ABUTMENT STRESS MODEL

Four rock types—namely strong and weak andesite, breccia, and aplite—predominately occur across the D Orebody. Figure 2 shows the general geology built into the FLAC^{3D} model. Rock mass properties used in numerical models are listed in Table 1. Rock mass properties are based on typical laboratory test values, with strength and moduli discounted according to the rock mass classification method proposed by Hoek, Kaiser, and Bawden [3]. The rock masses were assigned a very low or zero tensile strength due to the presence of joints. The Mohr-Coulomb strength criterion was used in the model to simulate the inelastic deformation of the rock mass under high abutment pressure. A hydrostatic pre-mining stress field with a 0.026 MPa/m depth (1.15 psi/ft) stress gradient was

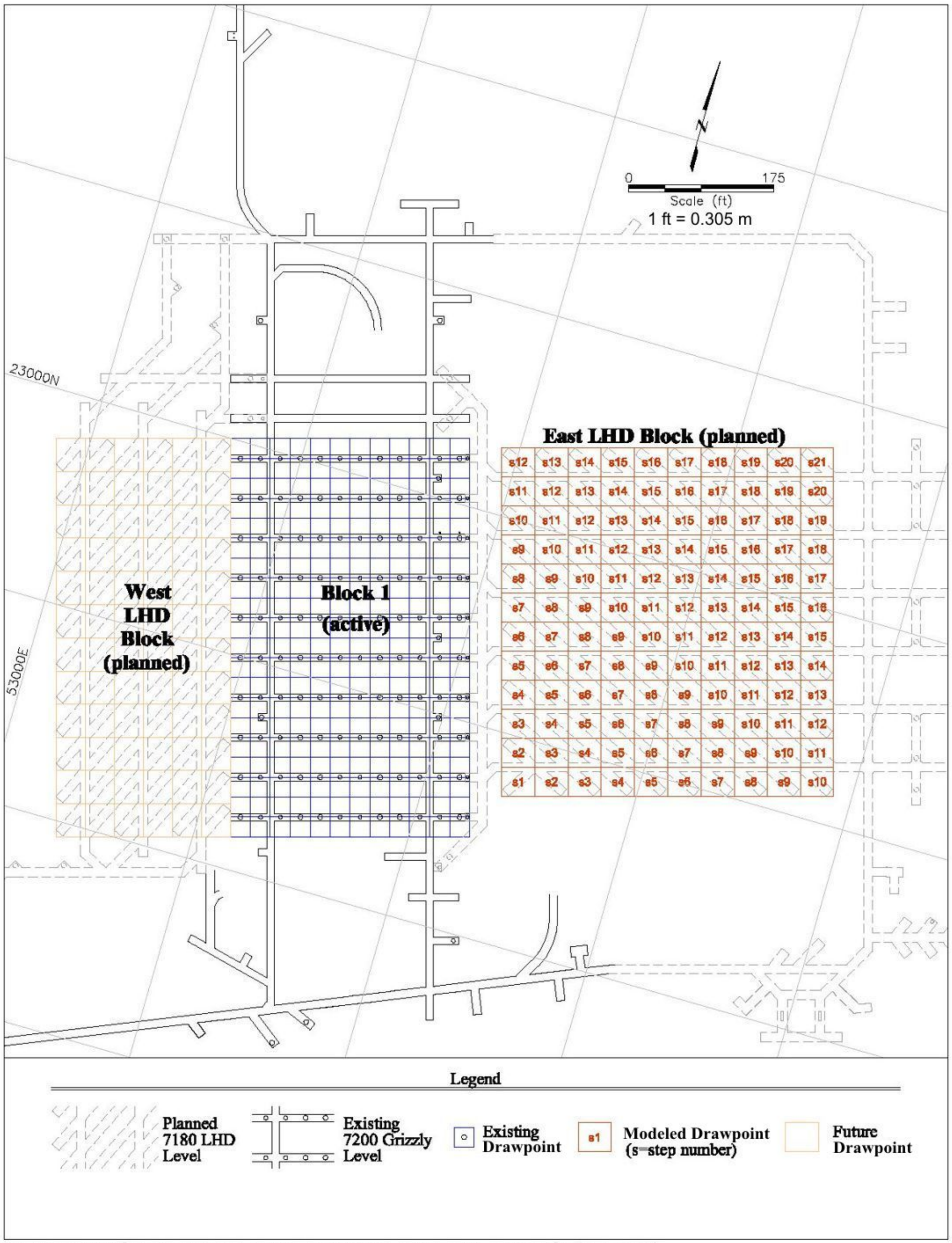

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Fig 1. D Orebody, Block 1, and planned LHD blocks.

prescribed in the model, based on experience and previous studies. The average overburden depth in the D Orebody was assumed to be around 609.6 m (2,000 ft).

