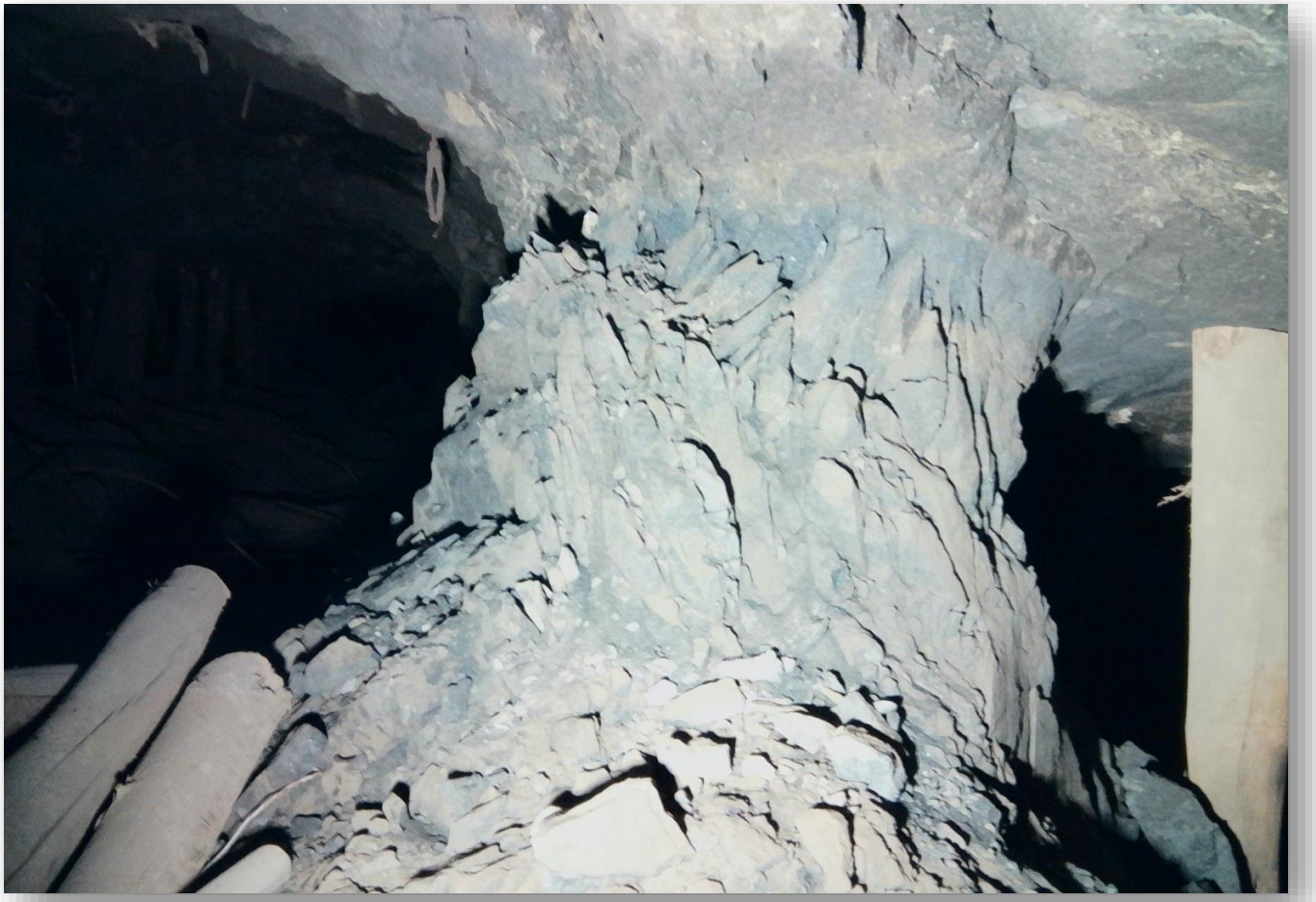
AngloAmerican

A Study of UG2 Pillar Strength using Underground Observations and Numerical Modelling



Juan Ahlers

Agenda

- Introduction
- Underground Observations and Measurements
  - Visual Observations
  - GPR Scans
  - Borehole Camera
- Numerical Modelling
- Conclusions

Introduction

- Most Mines are commonly using Hedley & Grant Formula for Pillar designs

$$\sigma_{Hedley\&Grant} = K\frac{w^{0.5}}{h^{0.75}}$$

- Calibration of the formula is difficult, most designs are probably conservative (K = ⅓ UCS)
- PlatMine Formula is available but further verification is required

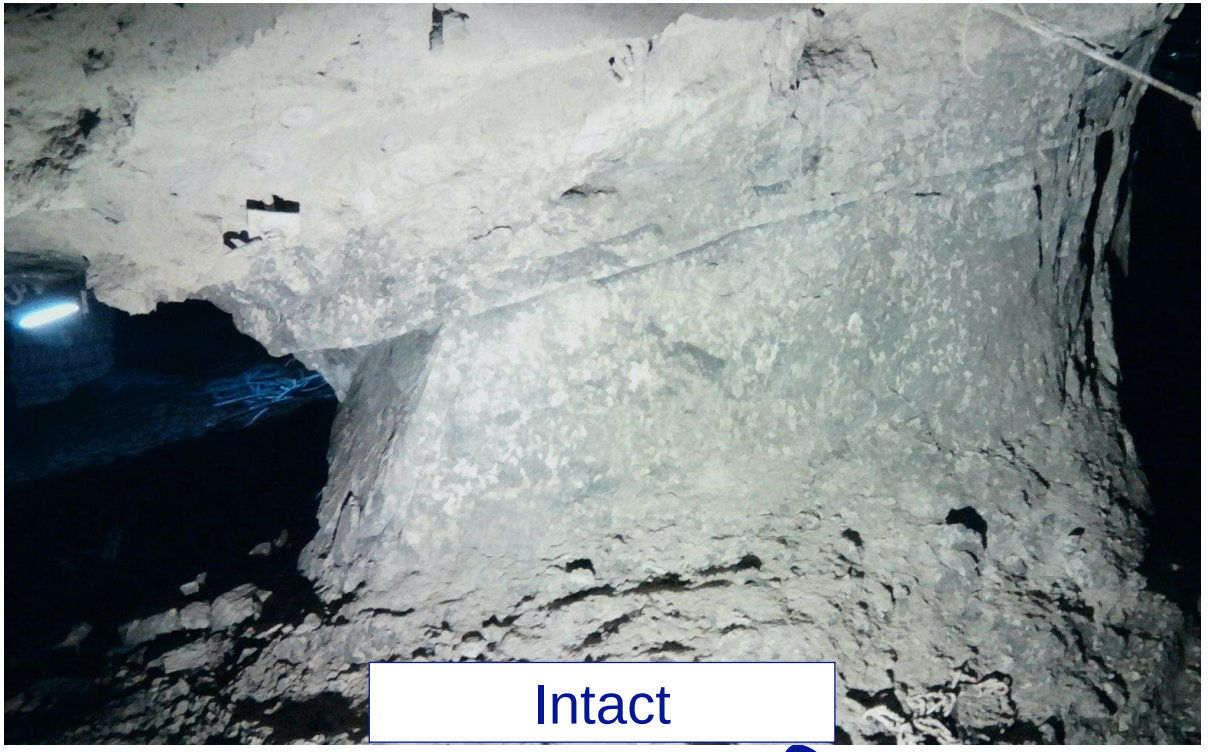
$$\sigma_{PlatMine} = 67MPa\frac{w^{0.67}}{h^{0.32}}$$

- Anglo American Platinum is currently busy with a number of experimental projects to determine underground pillar strength
- This presentation provides the progress to date – Still work in progress

Introduction

- The aim of the Study is to understand UG2 Pillar Behaviour:
  - How ? - Crushed/Intact
  - When ? - Crushed/Intact
  - Where ? - Crushed/Intact

