Mitigating Pit Floor Instability above a Confined Aquifer: Assessing Mining Block Dimensions and Sequencing Strategies

By

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Introduction and Background

- Situation: An open-pit mine is situated directly above a **confined aquifer system**, separated only by a **clay aquitard** of variable thickness. **What do you do?**

- **Problem Statement:** The Geotechnical Challenge
  - Mining above a **confined aquifer** poses a significant **pit floor stability risk** and **water blowouts**.
    - The presence of a clay aquitard above the aquifer acts as a **confining barrier** preventing groundwater **contamination** and groundwater from entering the pit.
    - Mining activities such as **excavating** the ore material from the pit, will **expose** the aquitard to the surface.
      - Reduces overburden pressure
      - Wetting and drying
      - Weathering

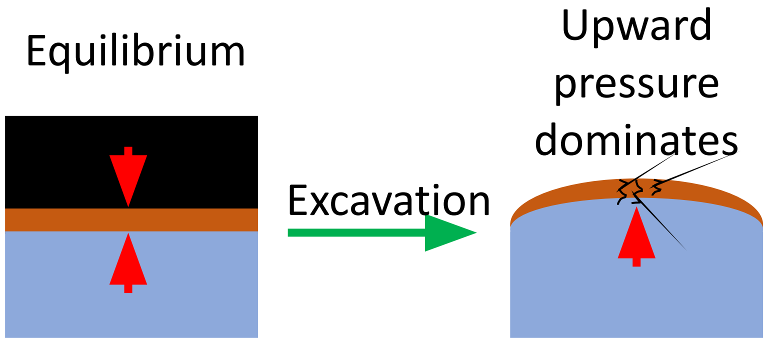
Disrupts equilibrium of stresses, thus allowing **upward** confined aquifer pressure to **dominate**.

Weakens the material

- ⬆ Permeability
- ⬇ Shear Strength
- ⬆ Water blowouts

- Without controls, the pit floor faces **instability and failure risks** during mining operations

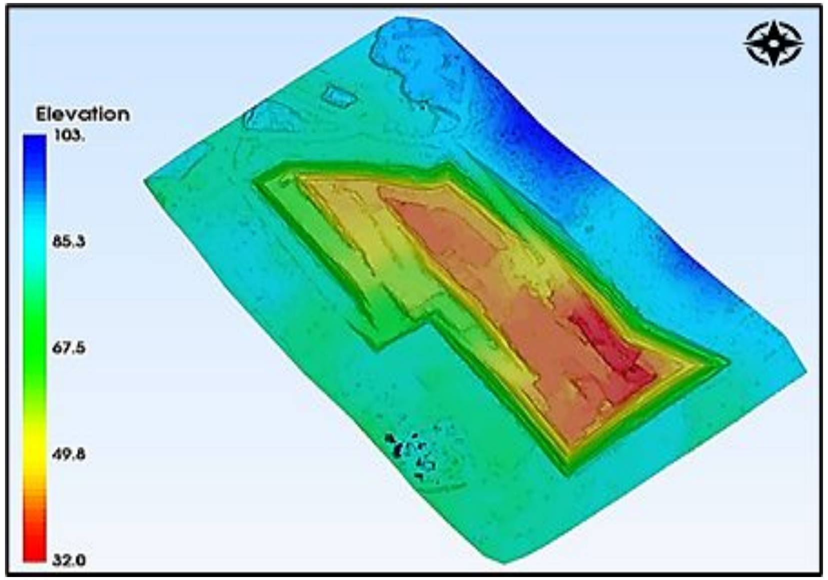
- **Key Message:** Maintaining the **integrity** of the clay aquitard is **critical** to prevent **hydraulic connectivity** and ensure pit floor **stability** during mining.