Figure 2 described the three-dimensional (3D) geometry of the FLAC^{3D} model. Finely-meshed LHD draw lines were encapsulated in a coarse-meshed D Orebody. Caving operations were planned for 120, 12.2 m by 10.7 m (40 ft by 35 ft), draw blocks. As shown in Figure 1, 21 caving steps were simulated to cave the orebody from southwest to northeast in the model. Each caving step comprised one or several draw blocks. Based on the anticipated draw rates, the caving height over the undercut level was assumed to decrease 9.1 m (30 ft) per caving step from the first step to the latest caving front. The Block 1 cave was represented as 70% mature at the time the first East Block drawpoint was activated in the model. The un-arched portion of the Block 1 cave was modeled as a 182.9-m-high (600-ft-high) void. It was assumed that only 45% of the caved column

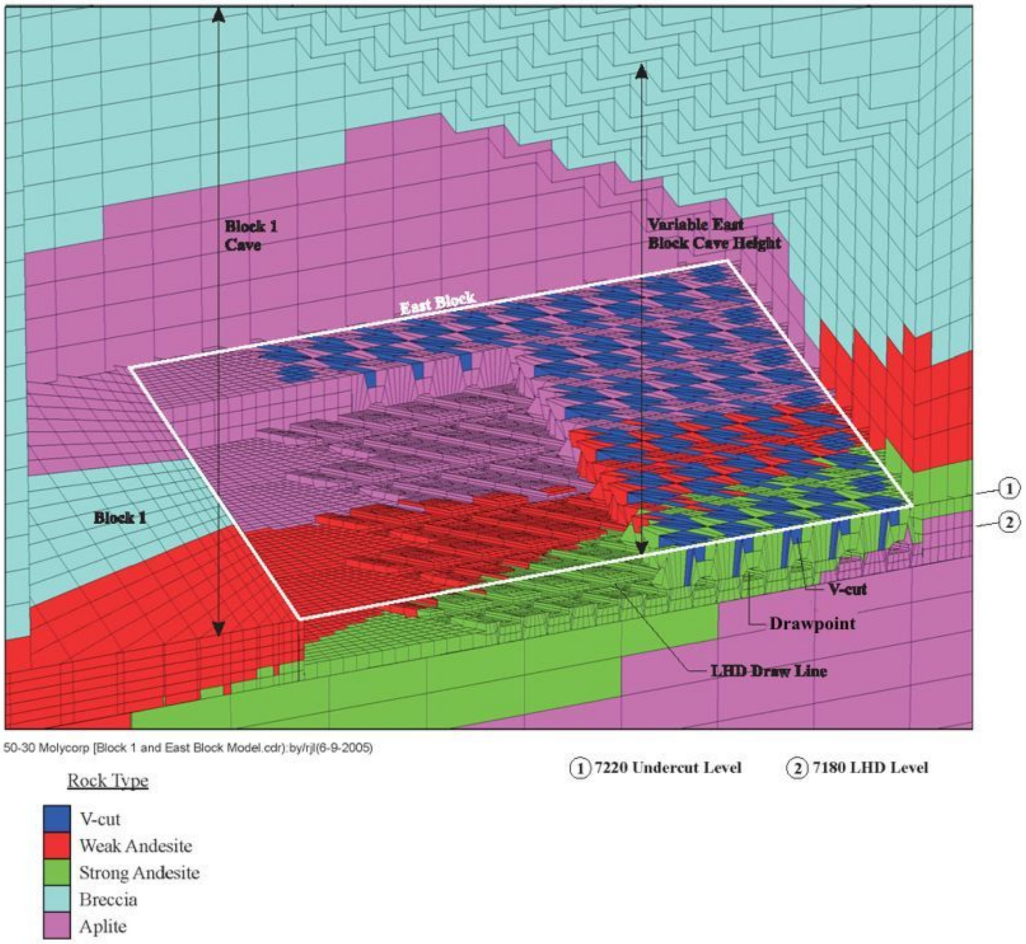

Fig 2. FLAC^{3D} model of Block 1 and East Block.

Table 1. Rock Mass Mechanical Properties

Rock Type	Intact Rock Specimen				Rock Mass					
	UCS MPa (psi)	m_i[†]	Poisson's Ratio	Q'	GSI[‡]	Elastic Modulus MPa (psi)	UCS MPa (psi)	Poisson's Ratio	Friction Angle	Tensile Strength MPa (psi)
Weak Andesite	137.9 (20,000)	19	0.30	0.023	10	1,000 (145,000)	3.8 (550)	0.30	28.7°	0 (0)
Strong Andesite	172.4 (25,000)	19	0.30	0.211	30	3,170 (459,000)	12.6 (1,820)	0.30	37.7°	0 (0)
Breccia	172.4 (25,000)	18	0.25	1.56	48	8,915 (1,293,000)	18.6 (2,700)	0.25	42.3°	0.02 (3)
Aplite	241.3 (35,000)	33	0.25	10.3	65	23,710 (3,439,000)	52.7 (7,650)	0.25	51.7°	0.12 (17)

‡ Constant based on lithology.

† Geological Strength Index (GSI) classification of observed rock mass quality; ranges from about 10 for extremely poor rock masses to 100 for intact rock.

height resulted in a gravity load on the floor of the undercut level. These gravity loads were applied to the base of Block 1 and floor of the undercut level at the East LHD Block. In each mining step, the load at each caving block was updated according to the corresponding caving height increase.