Crushed



Intact

Underground Observations and Measurements

- Observation Checklist
  - Pillar Dimensions
  - Pillar Classifications
  - Sketches
- Photos
- GPR Scans
- Borehole Camera

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Pillar Project Checklist

Date: _____
Shaft: _____
Section: _____
Workplace: _____
Panel: _____
Pillar No: _____

Pillar Location
- Find attached 1:200 & 1:1000 plan of pillar, including date of measurements and current face position.
- Find attached Vantage modelling

Pillar Description
- Coordinates of Pillar (X, Y, Z)_____
- Geological Strength Index (Use Attached Table)
- Q and RMR Parameters (Use Attached Tables)
- Pillar Classification through Lunder and Pakalnis (Use Attached Table)

Pillar Observations Data
- Measurements and Sketches of Pillar (Attached to Checklist)
- Support information (Attached to Checklist)
- Geological Information (Attached to Checklist)

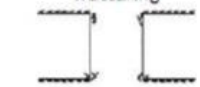
Parameters	Selected/Calculated
RQD	
Jn	
Jr	
Ja	
Jw	
SRF	
Pillar Classification	
Geological Strength Index	
Depth of Fracturing	

1

Pillar Project Checklist

PILLAR CLASS
Lunder and Pakalnis (1997)

☐ Stable - Class 1
No Sign of stress induced fracturing



☐ UnStable - Class 2
Corners breaking up only

☐ UnStable - Class 3
Fractures < ½ pillar height in length
Fracture aperture <5mm

☐ UnStable - Class 3
Fractures > ½ pillar height in length
5mm < Fracture aperture <10mm

☐ Failed - Class 5
Disintegration of pillar | Blocks falling out | Fracture through pillar core | Fracture aperture > 10mm

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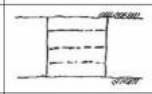
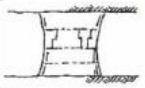
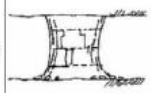
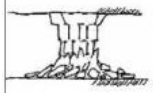
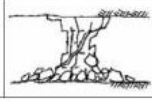
Pillar Project Checklist

Table 1. Pillar Stress Rating

Rating	Sketch	Description
1 None		No stress related fracturing or spalling observed. Joint or blast related damage may exist.
2 Minor		Minor slabs or spalling, fractures through intact rock at corners, pillar corners and walls may be concave, does not typically deteriorate after initial mining and scaling.
3 Moderate		Slabbing, onion-skin, fractures more than 1m long, joints opened, corner damage, pillars may need re-scaling after initial development. Original square pillar shape maintained.
4 Severe		Spalling to hourglass shape. Open cracks in pillar more than 1m long, debris around pillar, original square shape of pillar no longer visible, saw tooth slabs on ribs
5 Very Severe		Formation of large open cracks, extreme hourglass. Pillar likely lost most of its residual strength.

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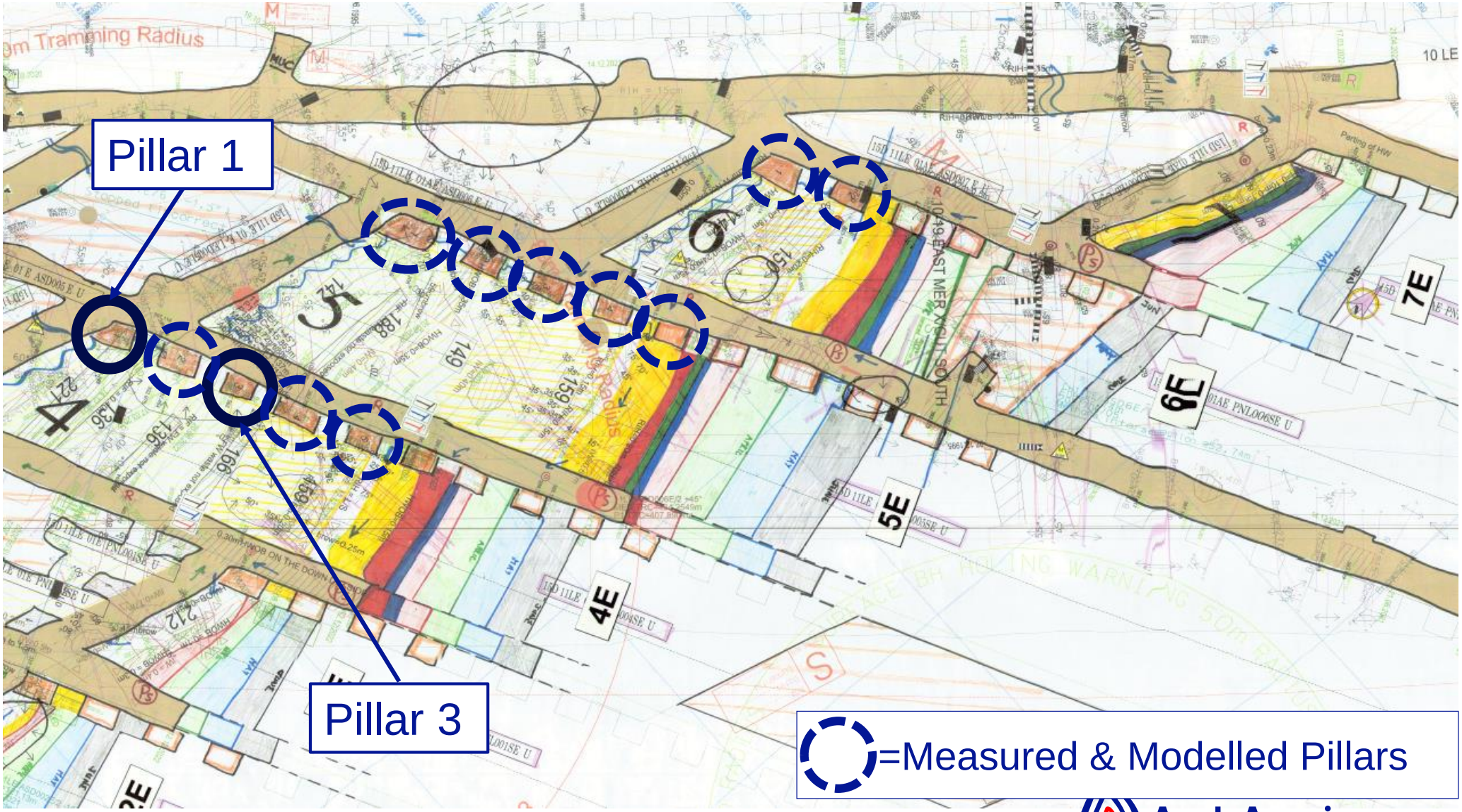
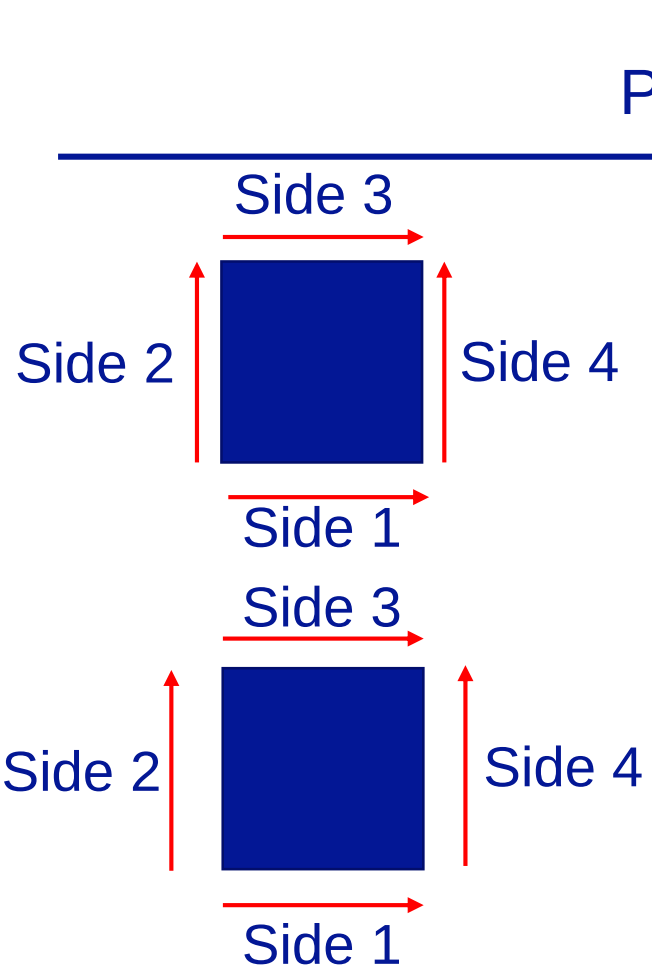
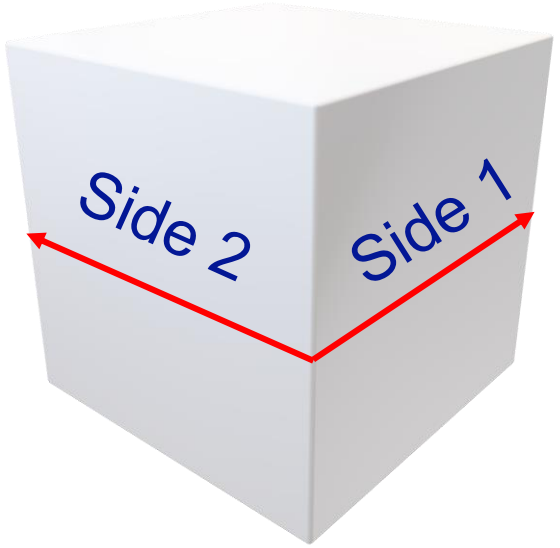
Underground Observations and Measurements



