Layers of possibilities

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Type of Ground Support Based on Numerical Modeling

Sia Taghipoor
Serge Tousignant
Dan Laing
Dean Switzer

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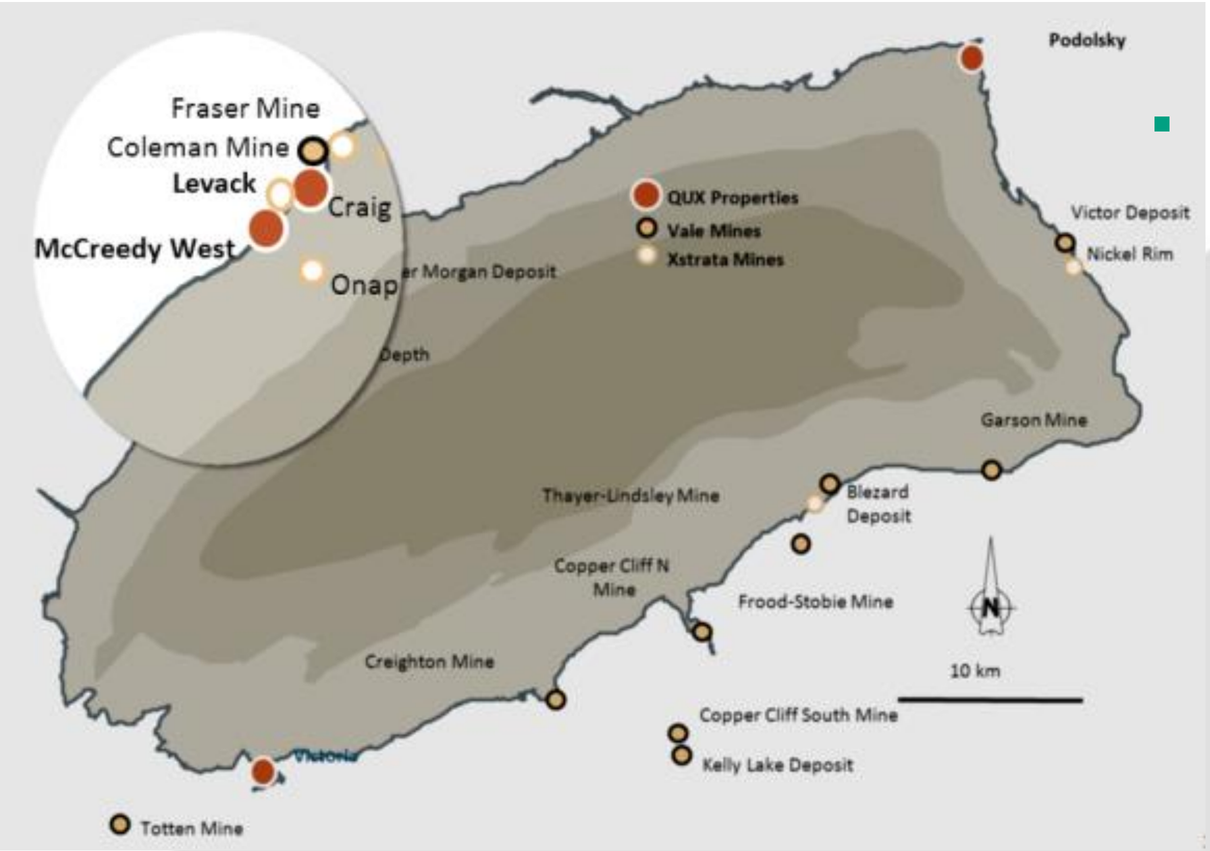
Morrison Mine: Location

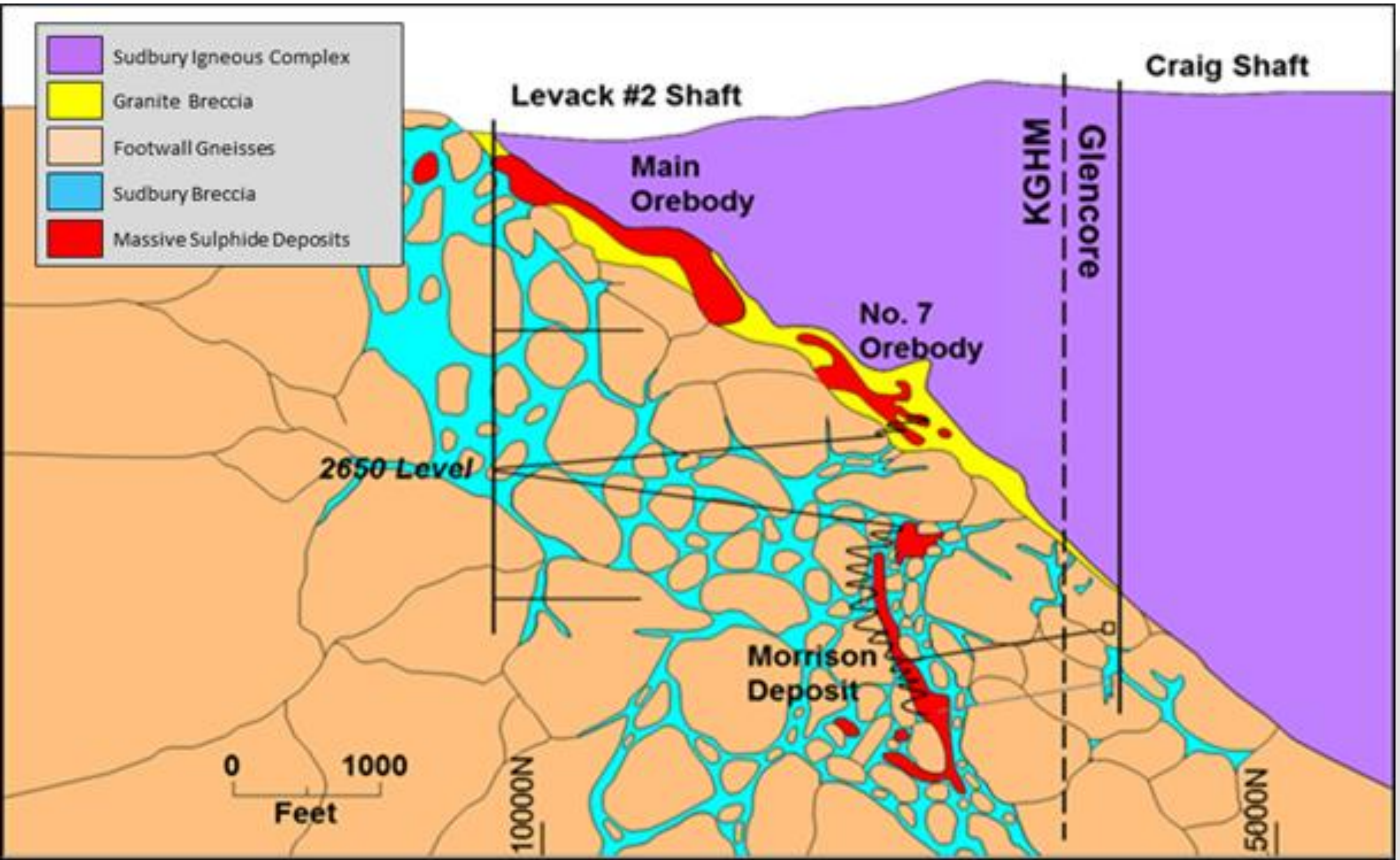
- The Morrison Mine is located in Levack Township within the City of Greater Sudbury, approximately 45 km north-west of the downtown core of the city.
- A 2012 agreement between FNX and Xstrata allows access to the Morrison Deposit via the Craig Mine Shaft.
- The Morrison Mine is situated on the margin of the 1.85 Ga Sudbury Structure, a remnant of a deformed multi-ring impact crater.



- The structure includes a prominent elliptical formation known as the Sudbury Igneous Complex (SIC), its associated offset dykes, and footwall-hosted pseudotachylite, locally known as Sudbury Breccia (SUBX).