The mining-sequence simulation output the vertical stress change at each point on the LHD Level. Figure 3 is a sequence of vertical stress maps that illustrate the stress abutment migration across the LHD lines during the East Block undercut. The maps show higher stresses concentrating in the aplite to the north because of

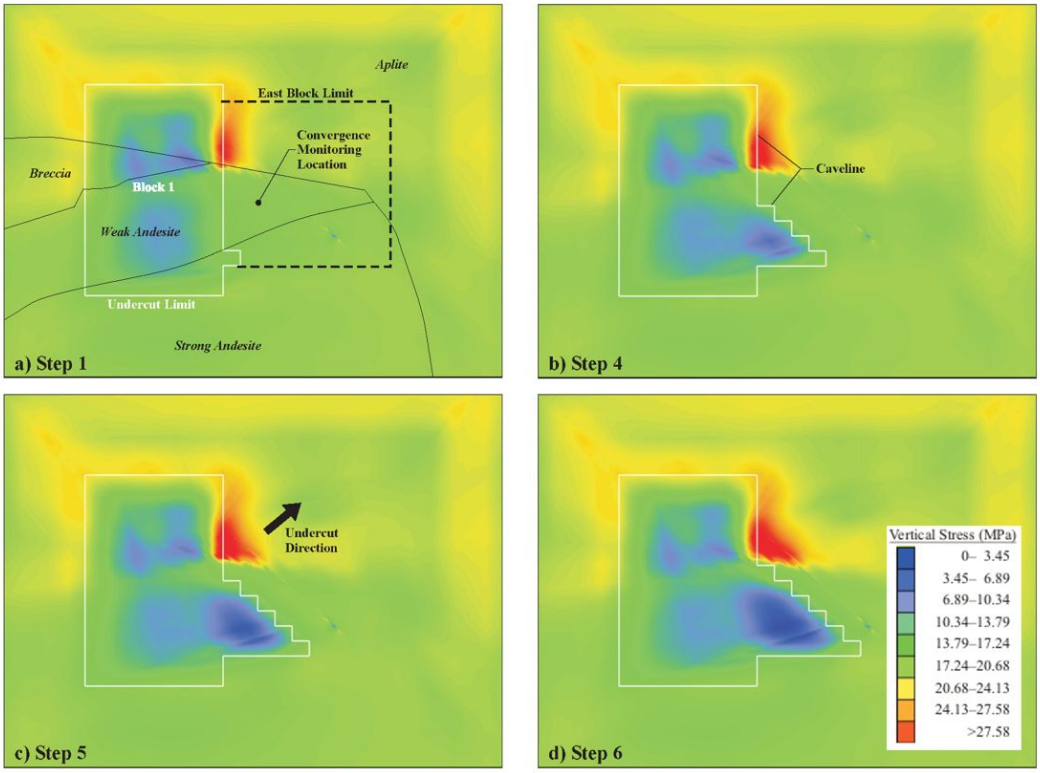

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Fig 3. Vertical stress on 7180 LHD Level—East Block undercut steps.

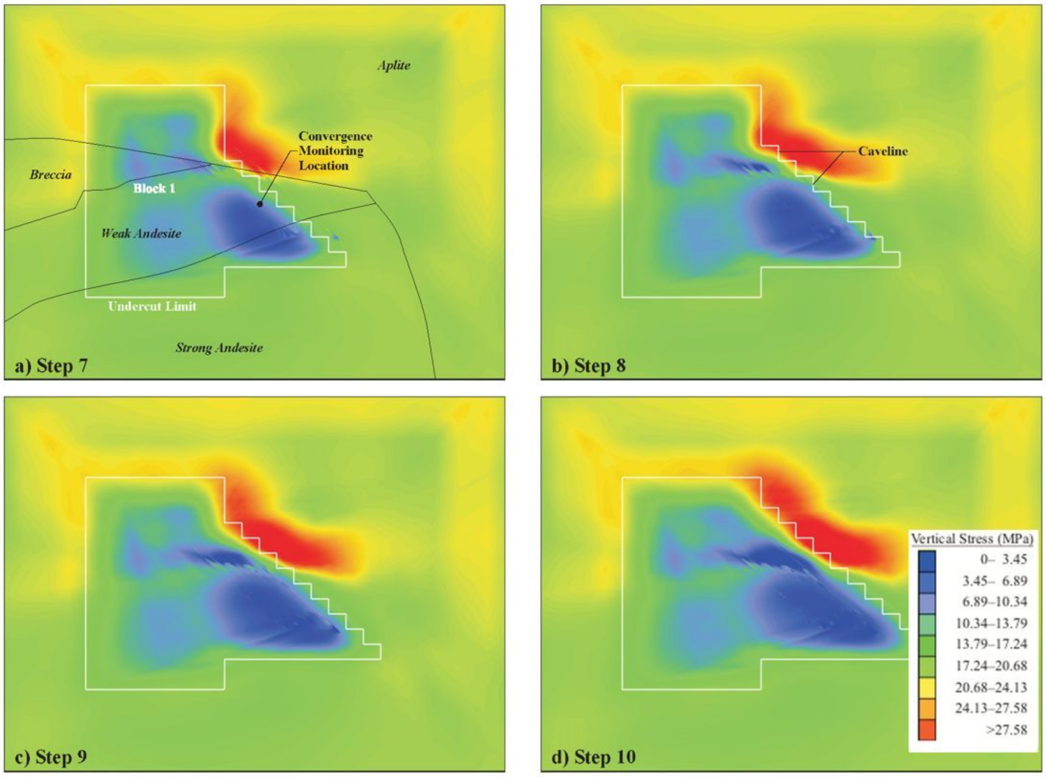

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Fig 3. Vertical stress on 7180 LHD Level—East Block undercut steps (*continued*).