Underground Observations and Measurements





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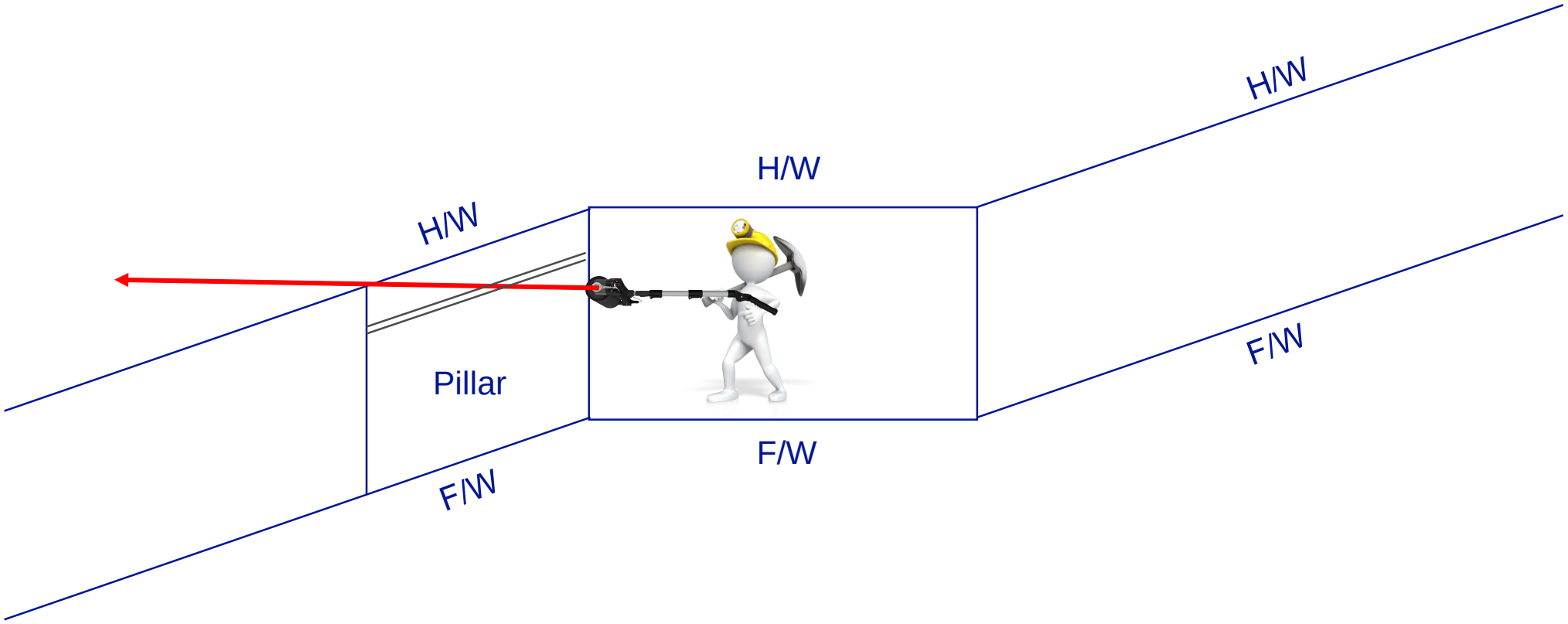