Levack Mine Idealized Geologic Section

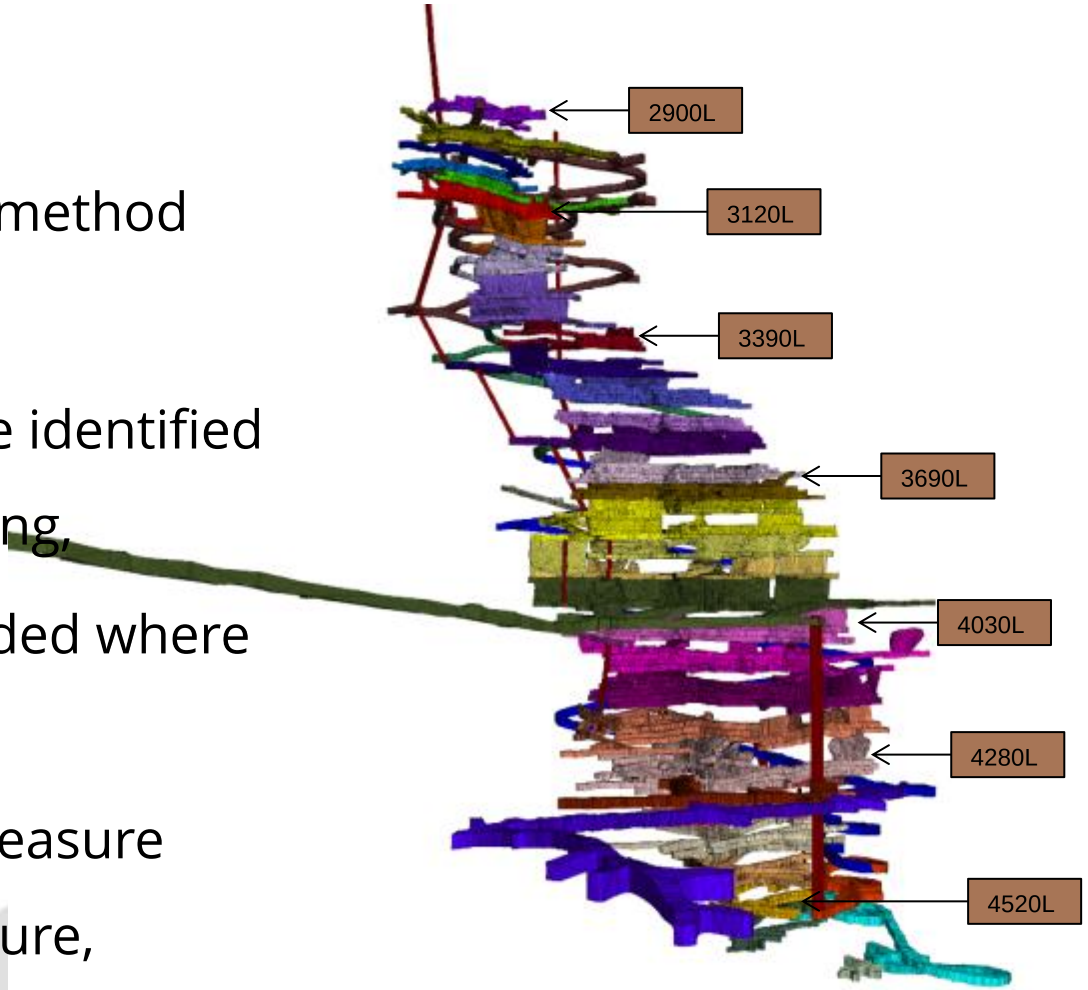
- Contact Ni mineralization occurs at the base of the main mass of the SIC, typically hosted within the Sublayer or Granite Breccia,
- Sulfides occur as massive, semi-massive and blebby. They are typically characterized by pyrrhotite, pentlandite ±chalcopyrite dominated assemblages.
- Footwall deposits are characterized by chalcopyrite-rich assemblages hosted typically within Sudbury Breccia proximal to the SIC contact.



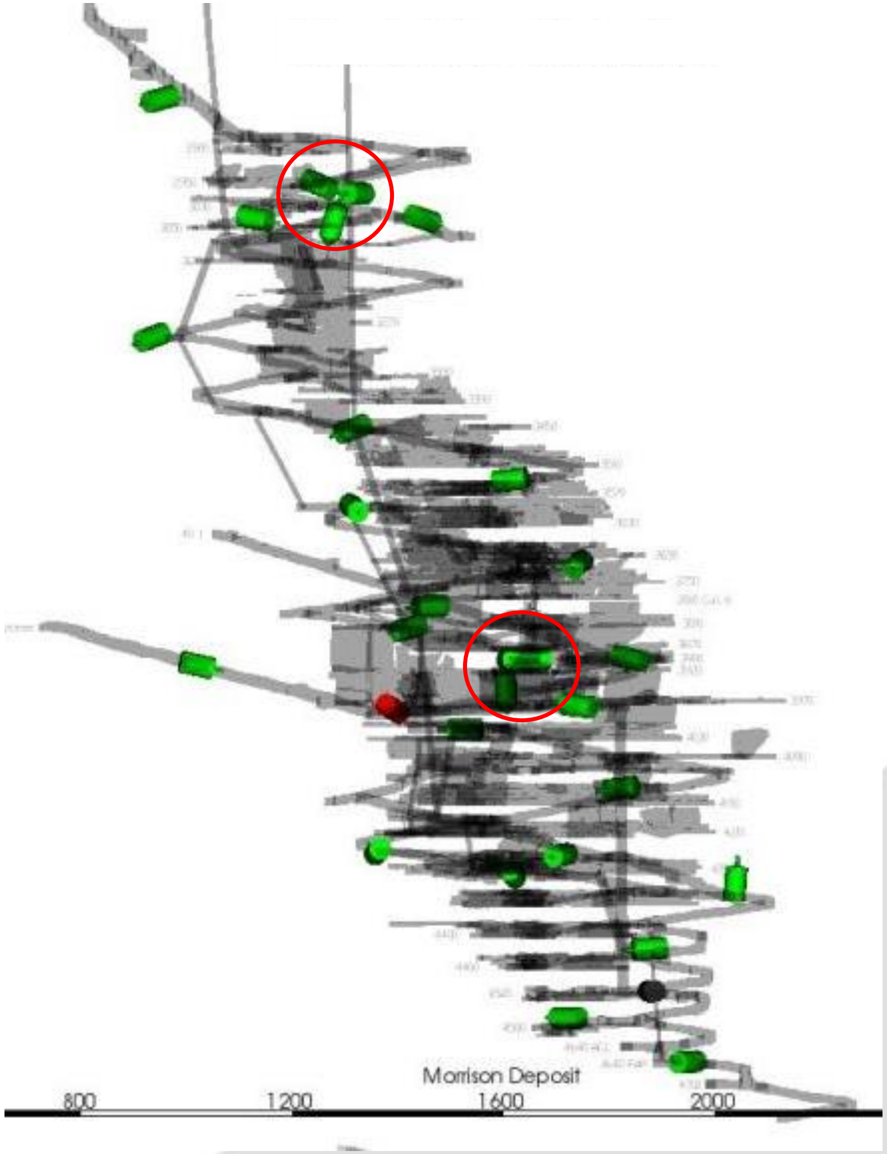
- Blocks of granodiorite gneiss, granite gneiss, mafic gneiss, and metagabbro are common within the SUBX package,