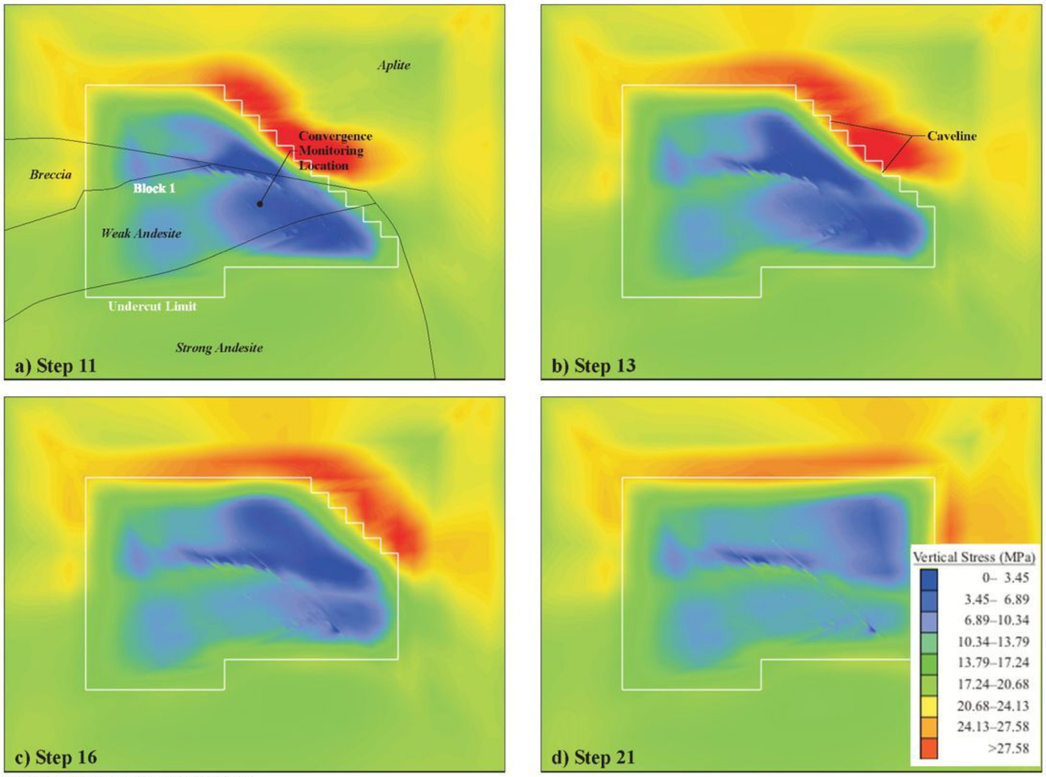

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Fig 3. Vertical stress on 7180 LHD Level—East Block undercut steps (*concluded*).

the geometry of the undercut and the stiffness contrast with the soft andesite to the south. Figure 4 describes the vertical stress history relative to the caving front for representative drawpoints in the aplite and weak andesite rock masses. Each LHD drawpoint is subjected to a transient rise in vertical stress as the edge of the undercut approaches, followed by stress relief after passage of the undercut. Results indicate that typical drawpoints in aplite could be subject to as much as a +28% (+4.1 MPa (+600 psi)) rise above pre-mining vertical stress levels (15.0 MPa (2,180 psi)) and relief of more than –90% (-13.8 MPa (-2,000 psi)) of pre-mining stress levels. A narrower range (+7% to –80%) is predicted in the weak andesite due to its lower rock mass stiffness.

The advantages of a pre-undercutting sequence proposed for the East Block are also demonstrated in Figure 4. The figure shows that a pre-undercutting sequence, which can delay development 100 ft or more beneath the edge of the undercut, avoids exposure to peak abutment loads. Thereafter, entries are subject to modestly increasing loads (up to +7.6 MPa (+1,100 psi)) as the cave grows. With a mature cave, steady-state stress levels are not expected to exceed about 60% of pre-mining levels (or about 9.0 MPa (1,300 psi)). The lower stresses encountered with a pre-undercutting sequence reduce requirements for ground support.

3. EVALUATION OF GROUND SUPPORT REQUIREMENT

Ground-support interaction analyses were performed for the weak andesite and strong aplite, respectively, at the planned four-way LHD line drawpoint intersections in the East Block (shown in Figure 5). In the model, production level excavation was simulated by deleting the material representing the drifts and incrementally reducing the pressure on the walls of the drifts from the pre-mining level to zero. At the end of each incremental relaxation, displacement of the drift wall was recorded.