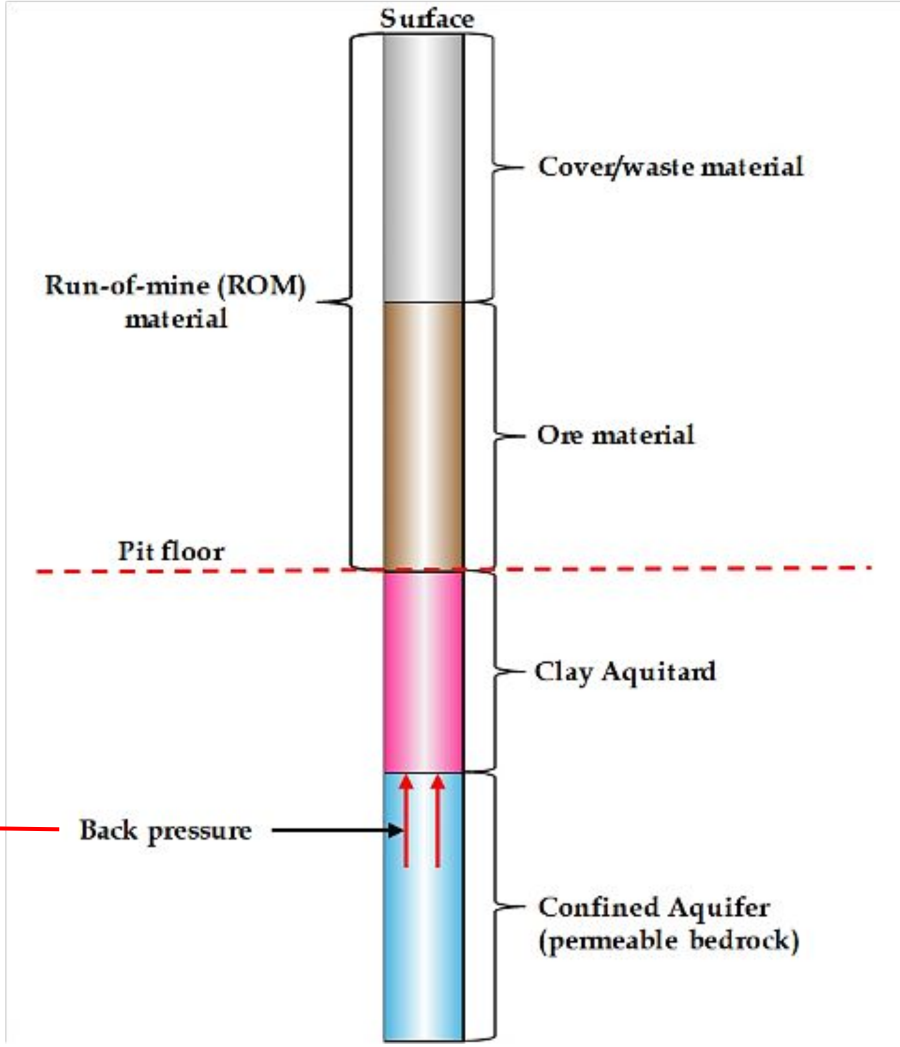
Aim of Study:

- To evaluate pit floor **stability risks** associated with open pit mining above a **confined aquifer**.
- To determine **optimal mining block dimensions** that **minimise** disturbance to the underlying clay aquitard.
- To assess **excavation sequencing methods** that reduce cumulative damage to the aquitard and **prevent hydraulic connectivity** between the surface and the aquifer.
- To recommend **practical ground control strategies** for safe mining progression over the confined aquifer.

Pit and Geology



Pit depth: ± 50m



650kPa

Consist of:

- Topsoil
- Overburden
- Calcretized Sand
- Oxidised Sand

Methodology Outline

- **Geotechnical Soil Classification**
  - Laboratory testing to determine the Atterberg Limits of the clay aquitard.
  - Determined behaviour of soil with changes in water content and stress environment.
  - Mohr-Column properties (cohesion and friction angle).

- **2D Numerical Modelling (RS2)**
  - Assessed vertical displacement and aquitard disturbance under different mining block widths.
  - Determined the maximum allowable mining block width.

- **3D Numerical Modelling (RS3)**
  - Simulated excavation in full 3D geometry.
  - Determined the maximum mining block length.
  - Assessed aquitard response to excavation progression.

- **Excavation Sequencing and Backfilling Assessment**
  - Compared strip mining vs checkerboard excavation sequences.
  - Evaluated cumulative and permanent aquitard disturbance under each sequence.
  - Assessed the effectiveness of controlled backfilling in limiting aquitard deformation after each mining block is excavated.