Morrison Mine Layout

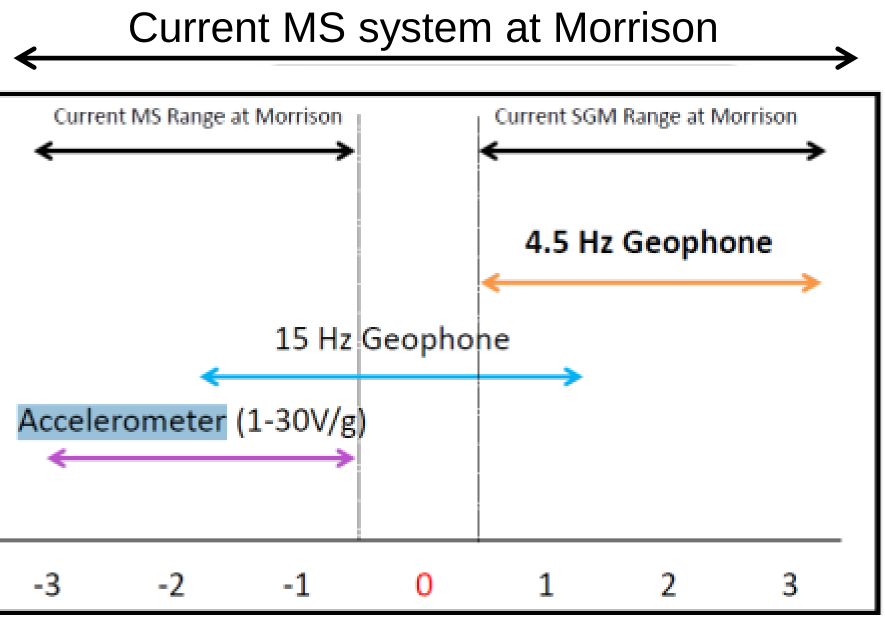
- Cut & Fill and Longhole mining method
- Sill Pillars mined with longhole,
  - Highly stressed areas were identified through numerical modeling,
  - Class Z, A & B support added where risk is higher
- Monitoring instruments to measure ground movement and pressure,
  - MPBX, Crack Gauge Meters, Pressure Cells and Telltales installed to measure ground displacement and strain,



Microseismic System – A Mixed Sensor Type Array



- Micro-Seismic monitoring System installed in 2013 and extended in 2014 and 2016,
- Procedure in place to automatically alert hoistman and engineering department when a large event or high rate seismicity occurs,



- 18 each Accelerometer (Uniaxials),
- 2 each 15 Hz Geophones (Triaxials),
- 2 each 4.5 Hz Geophone (Strong Ground Motion Sensor on Surface)`

Rock Burst Mechanism

- Stress
  - Stress exceeds strength of rock mass due to mining
  - Forecast requires knowledge of **rock mass strength**, in situ stresses and mined geometry
  - Severity depends on size of pillars and magnitudes of stresses, ground condition as well as mined volume
- Structures
  - Stress exceeds strength of part of a structure due to mining
  - Forecast requires knowledge of **orientation** and **strength of the structure**, in situ stresses and mined geometry
  - Severity depends on mined volume, in situ stress magnitudes and extend of movement on the structure
- This presentation investigates the rock bursts induced by stress concentration at the Morrison Mine.

Most Common Material Behaviors used in Numerical Modeling

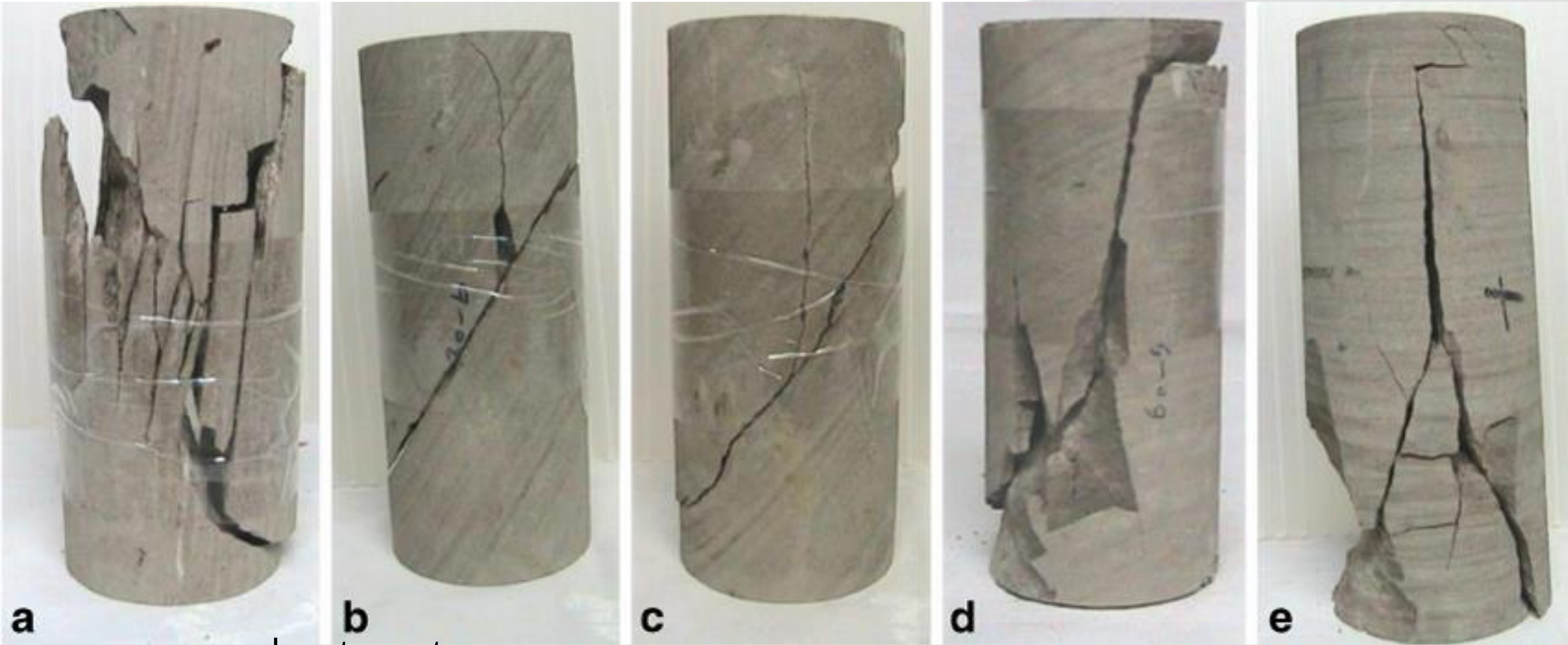
- **Elastic behavior**
  - Material can carry load **WITHOUT** limitation,
  - More loading leads to more deformation,
  - Load-deformation relation could be linear or non-linear,
  - Implementation imposes some level of risk as stress migration is not captured properly,

- **Elasto-Plastic behavior**
  - **Perfect plastic**
    - Material carries load up to a limit
    - Material deforms at strength limit **WITHOUT** any stress drop.
    - In other words, more damage does not affect material strength,

  - **Strain Softening**
    - Material loses strength at peak strength
    - As damage progresses, more strength drop is experienced. More damage leads to larger strength drop up to a point that material will not have cohesive strength.
    - Quick (abrupt) energy release due to failure causes rock burst,
    - Implementation requires accurate knowledge of strength and deformation characteristics of the rock mass

Why Elasto-Plastic Constitutive Model and Strain Softening?

- Fracturing process in rock mass involves strain localization and formation of shear bands,
- Shear bands includes cracks and fractures making the rock mass weaker than the initial condition,
- If elastic model is used, the material does not fail and keeps carrying load without limitation,
- Stress migration is not captured as it should,



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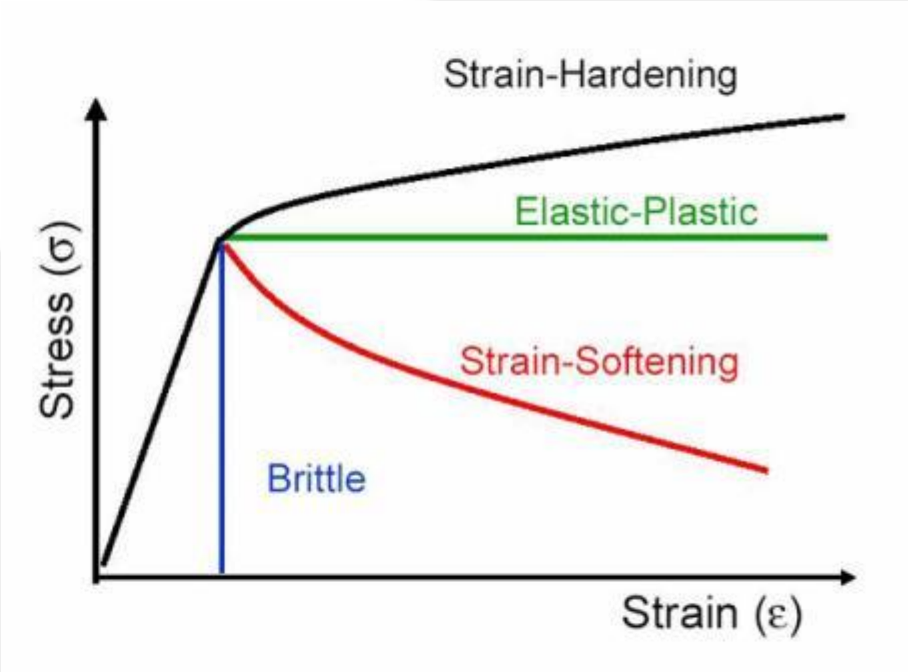
Why Elasto-Plastic Constitutive Model and Strain Softening?