Ground-reaction curves were calculated for three key stages during the undercutting sequence: (1) just ahead of the undercut, (2) immediately after the undercut, and (3) at a central location after the entire East Block had been undercut. The first stage represented peak abutment loading

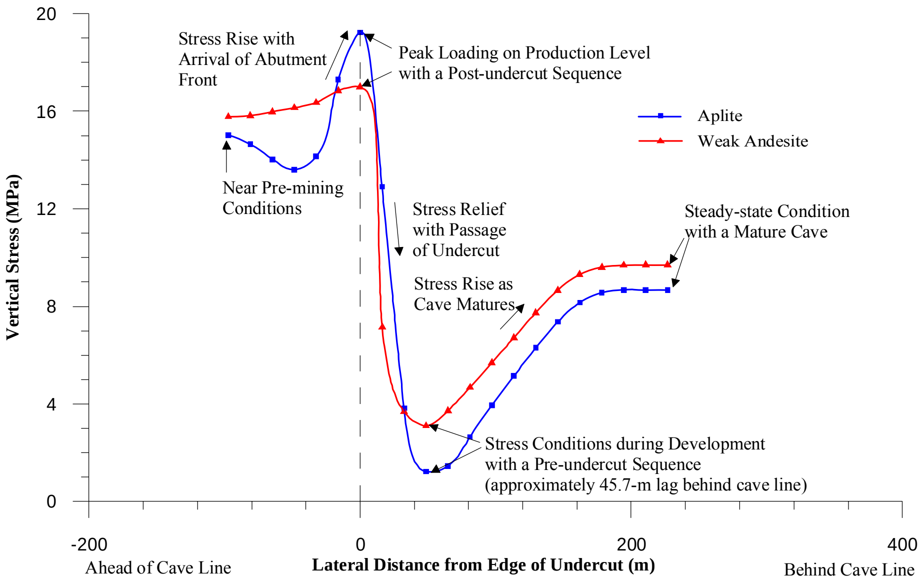

Fig 4. Vertical stress history on a typical draw line during the East Block undercut—7180 LHD Level.

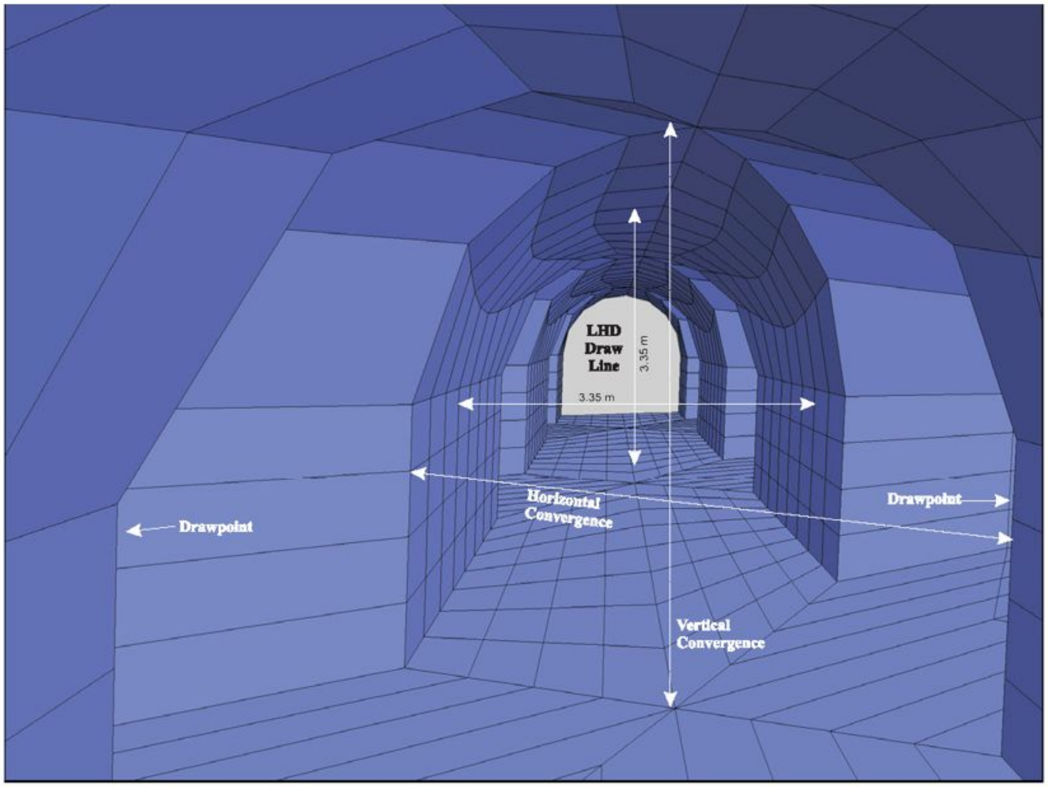

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Fig 5. LHD line-drawpoint intersection geometry detail—FLAC^{3D} model.

conditions that would be encountered with a post-undercutting sequence. The second stage represented worst-case ground conditions anticipated with a pre-undercutting sequence. Finally, the third stage represented the steady-state conditions long after passage of the undercut for either a pre- or post-undercutting sequence.

Figure 6 shows calculated reaction curves for the 7180 LHD Level line-drawpoint intersections in weak andesite. Model results indicate that as much as 16.5 cm (6.5 inches) of vertical and 7.6 cm (3 inches) of horizontal convergence will develop in the weak andesite with a post-undercutting sequence if no significant support is used, as illustrated in Figure 7a. This amount of convergence is expected to result in disintegration of the rock mass and collapse of the opening.