Soil Classification – Clay Aquitard

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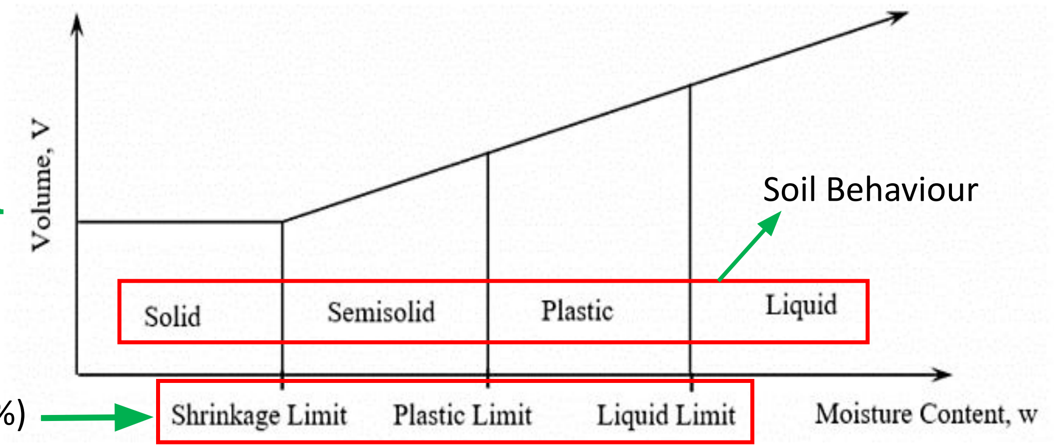
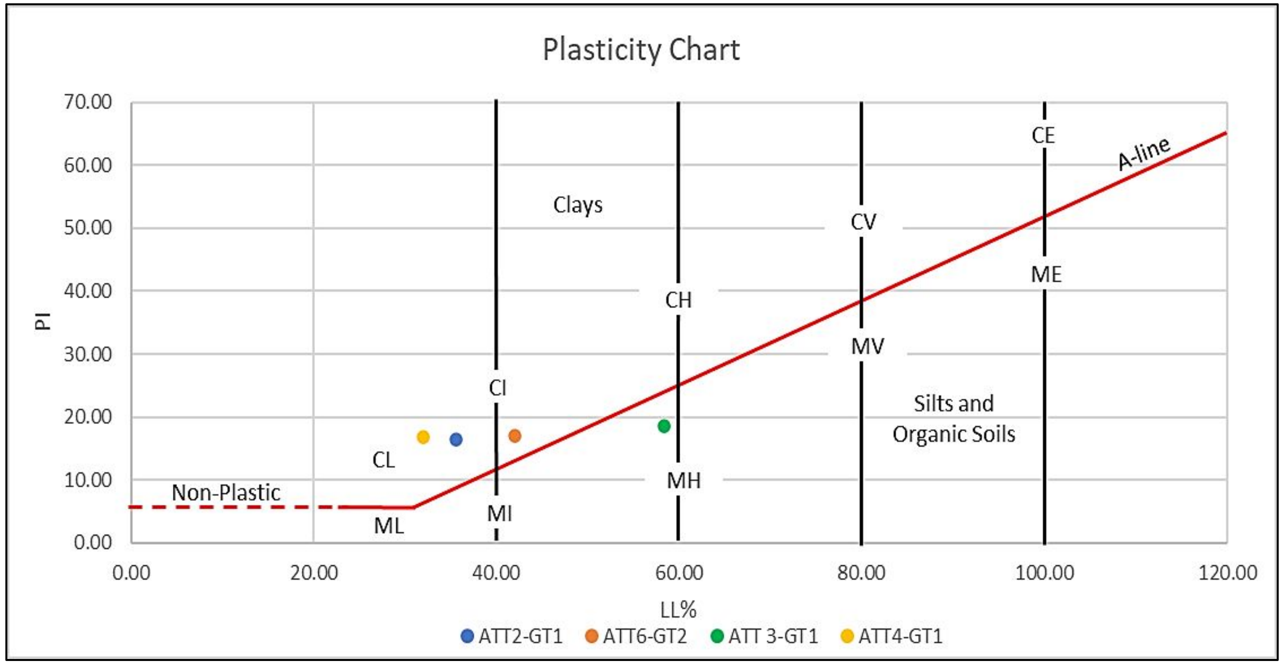
- How?
  - Particle Size Distribution
  - Atterberg Limits
    - Critical water contents of fine-grained soil
    - Behaviour of soil at varying water content values
    - Dictates the behaviour of the soil