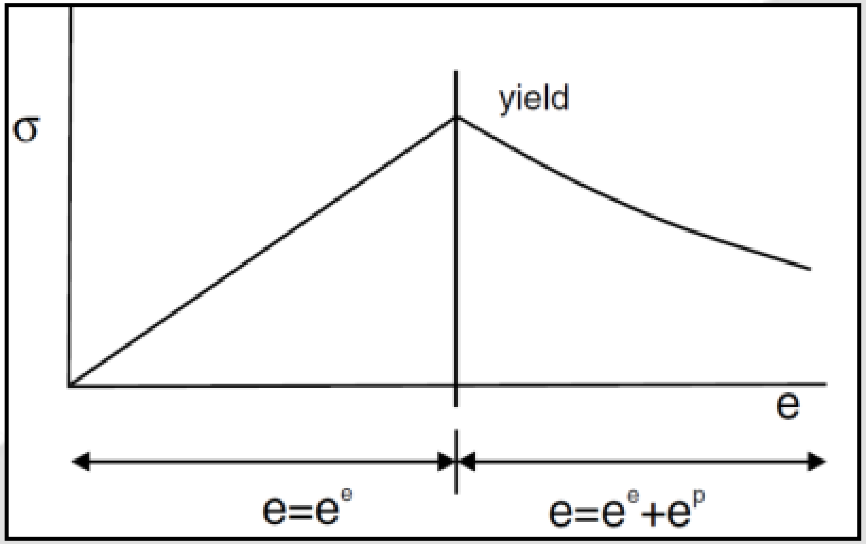
- Elasto-plastic strain softening constitutive model provides the opportunity to properly simulate post peak behavior in mined pillars
  - i.e. the transfer of excessive stress to adjacent pillars,
- Also the accumulated plastic shear strain can be used as a measure to forecast damage,
- Stress path as well as cohesion can also be used to identify high risk areas and forecast rock bursts,



http://www.theconcreteportal.com

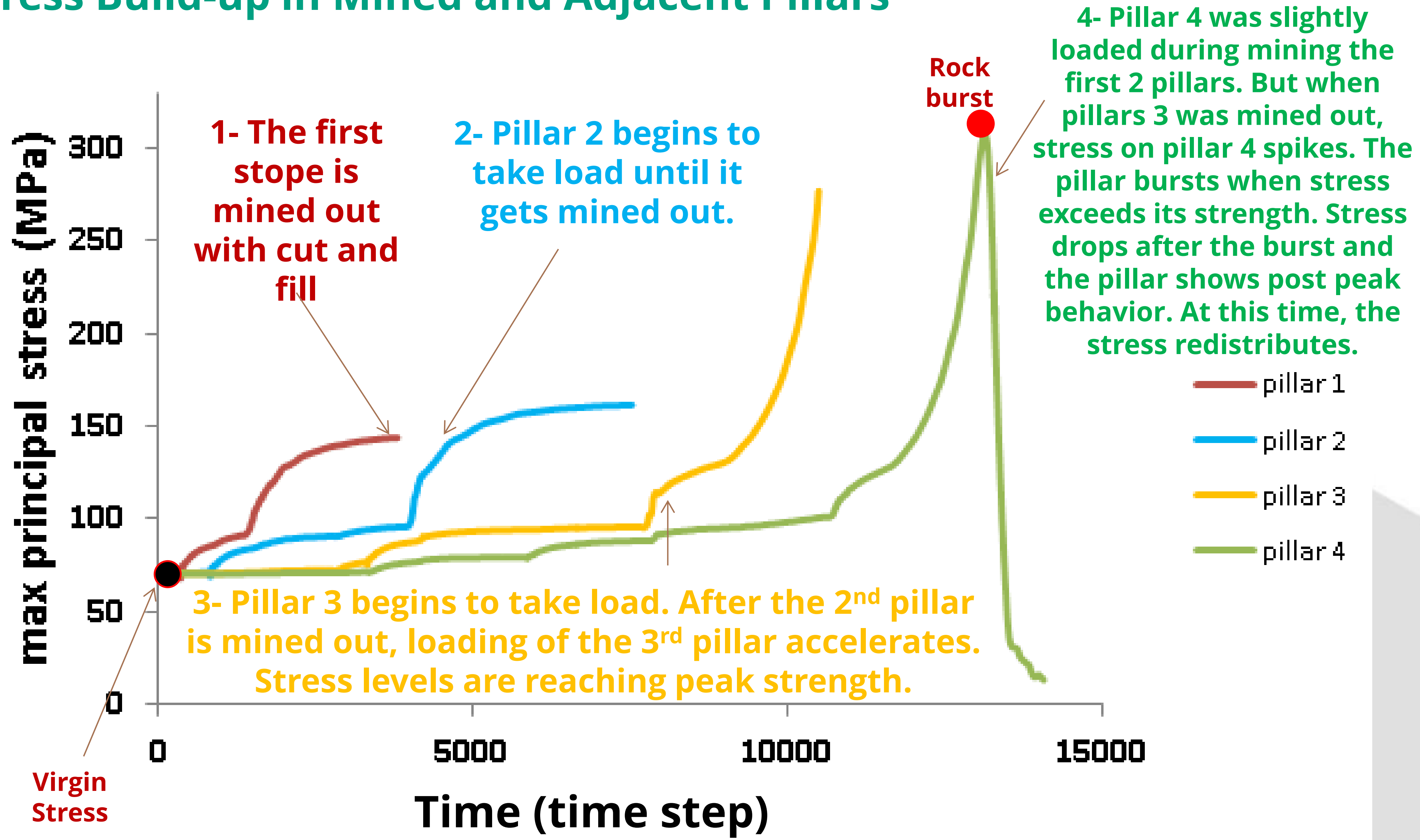
Numerical Model of the Morrison Mine

- FLAC 3D (Itasca, 2015) was used for modeling purposes,
- Rock mass properties were estimated based on UCS and triaxial tests were performed and combined with rock mass classification,
- With the estimated magnitudes and direction of the in situ stresses, back analysis was performed to refine the rock mass properties,
- A good match was obtained with the microseismic data and observed damage (FOG and Rock Bursts)
- The model is currently being used to identify high risk areas, assign proper dynamic support and forecast damage,