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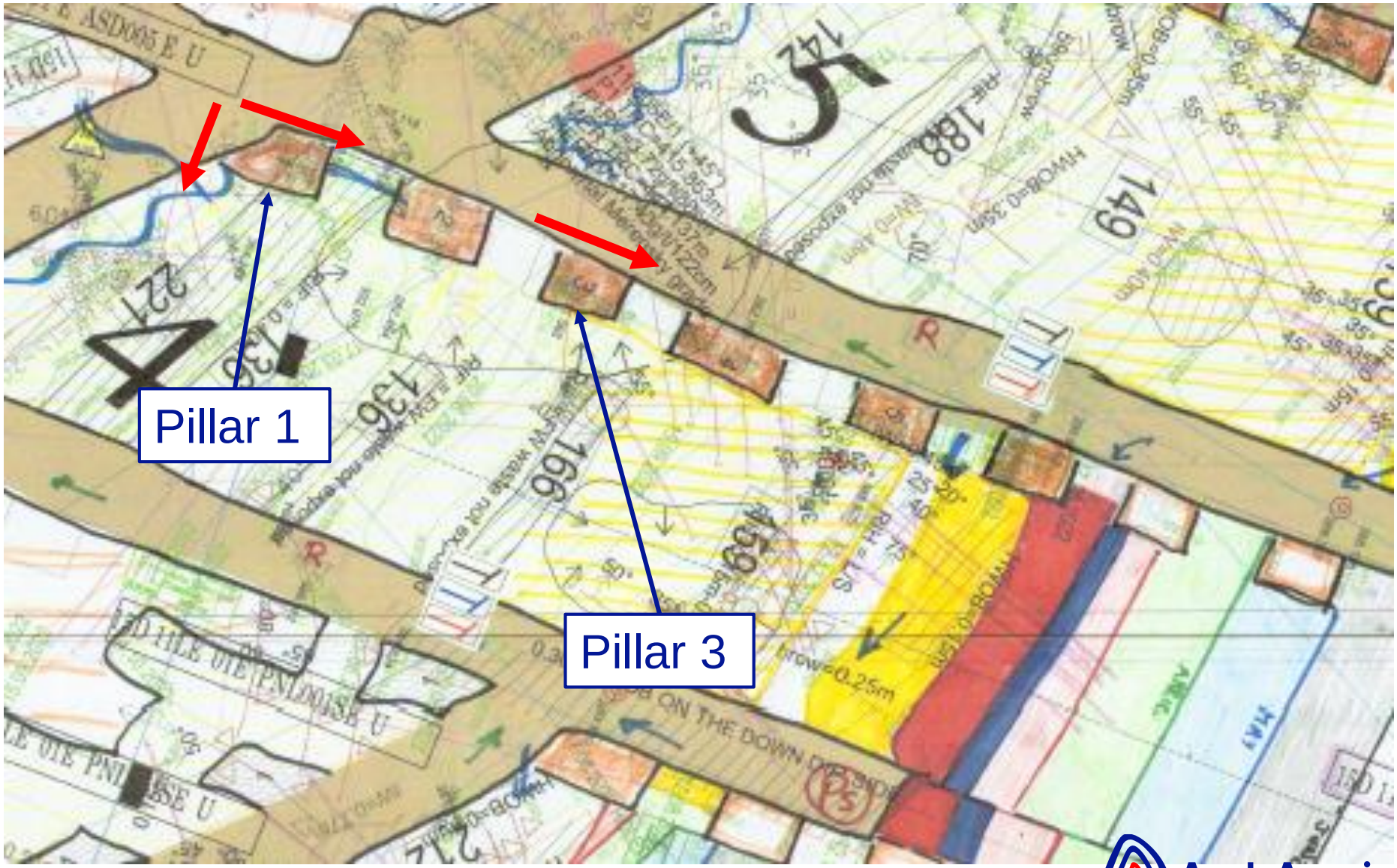
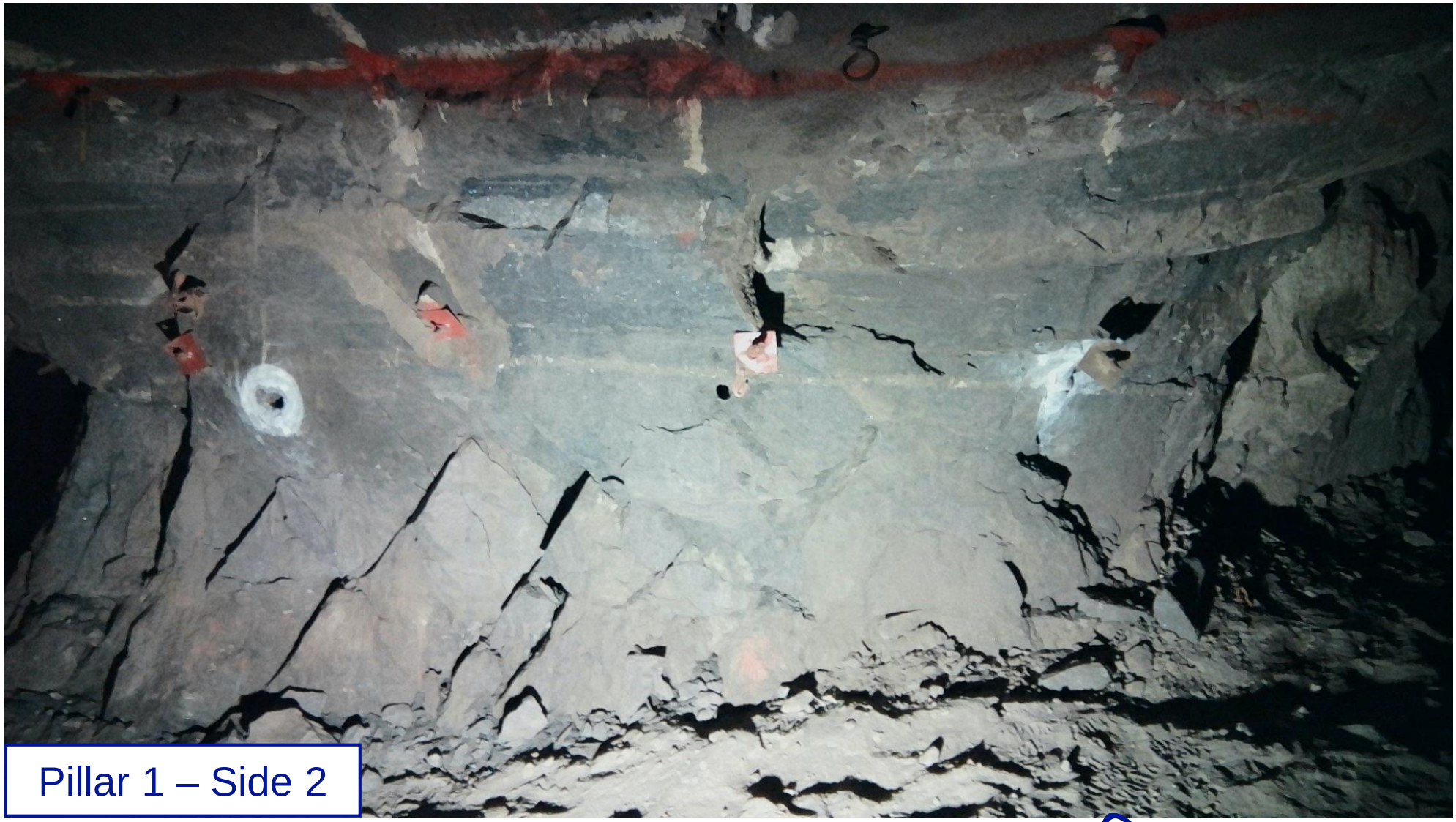
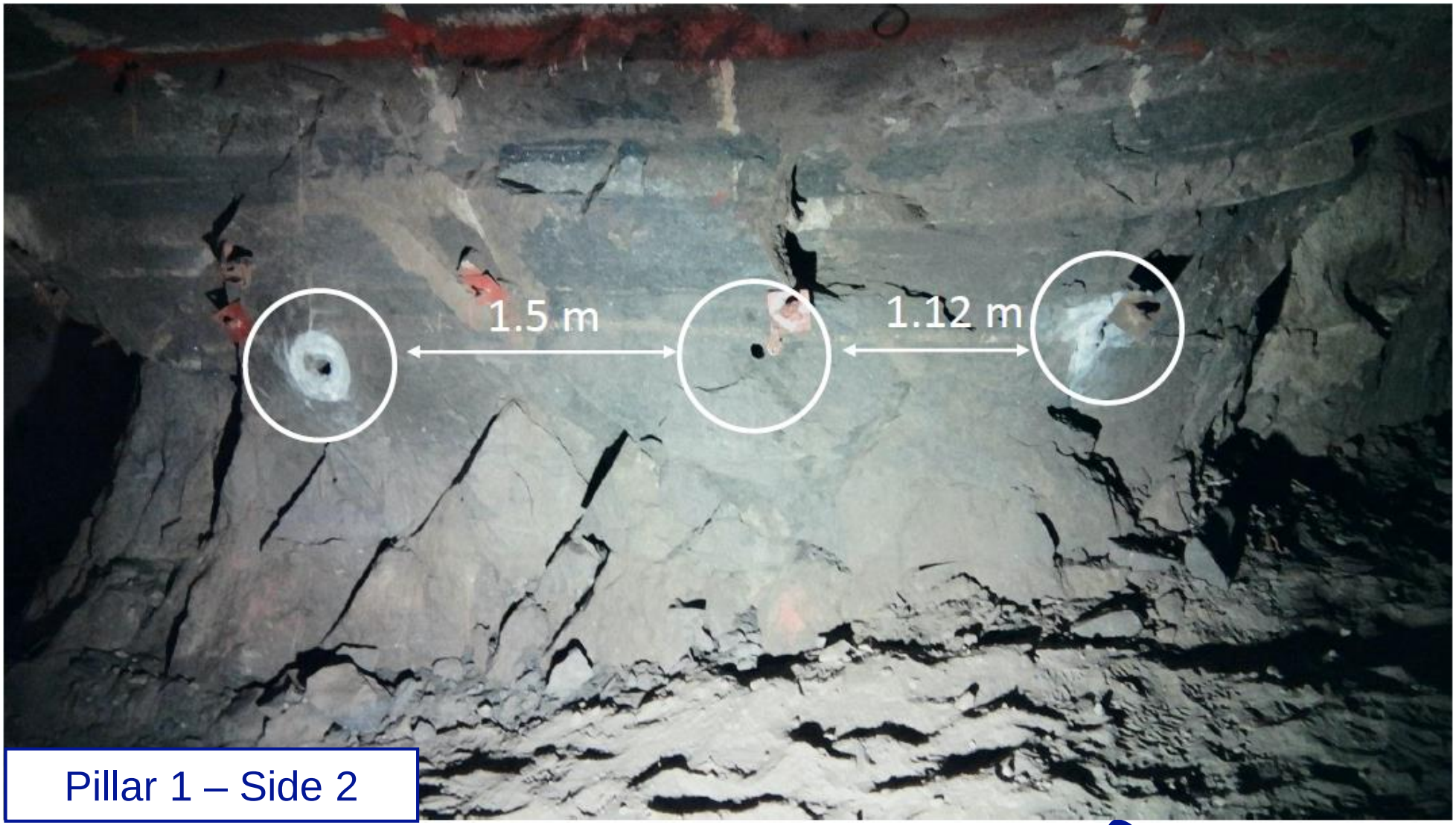