  - Plasticity Chart
    - PI (LL-PL) vs LL
    - Classifies plasticity of the soil
    - Determines soil type
    - A-Line – Boundary between Clay and Silt
      - Calculated as:

$$\mathbf{I_P = 0.37(w_L - 20)}$$

I_P: Plasticity Index
w_L: Liquid Limit



Soil Classification – Clay Aquitard

- Why this is important:
  - PI measures the range of moisture content over which the clay behaves plastically
  - A high PI indicates:
    - Material can undergo a large degree of deformation before cracking (Failure)
    - However, once saturated or disturbed, material loses shear strength rapidly
    - Increased vulnerability to cracking, seepage, and failure under stress.
  - PI affects the material's ability to act as a water barrier and maintain pit floor stability

- Thus, the PI directly influences:
  - The need to limit excavation size (mining block dimensions)
  - The urgency of backfilling after mining

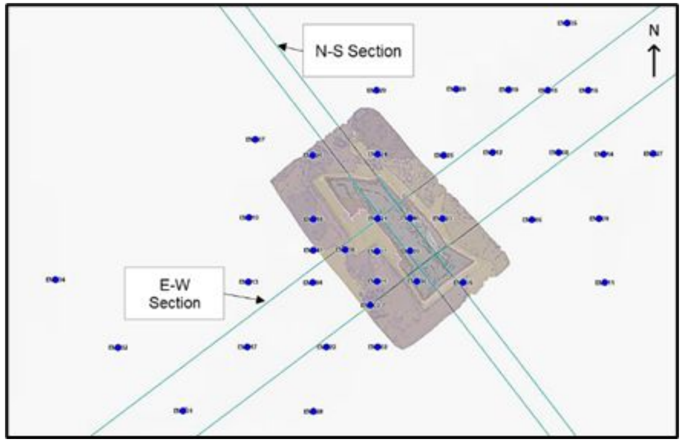
2-Dimensional Modelling: RS2

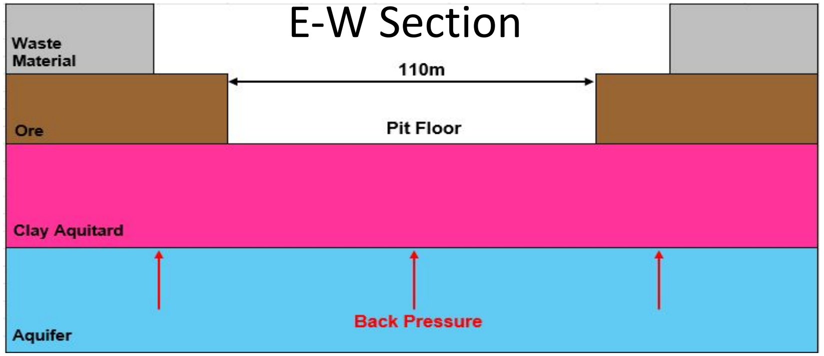
- Purpose:
  - Identify the maximum mining block width that could be excavated without causing excessive upward deformation or permanent damage to the aquitard.