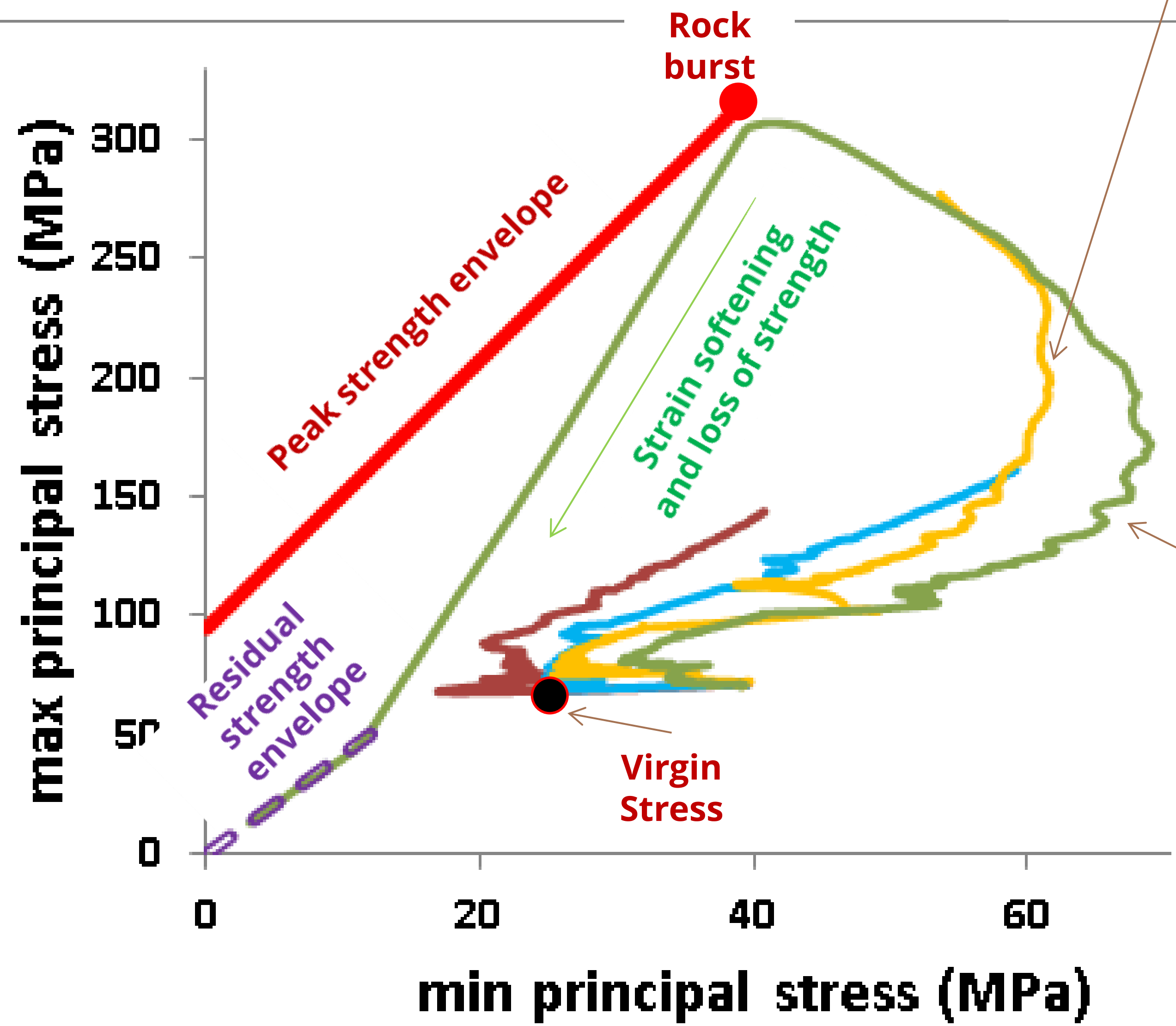
Conceptual stress-strain behavior in strain softening model (ITASCA, 2013)

Stress Build-up in Mined and Adjacent Pillars



Stress Path Signature of a Rock Burst

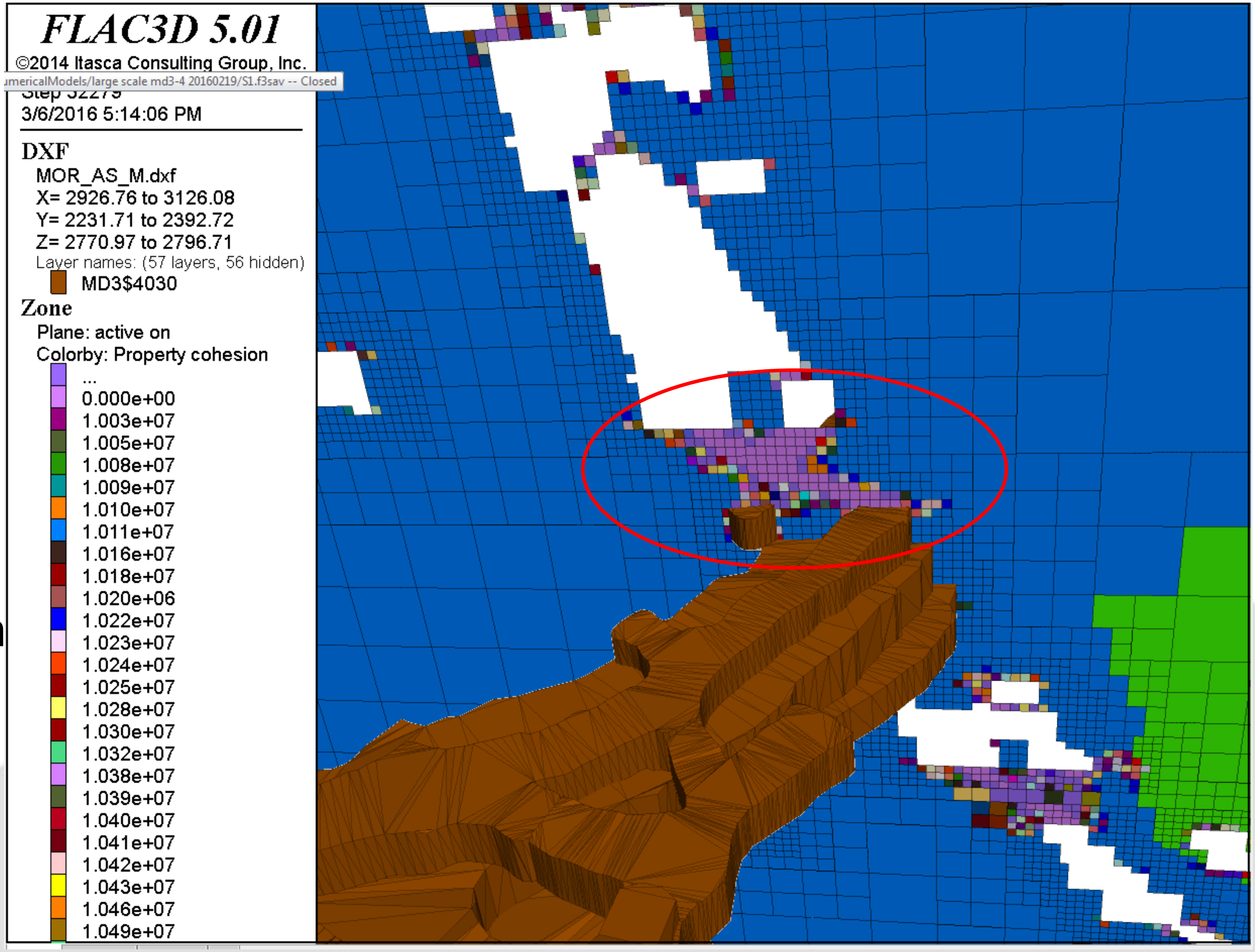
1) Pillar 3 was loaded significantly but mined out before stress reaches the rock mass strength



2- Stress on pillar 4 spikes due to mining the first 3 pillars. The pillar bursts when stress exceeds its strength. Stress path hits the peak strength and rock burst occurs. Material fractures and subsequently, stress path follows the residual strength and the pillar shows post-peak behavior.