Underground Observations and Measurements



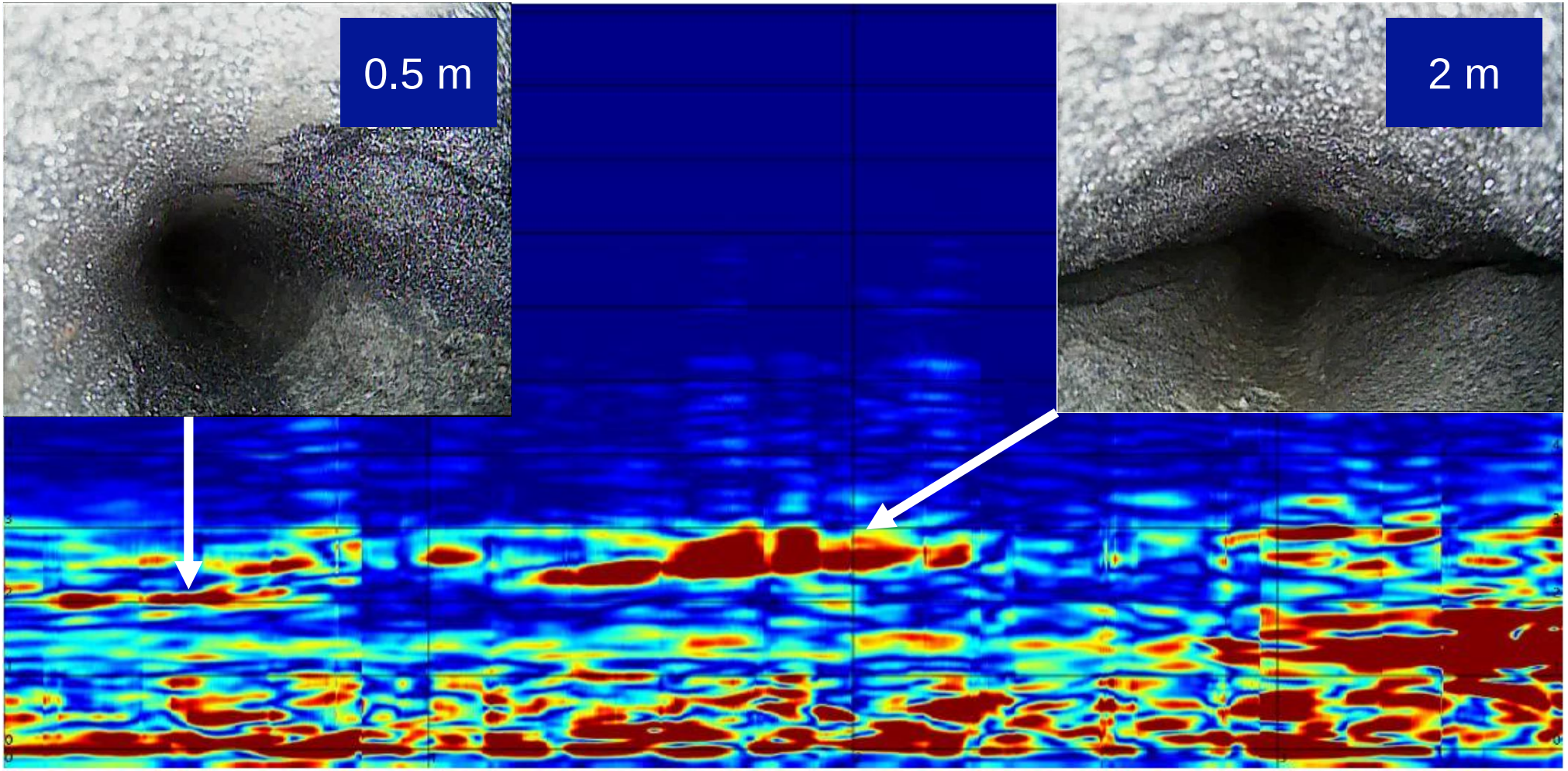
Pillar 1 – Side 2

Underground Observations and Measurements



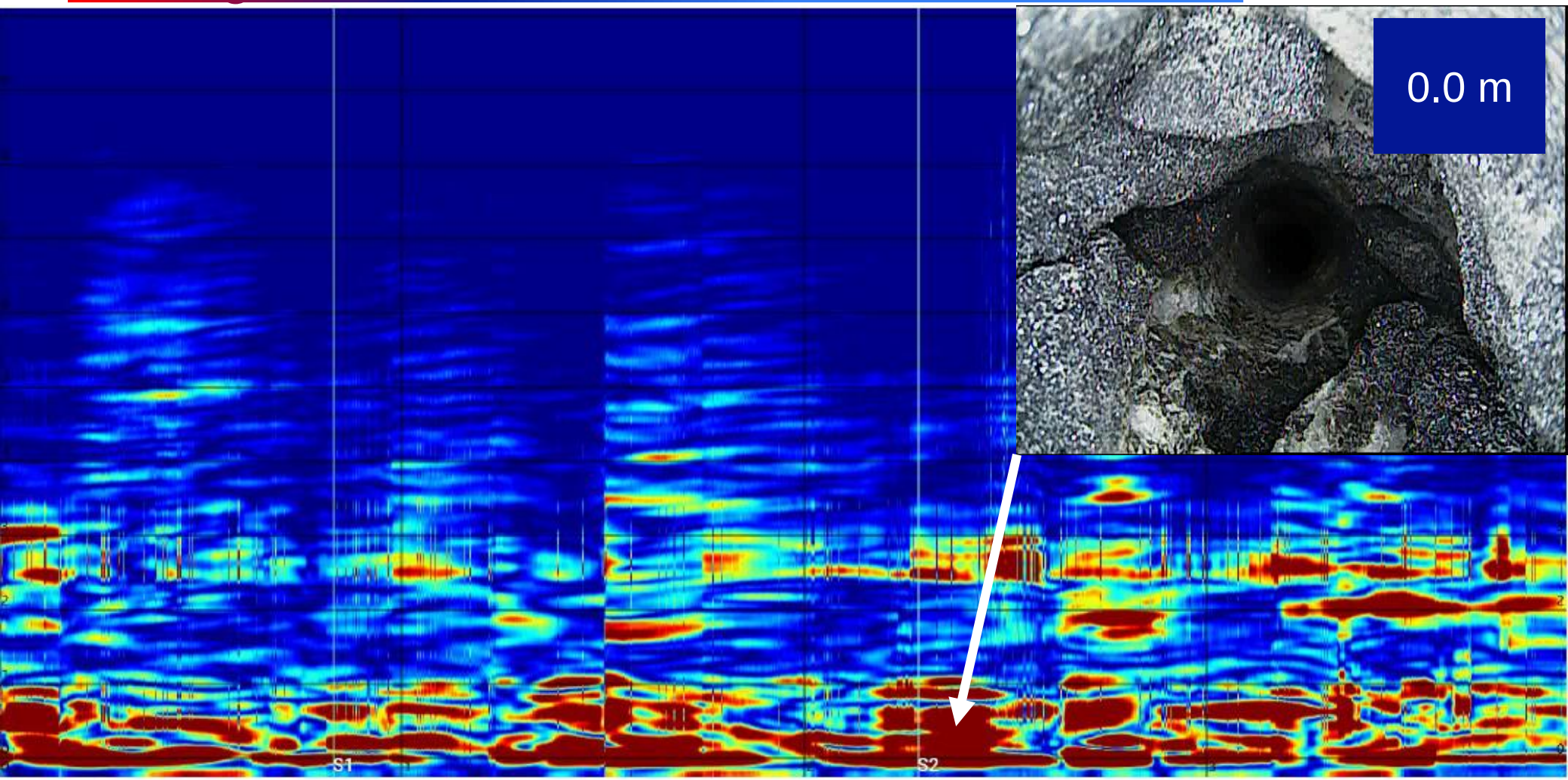
Pillar 1 – Side 2

Underground Observations and Measurements



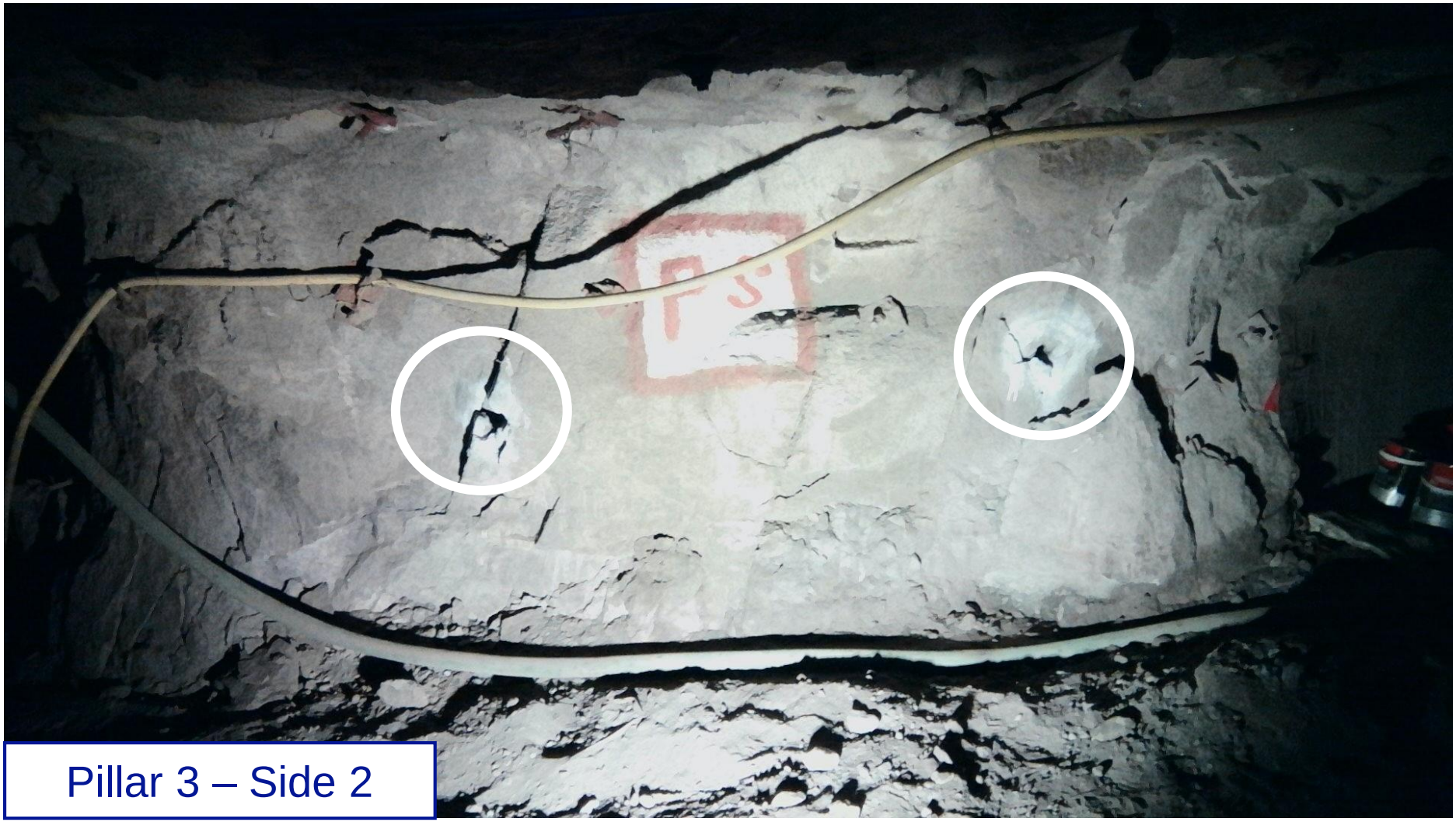
Pillar 1 – Side 1

Underground Observations and Measurements