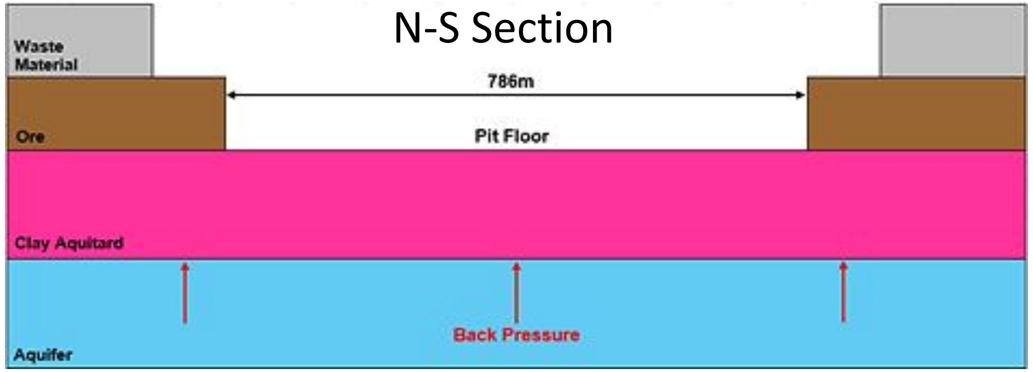
- Allowed detailed assessment of how the aquitard deforms under different excavation widths without the complexity of 3D geometry.

- What was modelled?
  - Cross-sectional cuts through the pit
  - Various excavation widths (mining block widths) and clay thicknesses
  - Applied the back pressure from confined aquifer
  - Simulated the removal of overlying material and recorded the aquitard's response

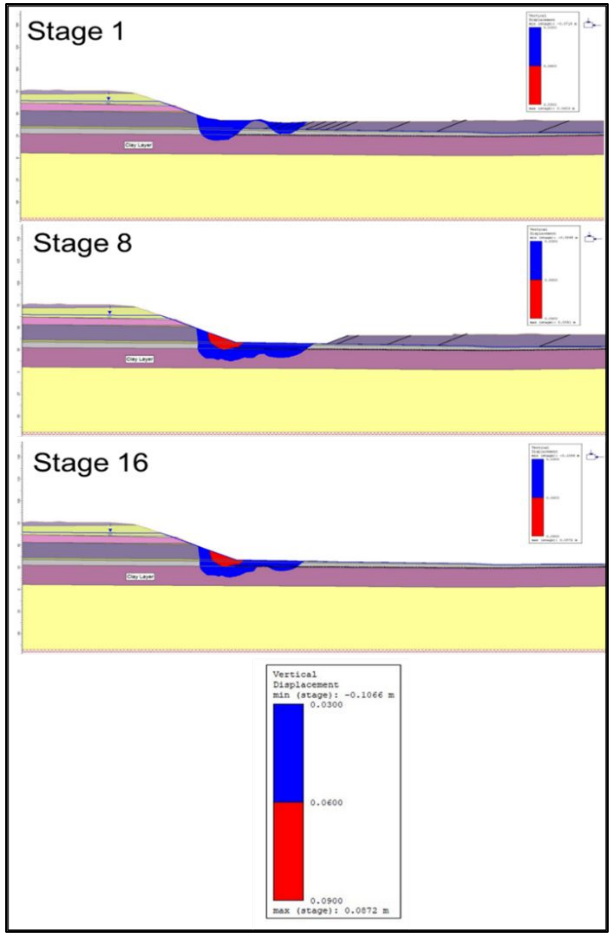
- Parameters analysed:
  - Vertical Displacement
  - Extent of disturbance within the clay aquitard
  - Plastic deformation