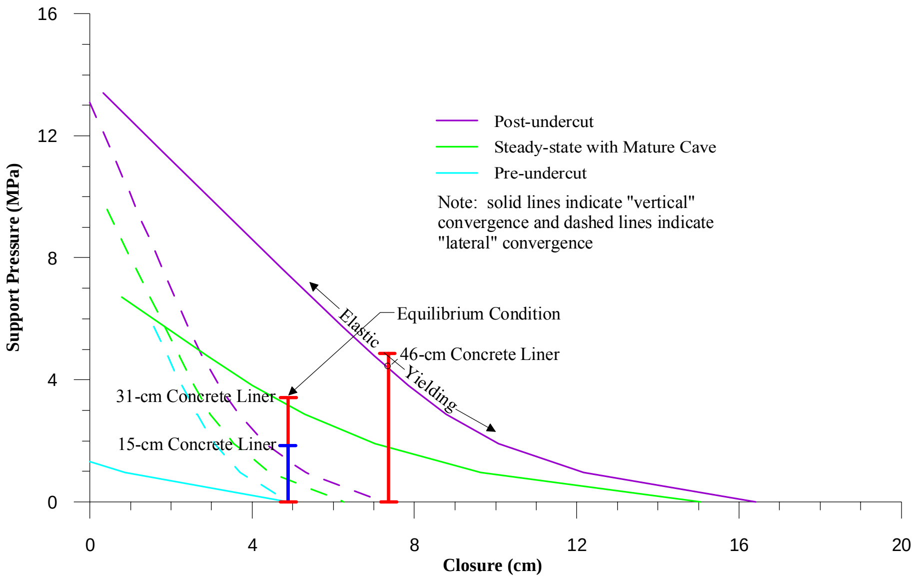


Fig 6. Ground-support interaction curve for typical LHD line—Drawpoint intersection in weak andesite.

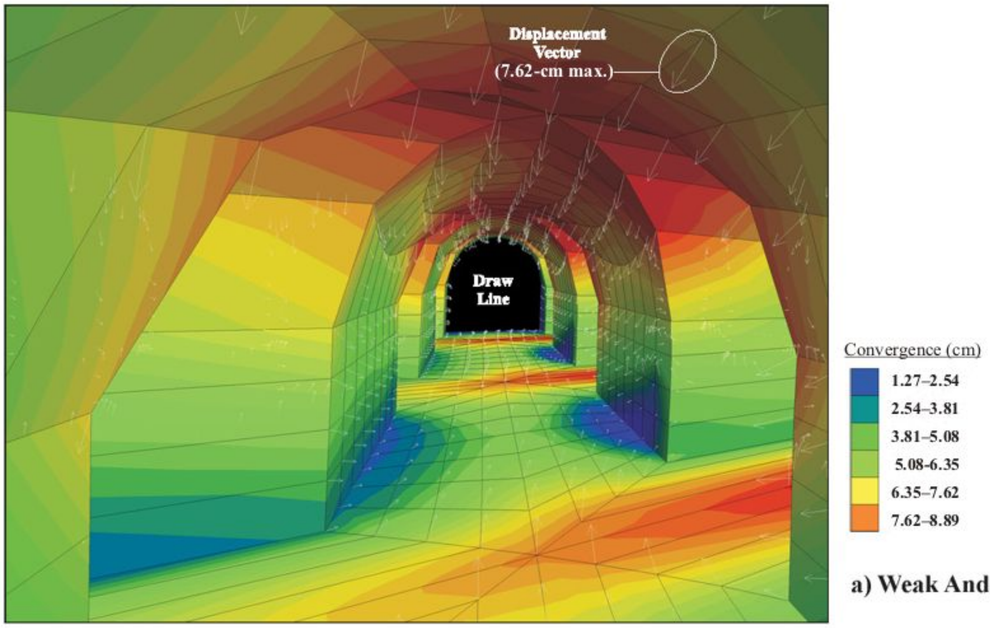
Extensive rock mass yielding around production lines and drawpoints is indicated in the model results shown in Figure 8a. Modeled convergence (vertical and horizontal) is reduced to approximately 5.1 cm (2 inches) by selecting a pre-undercutting sequence. Although the opening is still predicted to be unstable without support, implications are that a pre-undercutting sequence will substantially reduce the amount of support required to maintain stability.

Support stiffness and pressure capacity characteristics are calculated from equations of support performance documented by Hoek, Kaiser, and Bawden [3] and Brown [4]. The support stiffness and equivalent pressure capacity for concrete used in the calculations are listed in Table 2. Results indicate that 30.5 cm of concrete will be required working together with 2.4-m, 2.2-cm-diameter (8-ft, ⅞-inch-diameter) torque tension rockbolts for the production drifts in weak andesite. The contribution of other support elements such as split sets and rockbolts is minor relative to that of a shotcrete/concrete liner, and can be ignored in the support pressure calculations. However, because split sets and rockbolts can be installed earlier than shotcrete/concrete, they are useful for preserving the in situ strength of the rock mass by limiting early-stage convergence during development.