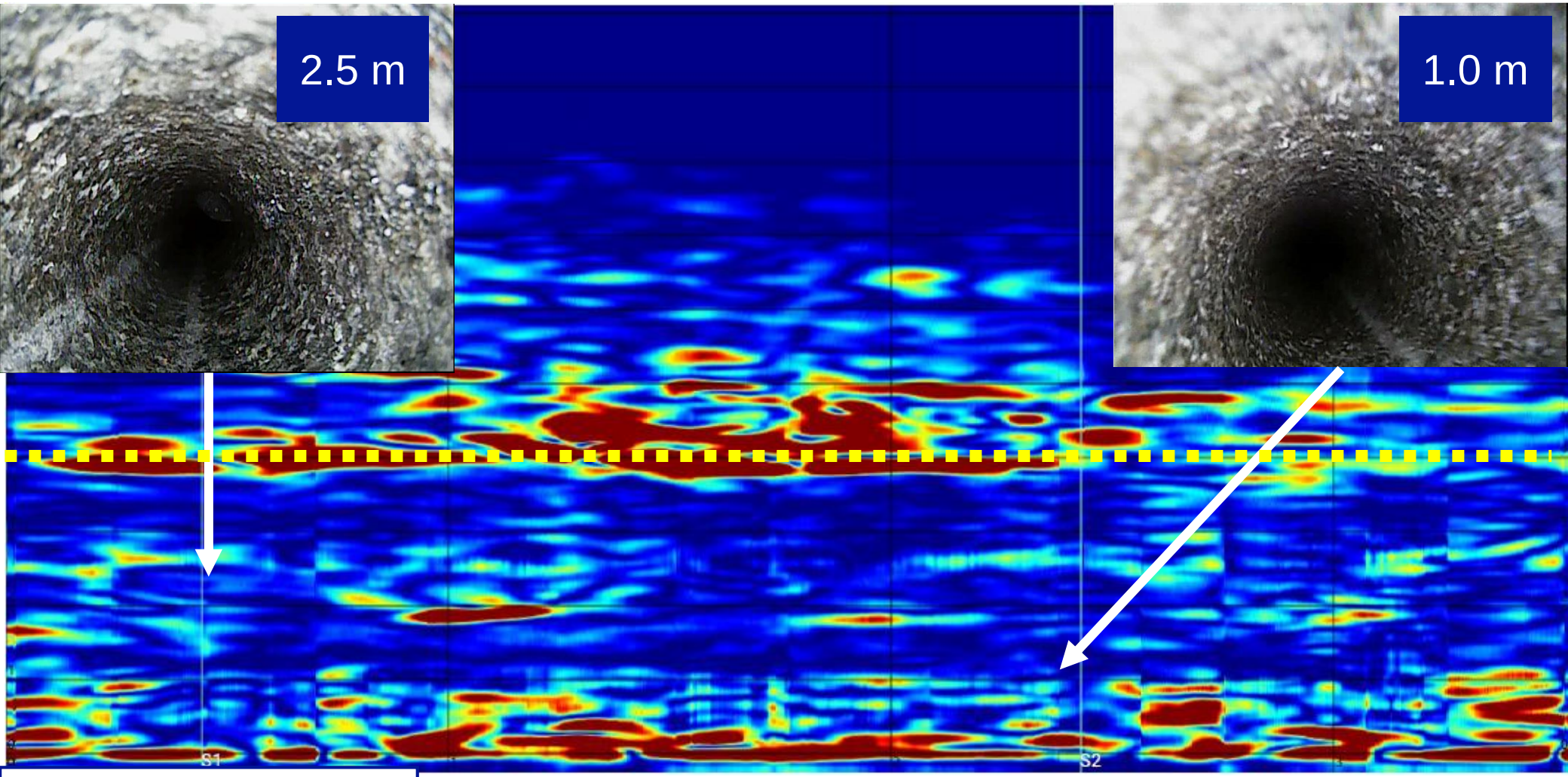
Pillar 1 – Side 2

Underground Observations and Measurements



Pillar 3 – Side 2

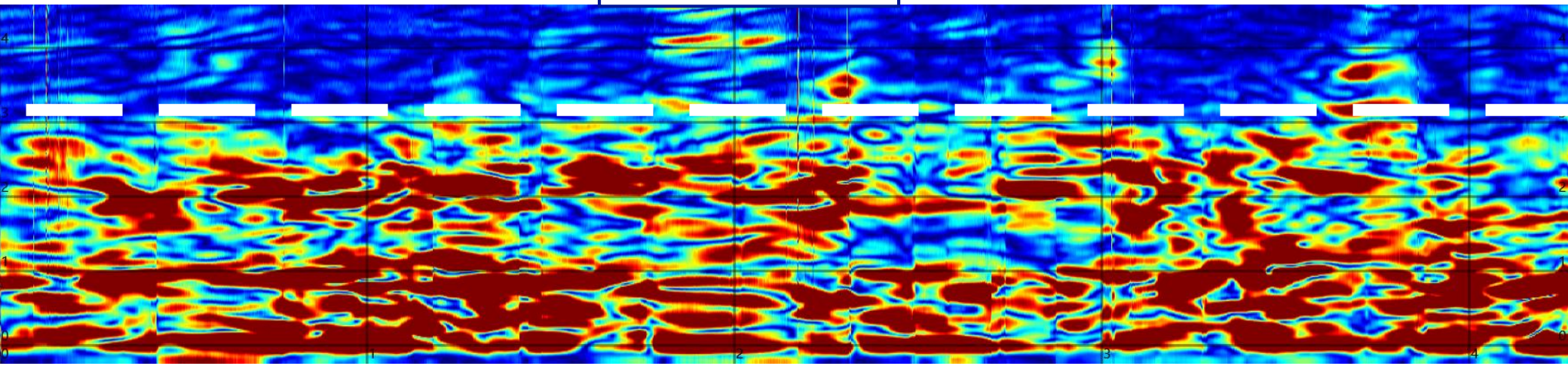
Underground Observations and Measurements



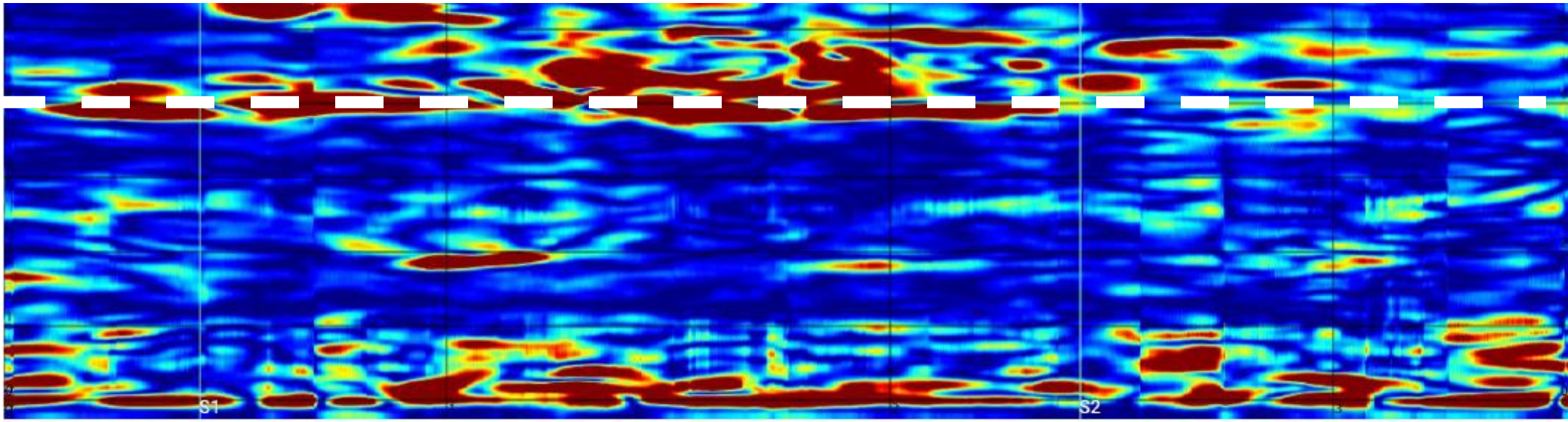
Pillar 3 – Side 2

Underground Observations and Measurements

Crushed



Intact