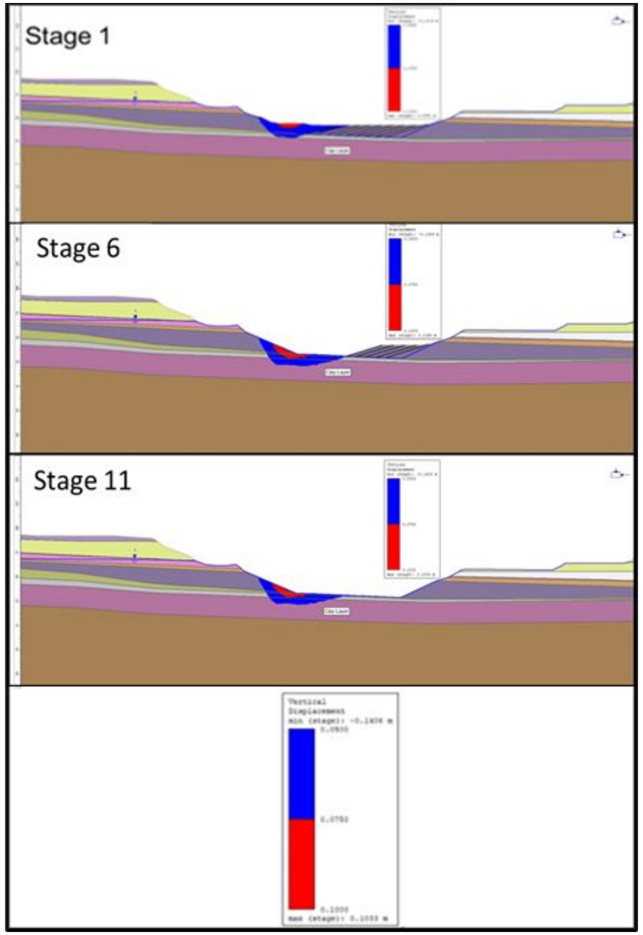




RS2 Model Results – Vertical Displacement



Vertical displacement for the long section (N-S)



Vertical displacement for the short section (E-W)

Clay Exposure Limit

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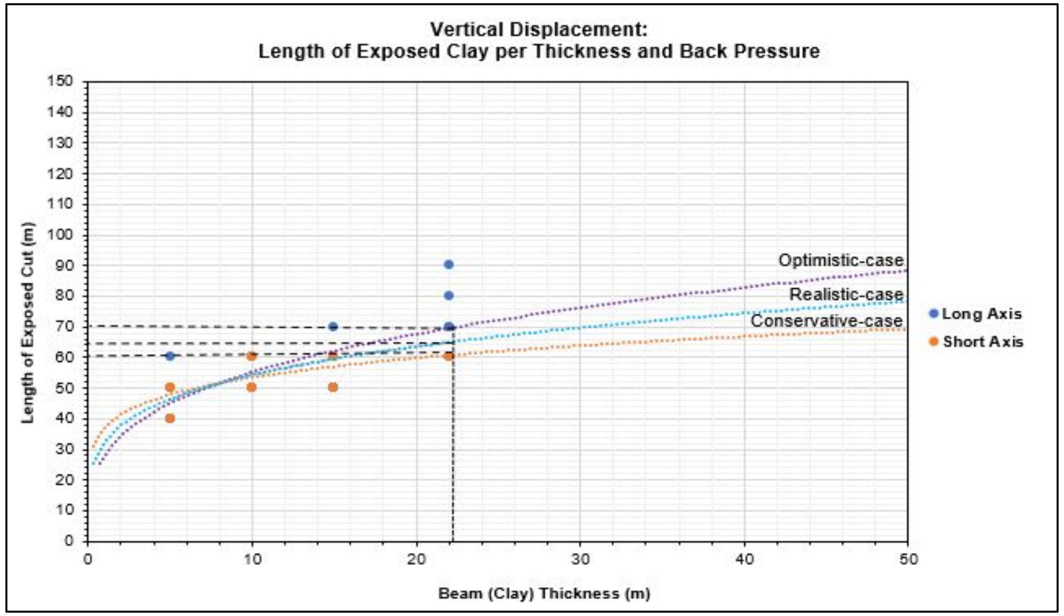
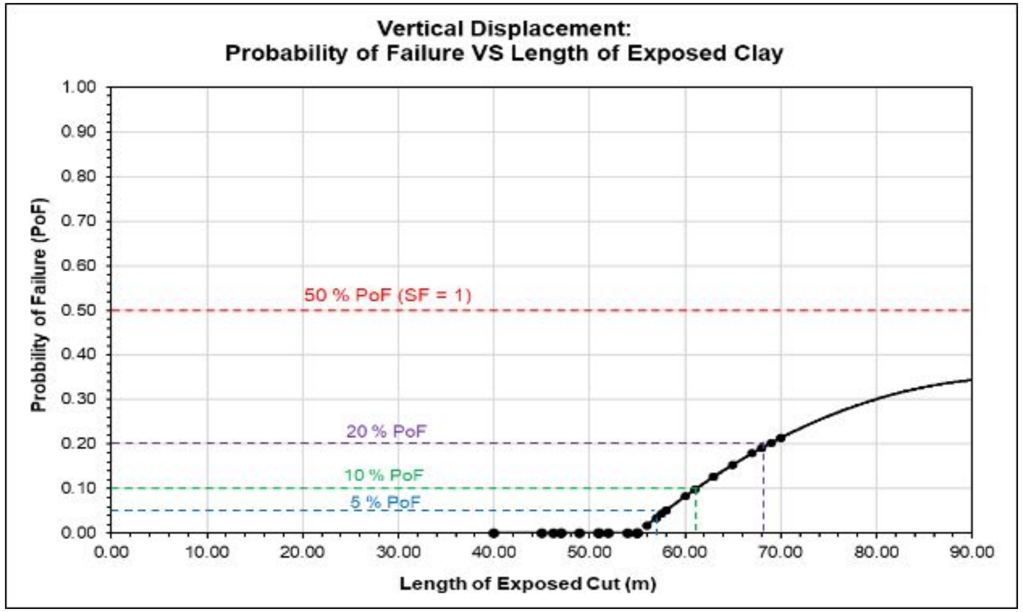
- Vertical displacement data was extracted from RS2 models and analysed
  - Identified the excavation width at which **permanent deformation** was starting to occur.
    - This indicated the onset of irreversible damage in the clay aquitard (likely leading to cracking and loss of hydraulic integrity).
    - This point provided us with a limiting excavation width for all variations of the 2D models
    - At each limiting width, associated vertical strain thresholds were also identified to understand how strain levels related to failure initiation.
    - The limiting width results were then related to the clay aquitard thickness and plotted on a graph to visualize all limiting widths identified throughout the models.
    - As the site showed evidence of a 22m thick clay aquitard, the limiting exposure width was deemed as approximately 70m.