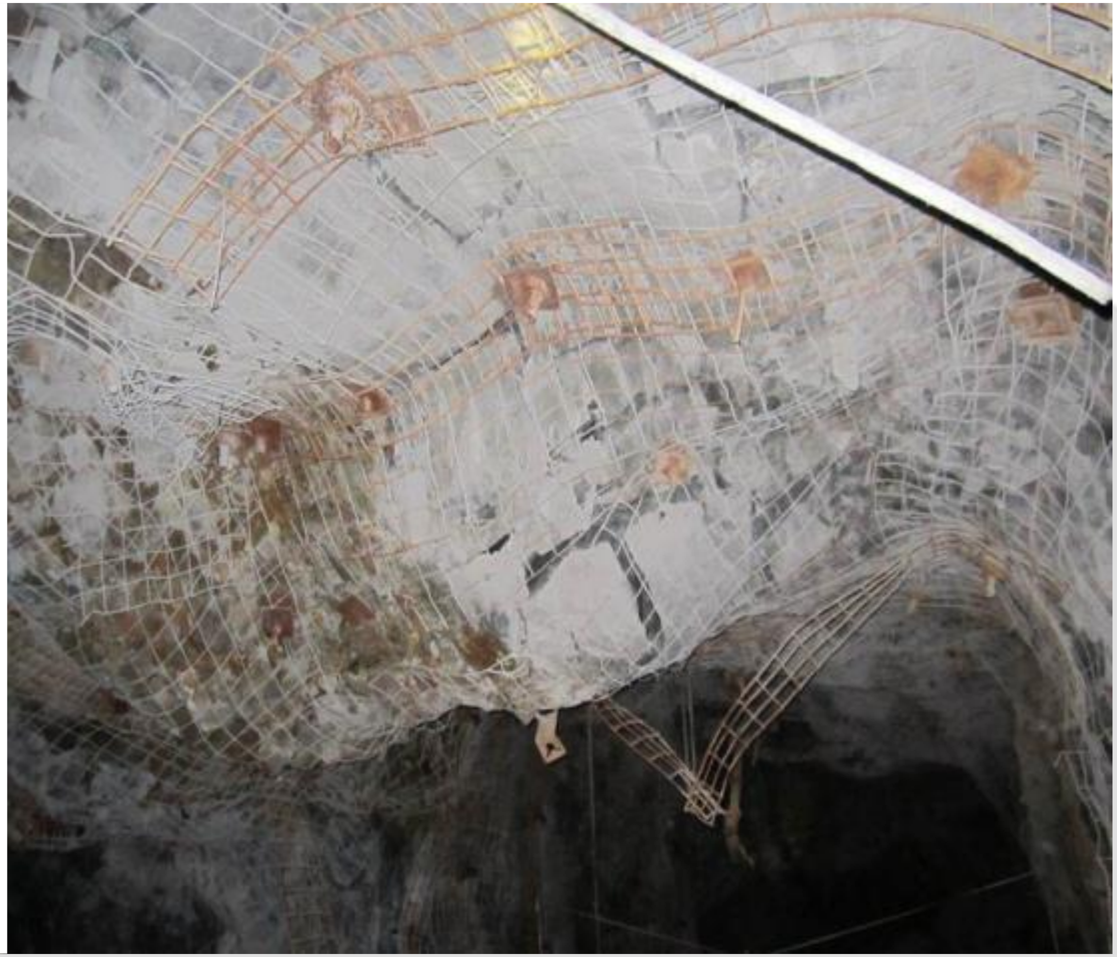
Case 1: Loss of Cohesion-Sign of Rock Burst– 4030L

- The results of modeling indicated that a pillar burst is likely to occur,
- Stress concentration was almost symmetric within the pillar,
- The whole pillar was highly stressed out,
- Cohesion was lost in the whole pillar, which is shown by purple color in the plot,
- Degradation of cohesion, which occurs due to strain softening, is a sign of overstress and potential rock burst,

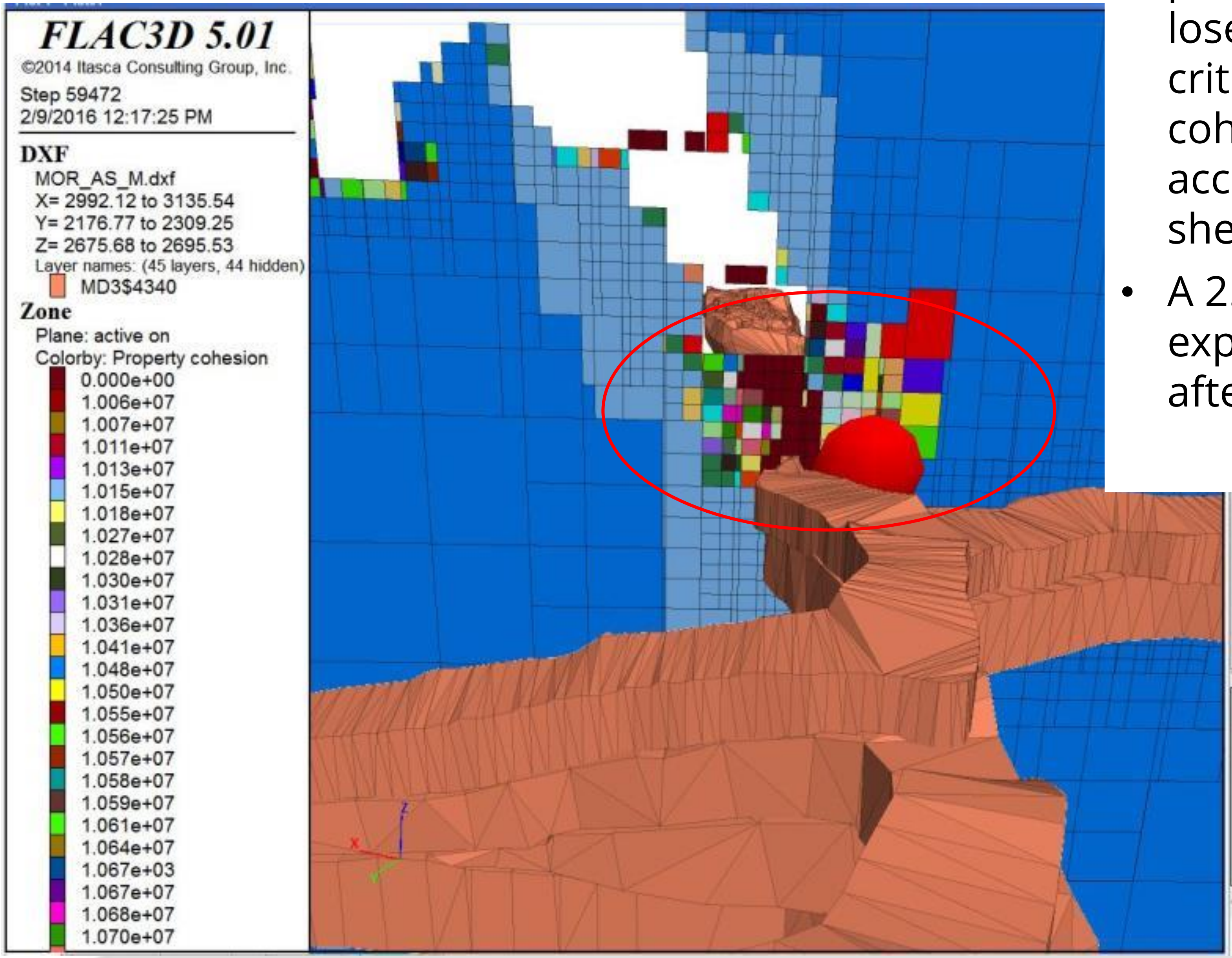


Stress Concentration-Rock Burst in Back – 4030L

- Three concurrent development blast were taken at the level, which momentarily pushed the stress path toward peak strength,
- A few hours after the blasts, a 2.55 M_w event (largest ever at Morrison) occurred that caused severe damage to the drift,
- Damage was concentrated in the ore in the back and shoulders only,