Numerical Modelling of Pillar Scaling Using TEXAN

A Limit Equilibrium Model to Simulate Pillar Failure

- **Force balance in slice:**

$$\mathbf{H\sigma_s(x+\Delta x) = H\,\sigma_s(x) + 2\tau\Delta x}$$

- Two assumptions are made in the model

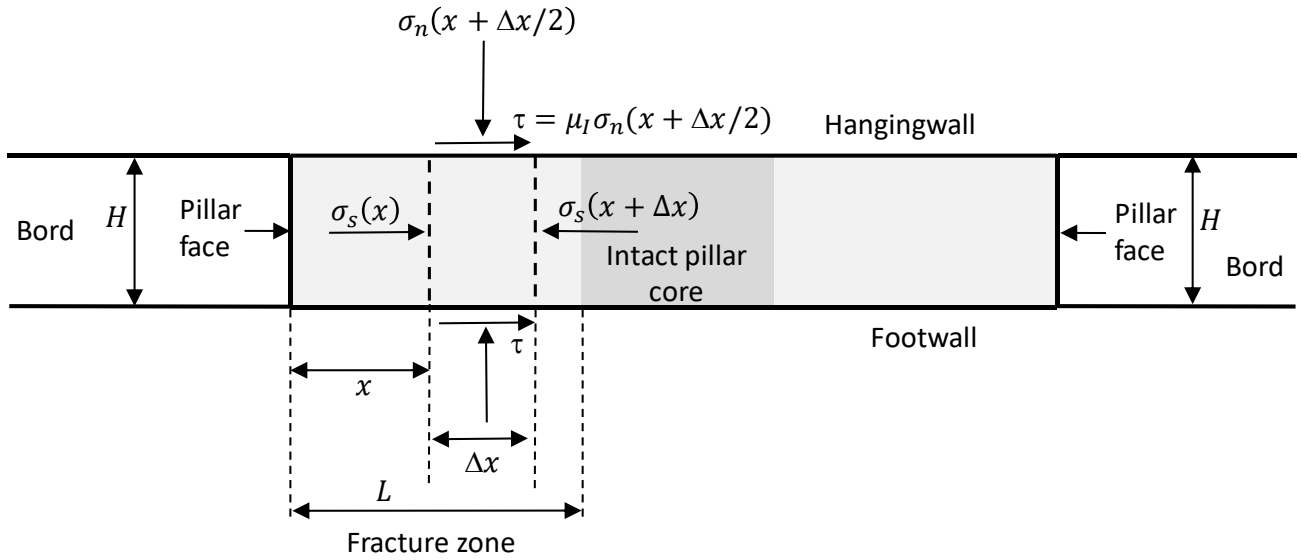
1. Assume that τ is related to the pillar-normal stress σ_n by a frictional interface condition