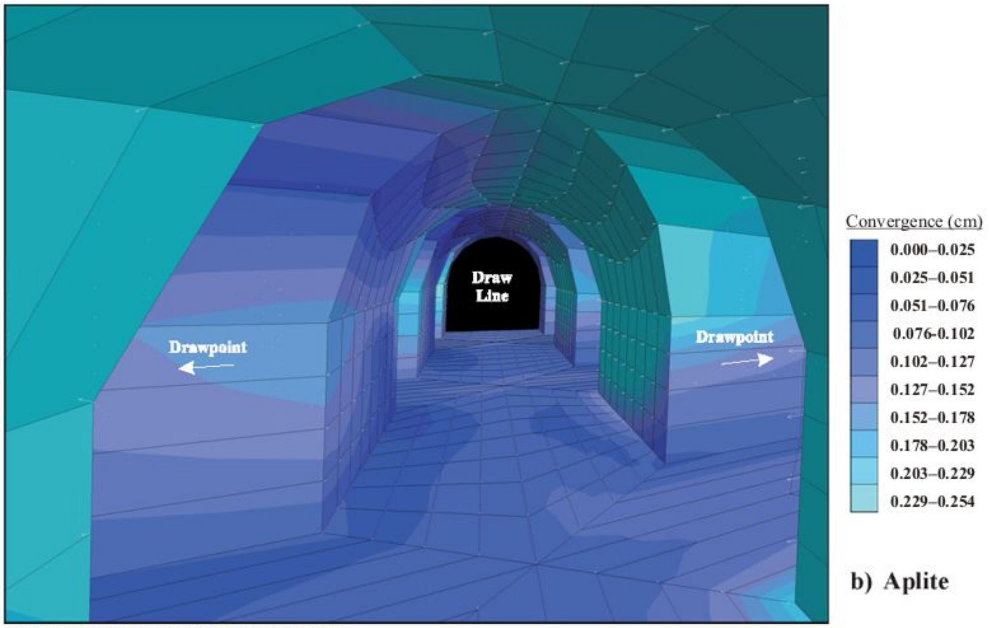
Figure 9 shows the pressure-deformation curves for the production drifts in strong aplite. Results indicate that peak ground pressures will not exceed the strength of the typical aplite rock mass in the East Block. Model results show that entry convergence is limited to elastic-only deformation. This is evident by the very small magnitudes of convergence and linearity of the ground-reaction curves in Figure 9. Figure 7b shows minimal convergence in the production lines in the aplite relative to the weak andesite. No significant rock mass yielding is likely to occur, even under worst-case abutment loading associated with a post-undercutting sequence, as shown in Figure 8b. The figure indicates only minor tensile yielding on the ribs of the entries caused by the "rebound" effect after removal of overburden pressures during undercutting. Implications are that only relatively light and flexible secondary support, designed to control spalling and surface dilation, will be required in the competent aplite.

4. CONCLUSIONS

Ground support requirements for the D Orebody, LHD West and East blocks vary according to rock mass quality and undercutting sequence. Based on the results of calibrated numerical modeling and mining experience, conclusions are that thick shotcrete liner will be required in the southern half of the D Orebody where andesite is prevalent, while relatively light support will be required in the aplite to ensure reliable performance during caving operations. Compared to a post-undercutting sequence, pre-undercutting significantly reduces abutment loading on the lines and drawpoints by locating development beneath the stress shadow of the undercut.