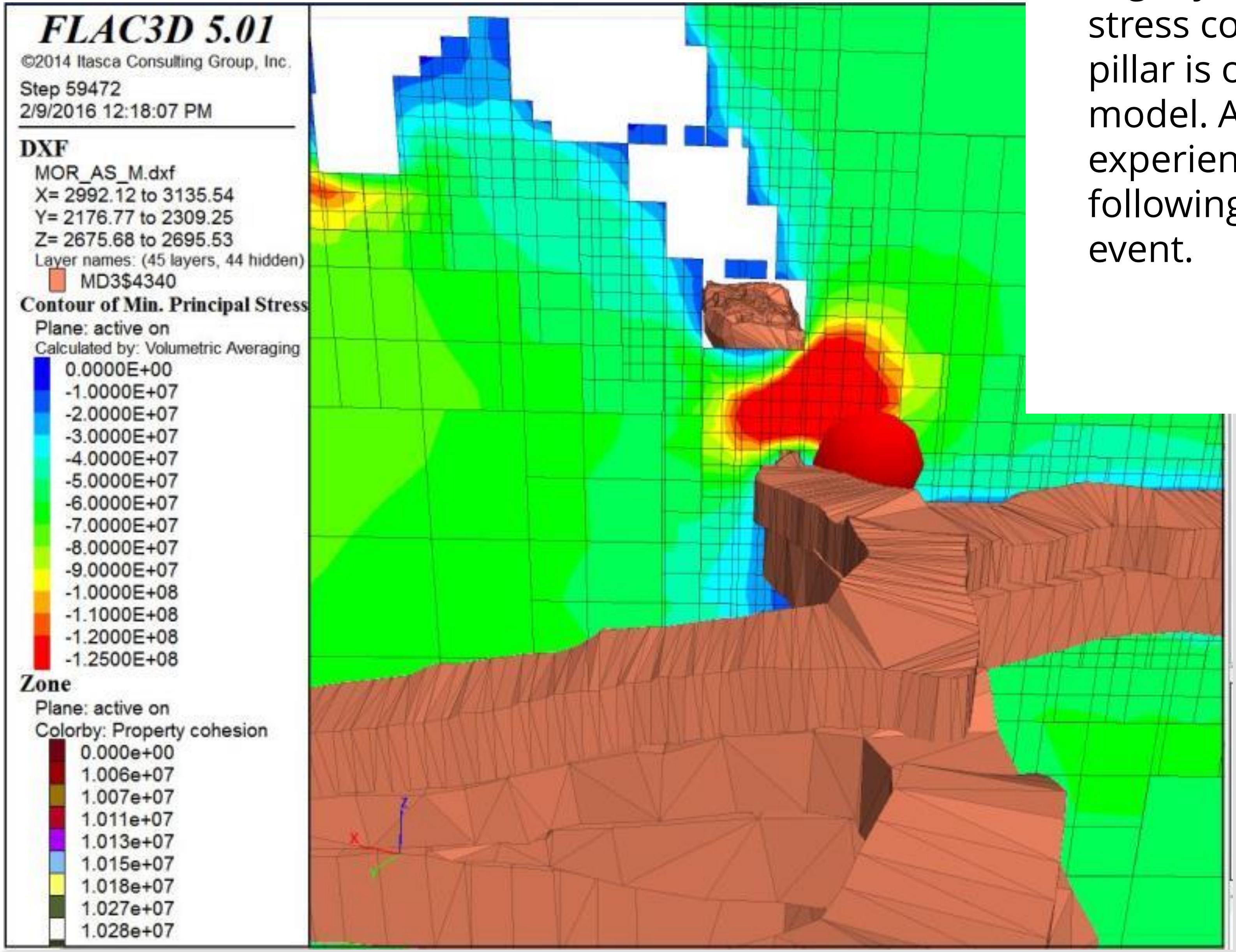


Case 2: 4340L, Contours of Cohesion



- As the stress path hits peak strength, material loses cohesion. In a critically loaded pillar, cohesion drops with accumulation of plastic shear strain,
- A 2.25 MM event was experienced in the pillar after a stope was taken.

4340L, Contours of Maximum Stress,



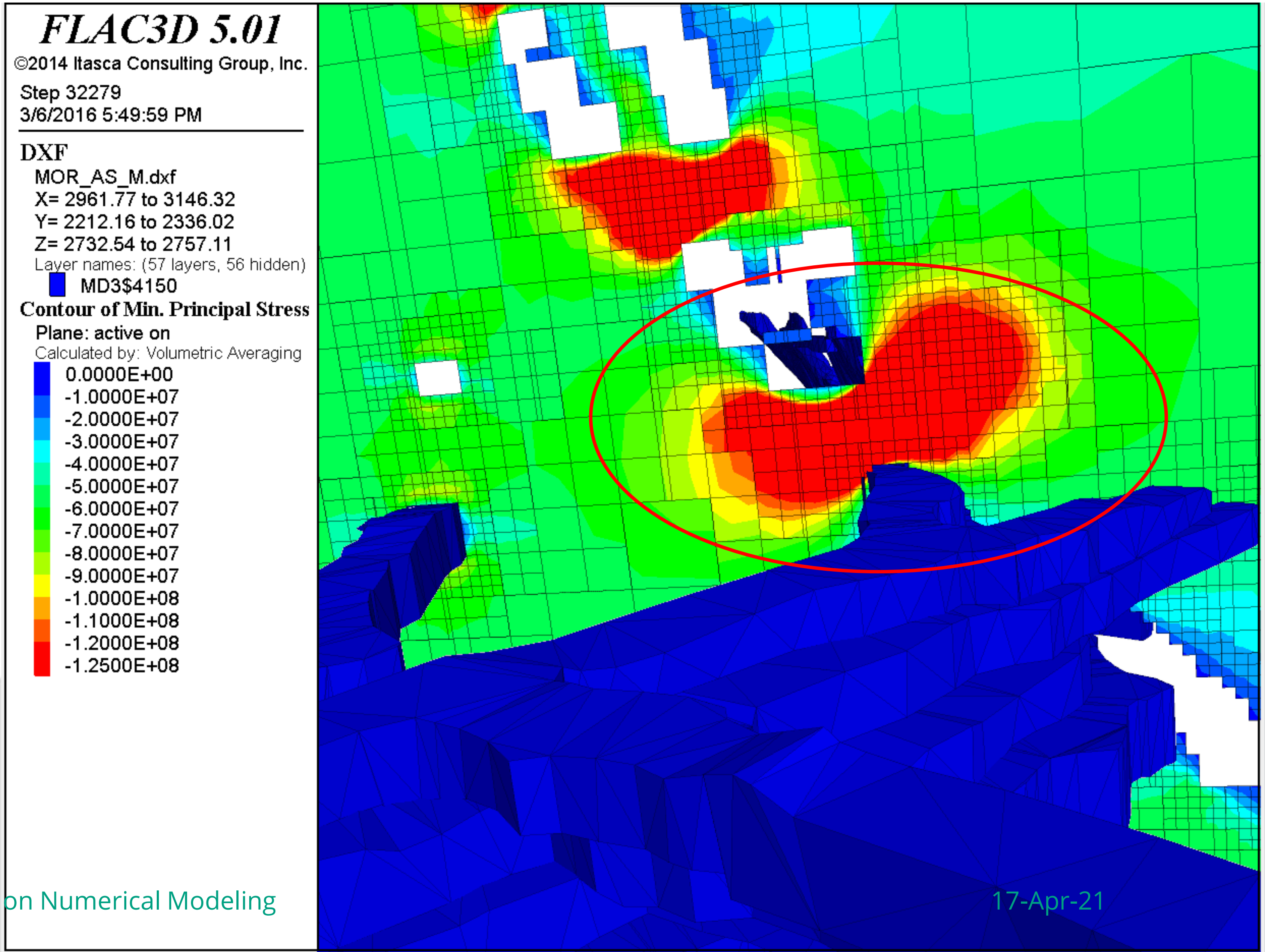
- Slightly non-symmetric stress concentration in the pillar is observed in the model. A rock burst was experienced in the left wall following the 2.25 MM event.

Wall Burst due to the Vein Appearing in the Wall

- Extended Class A Burst prone ground support
- Wall burst was experienced in the left wall following the 2.25 MM event.