$$\tau = \mu_I \sigma_n(x)$$

2. Assume a failure relationship between σ_n and σ_s. The parameters σ_c and m are constants.

$$\sigma_n(x) = \sigma_c(x) + m(x)\sigma_s(x)$$

$$\sigma_n = Se^{2mx\tan\phi/H}$$



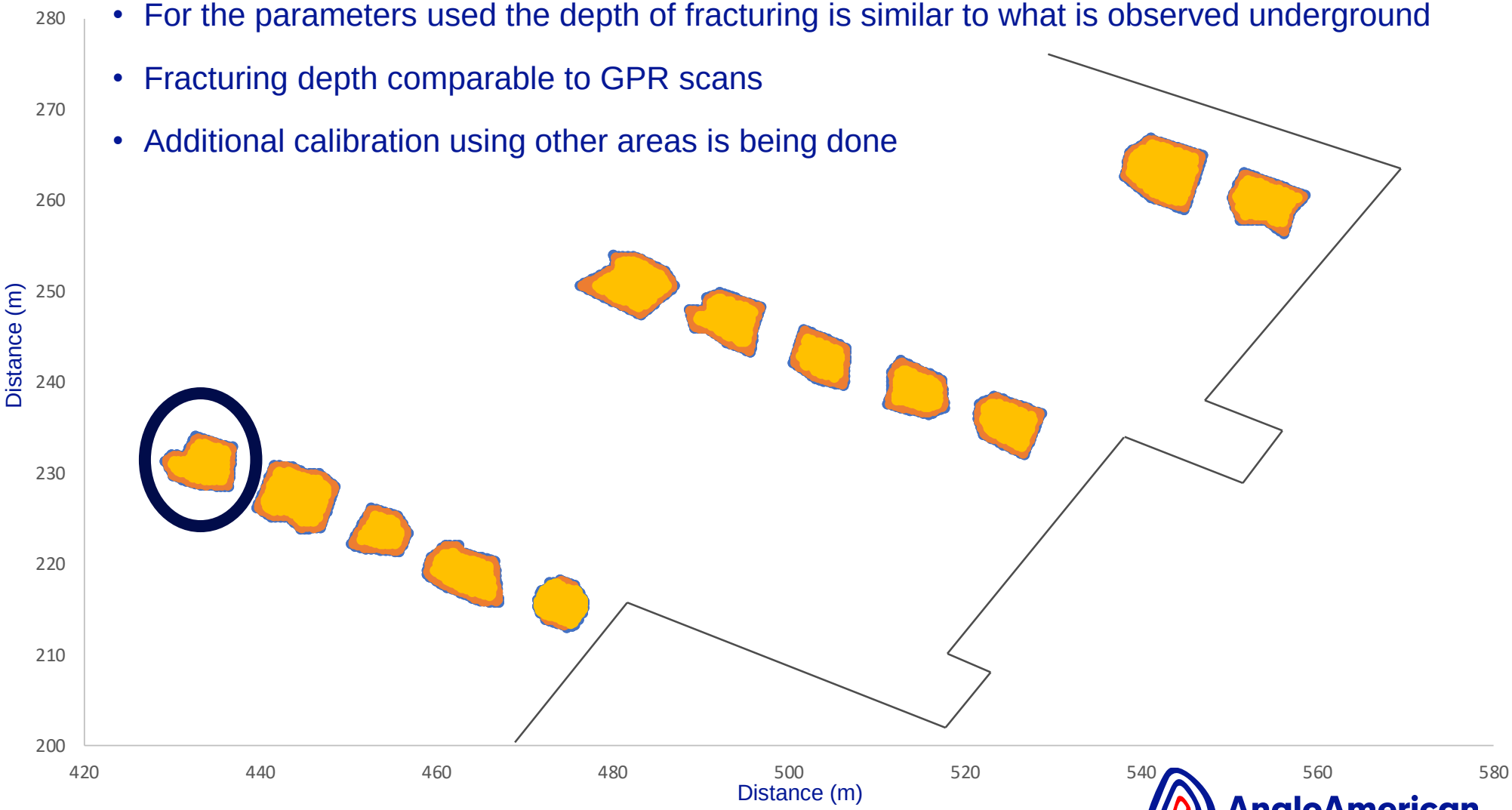
Simulating Pillar Scaling

Parameter	Value
Intact Strength Intercept, S^0	60 MPa
Intact Strength Slope, m^0	7
Initial Residual Strength Intercept, S^c	4 MPa
Initial Residual Strength Slope, m^c	7
Effective seam height, H	1.5 m
Intact rock Young's Modulus, E	90 GPa
Intact rock Poisson's Ratio, v	0.3
Intact seam stiffness modulus, k_s	60 000MPa/m
Fracture Zone interface fiction angle	35^o

Objective of this modelling – preliminary calibration of the LEM

TEXAN Model Results

- For the parameters used the depth of fracturing is similar to what is observed underground
- Fracturing depth comparable to GPR scans
- Additional calibration using other areas is being done



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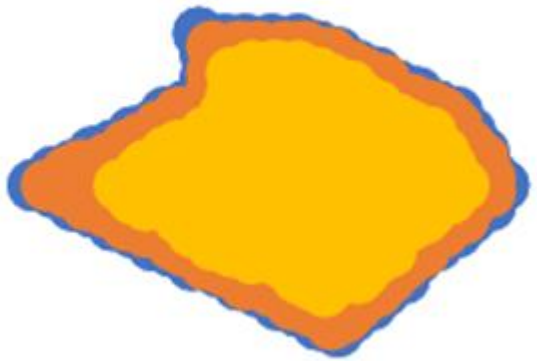
TEXAN Model Results



Pillar 1

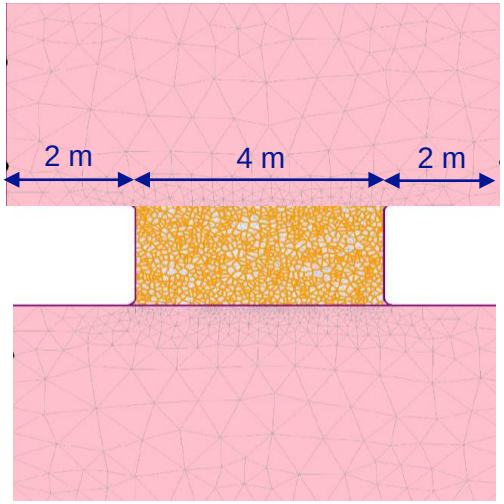
0.0 m to 0.1 m

0.1 m to 0.5 m

Solid

Conclusions

- Agreement between Borehole Camera Images and GPR Scans
- Limit Equilibrium Model in TEXAN is useful to simulate failure on the Pillar Edges
- Further work needs to be done in areas where pillars are completely crushed
- Future work needs to determine if numerical modelling approach can replace the traditional pillar empirical design formula
- The Future of Amandelbult Projects involves the exploration and investigation of UG2 Pillar designs that have not been seen before



vs

$$\sigma_{Hedley\&Grant} = K \frac{w^{0.5}}{h^{0.75}}$$

Acknowledgements

- Anglo American Platinum for making the research project possible
- Line Managers for their exceptional support and guidance:
  - Lizelle Prinsloo – Principal Geotechnical Engineer
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  - Chilly Khandela – General Manager Dishaba
  - Charl Engelbrecht – General Manager Tumela
  - Franz Bruwer – Chief Rock Engineer
  - Sifiso Mashile – Chief Rock Engineer
  - Renier Gerber – Chief Rock Engineer
- Prof Francois Malan my Masters Supervisor at the University of Pretoria

Thank you