a) Weak Andesite



b) Aplite

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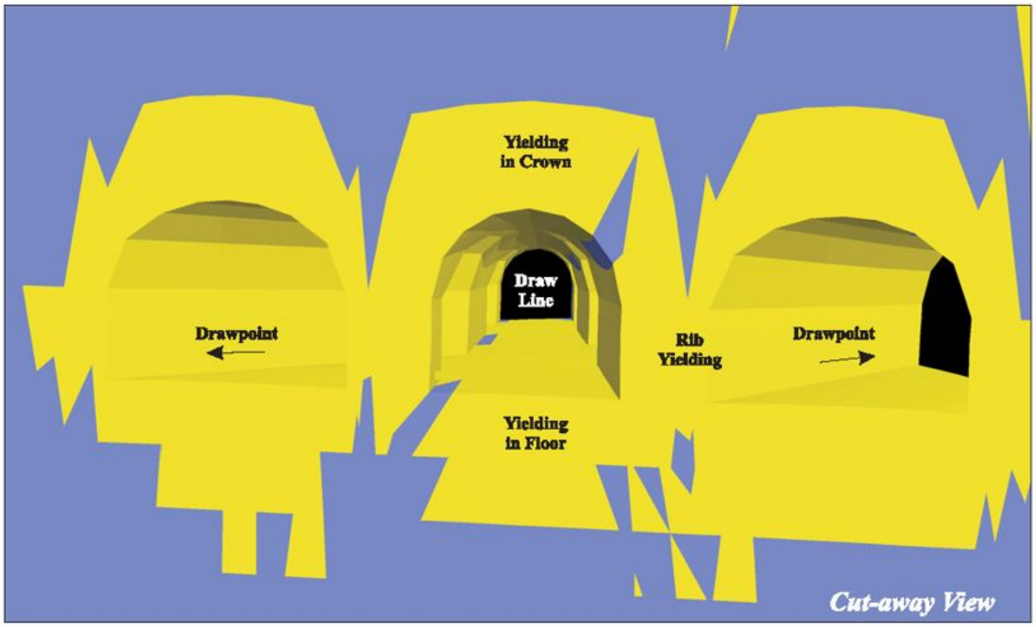
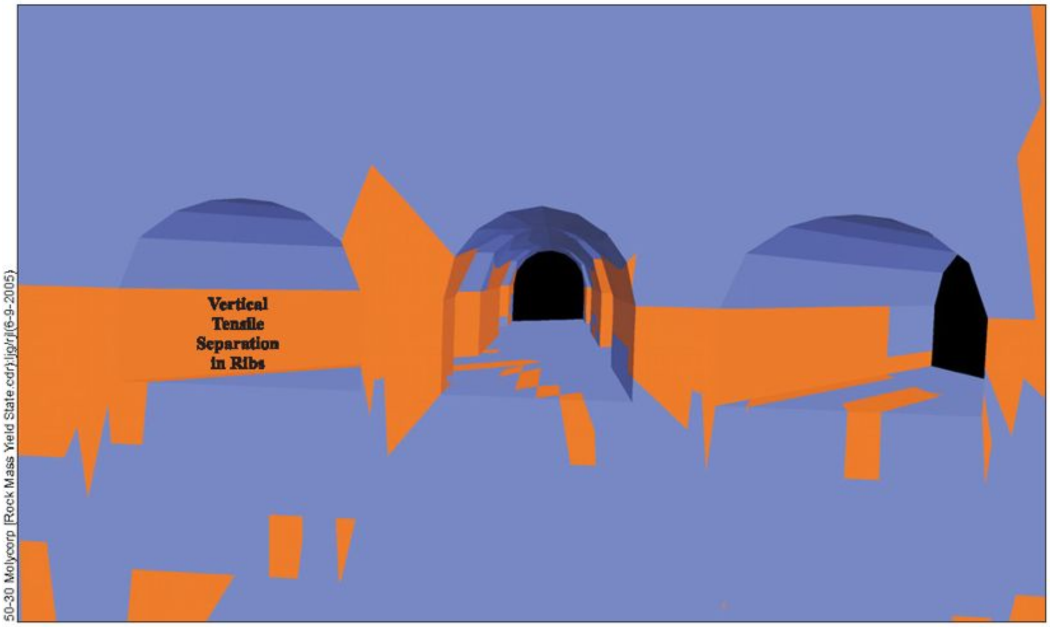
Fig 7. Modeled draw line convergence with a post-undercutting sequence, peak abutment loading—7180 LHD Level.



Rock Mass Yield State Key

🟦 None 🟧 Tension 🟨 Shear

a) Weak Andesite



b) Aplite

Fig 8. Modeled rock mass yielding around a draw line with a post-undercutting sequence, peak abutment loading—7180 LHD Level.

Table 2. Support Characteristics of Concrete Liner and Rock Bolts.

	Concrete Liner Thickness		Rockbolts‡
	15.2 cm† (6 inches)	30.5 cm† (12 inches)	
Support Stiffness, MPa (psi)	21,650 (3,140,000)	46,750 (6,780,000)	22.8 (3,310)
Equivalent Support Pressure, MPa (psi)	1.8 (260)	3.4 (495)	0.1 (16)

† Concrete compressive strength 20.7 MPa; concrete liner assumed to be a closed ring.

‡ 2.4-m-long (8-ft-long), 2.2-cm-diameter (⅞-inch-diameter), Grade 60, resin-anchored rock bolts; bolt tributary area 1.46 m^2 (15.7 ft^2) (9-bolt ring, 152.4 cm-longitudinal (60-inch-longitudinal) spacing).

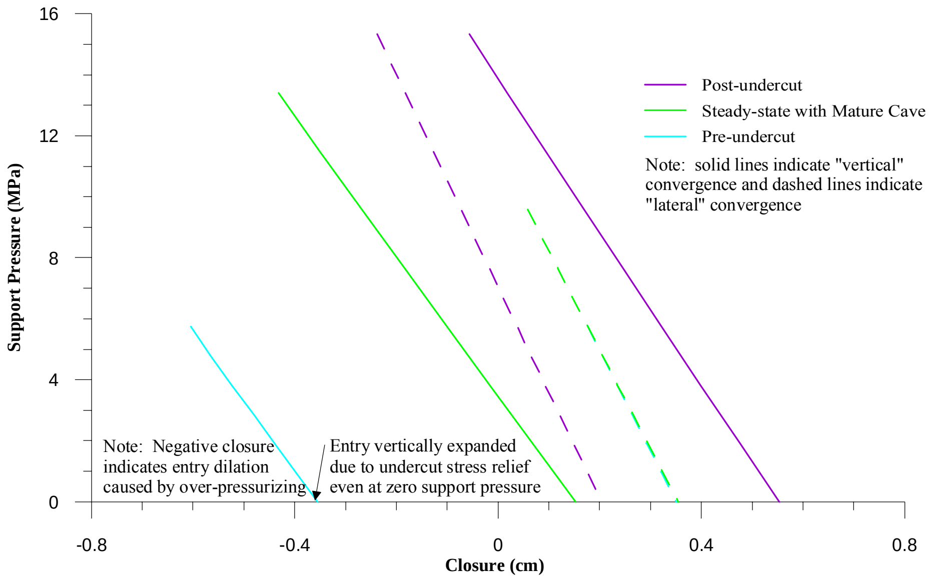


Fig 9. Ground-support interaction curve for typical LHD line—drawpoint intersection in aplite.

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