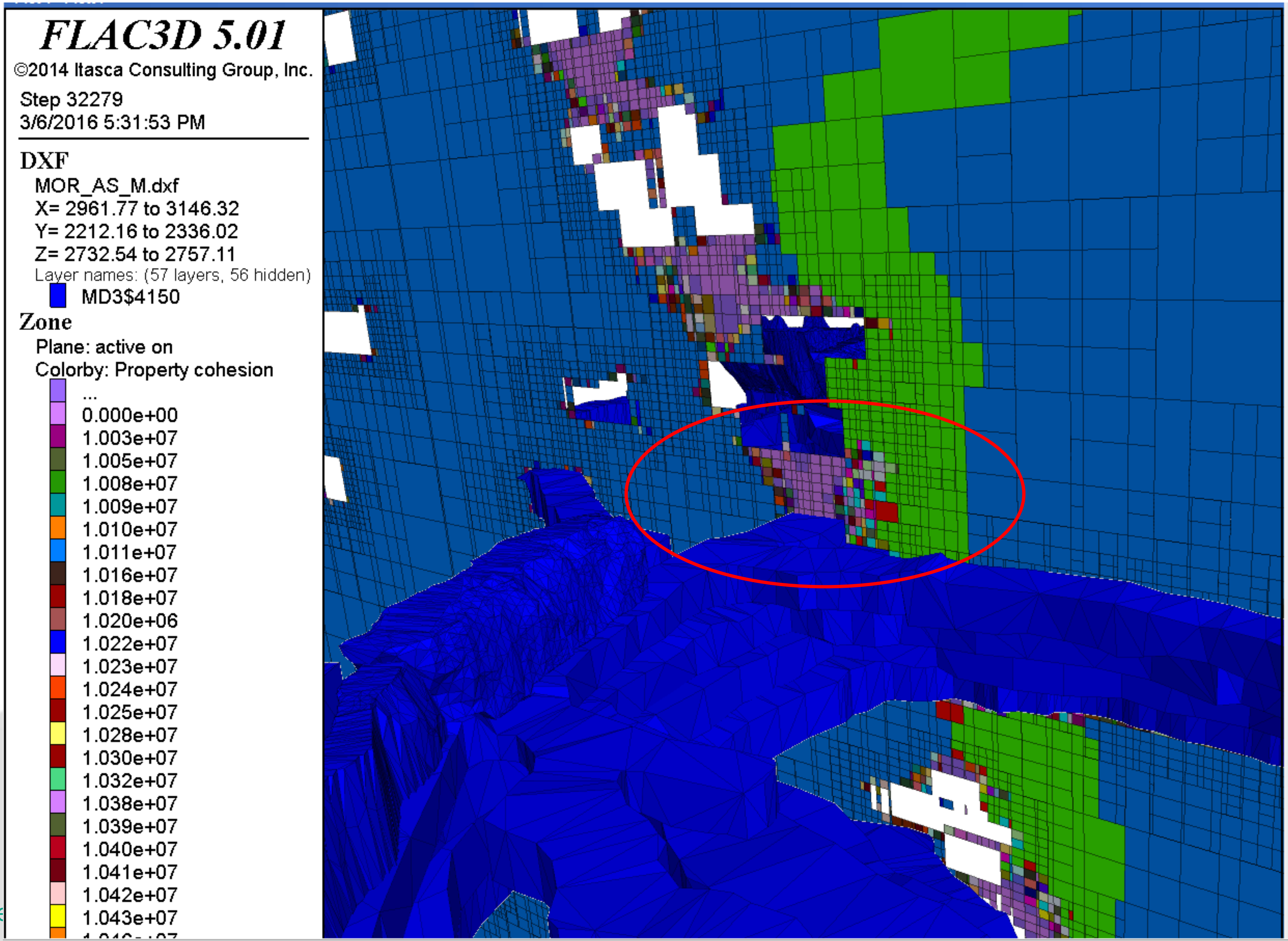
Case 3: Stress Concentration, Rock Burst in Walls – 4150 Cut 4

- Stress rotation as well as critical loading of the sill pillar,
- As stress is not symmetric, stress concentration was observed in the toe of right wall and in the left shoulder,



Cohesion Loss, an Indication of Rock Burst

- Contours of cohesion in the model indicated strain softening and loss of strength in the sill pillar, which previously proved to be an indication of a rock burst,



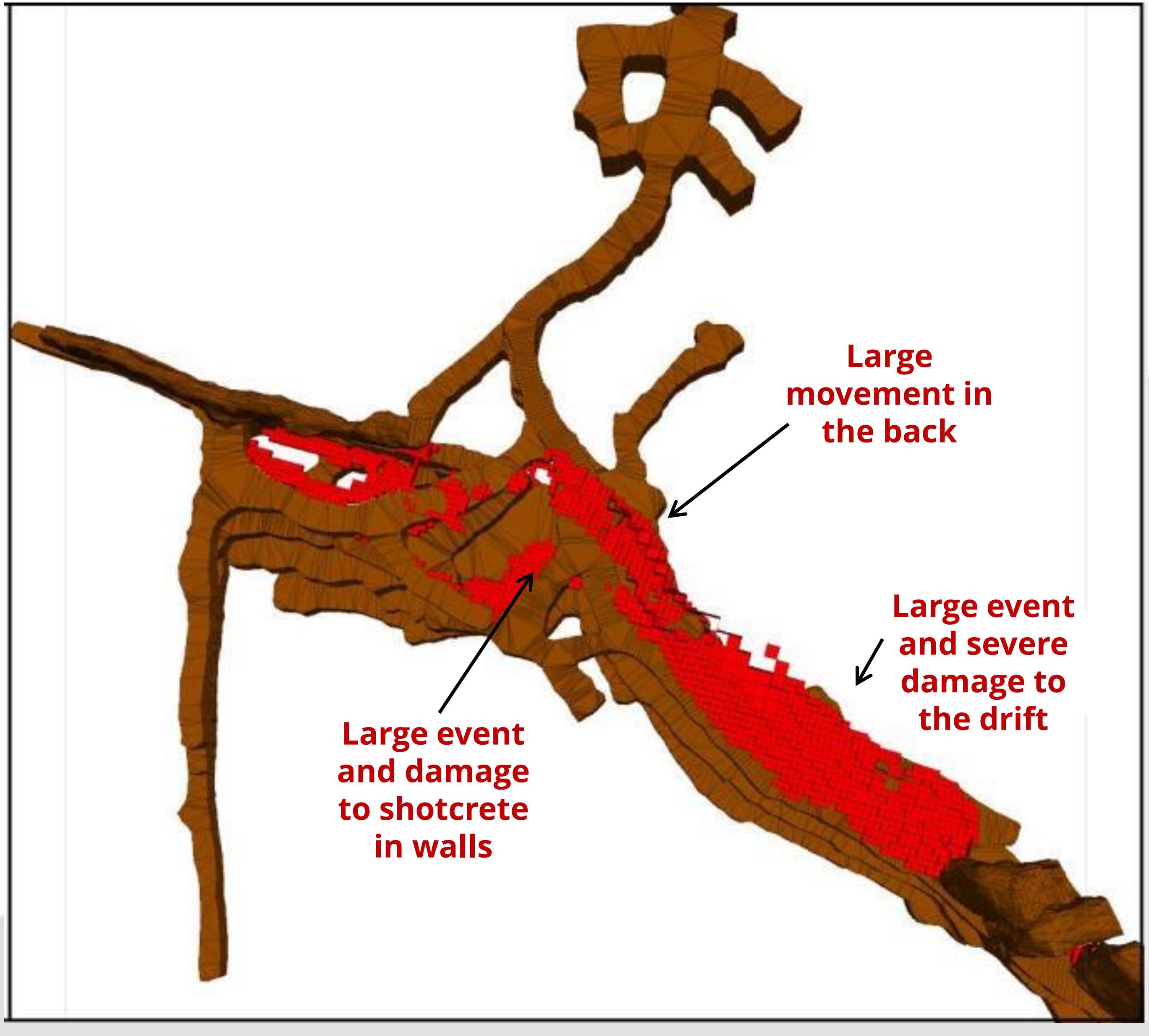
4150 Rock Burst

- 2 tons of material at the toe of the right wall was ejected following a 2.2 MM event,

- Class Z Burst prone ground support

Observed Rock Burst at the Toe of the Wall

Forecasting Damage – Volumetric Strain (Iso-Surfaces of 2%)



Summary and Conclusion

- Elastoplastic constitutive models with strain softening are proper tools to have a good resolution of the areas with potential rock bursts and enhances safety of crews
- In the case of an elastoplastic model with strain softening, stress migration is accurately modeled and critically load pillars adjacent to a mined out stope can be identified ,
- Stress path can be used as a strong tool to forecast rock bursts
- Abrupt cohesion loss could also an indication of rock burst. Cohesion loss in a pillar releases a large amount of energy as material goes post peak,
- Stress rotation due to ore shape, undercut relative location etc. can change the location of rock burst (back, shoulders, wall, toe of walls),
- Slight rotation of the maximum principal stress causes rock burst in wall. Large rotation can eject material from toe of walls.
- Proper dynamic support can be assigned to back, shoulders, walls as well as to toes, if stress is properly modeled,
- Proper material model and also brings saving in the use of dynamic support,