Clay Exposure Limit – Continued

- A deviation point was identified at which the different scenarios indicated a sudden change in behaviour (previous graph).
- The deviation point is located at an exposure width of 55m.
- This point marks a **practical control point** or **conservative design threshold** within the data, beyond which the predictability of aquitard performance decreases and the associated risk of structural compromise increases.
- A controlled risk allowance of 20% was incorporated beyond the conservative design threshold to enable operational flexibility while ensuring the aquitard's role as a hydraulic barrier remains effective.



This graph illustrates the follow:

- PoF increases non-linearly as excavation length grows.
- <u>55m Conservative Design Threshold:</u>
  - Based on scenario divergence.
  - Beyond this, performance predictability decreases.
- <u>70m Optimised Design Limit (20% PoF):</u>
  - Managed risk boundary for operations.
  - Allows practical excavation length while maintaining acceptable risk.

3D Modelling and Sequencing – RS3

- 3D Modelling allowed:
  - Simulation of the full excavation geometry, reflecting realistic pit and block layouts.
  - Capture of deformation effects across the length of the mining block.
  - Assessment of how different mining sequences impact the aquitards integrity.

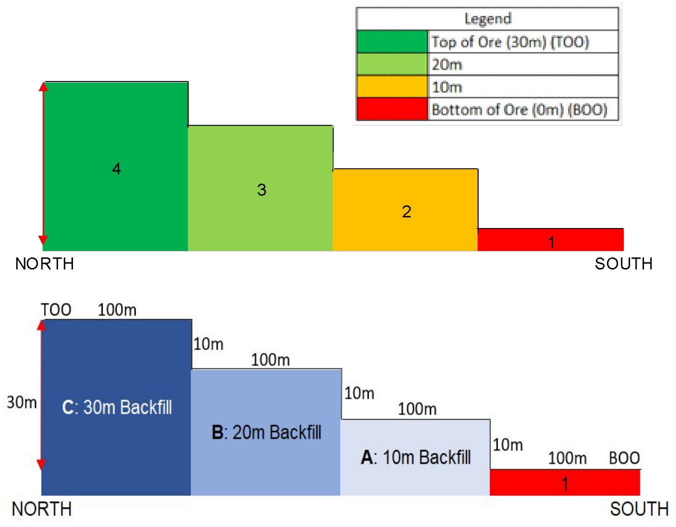
- This enabled a three-dimensional understanding of aquitard behaviour, allowing for optimisation of block lengths and sequencing to minimise cumulative and permanent damage.

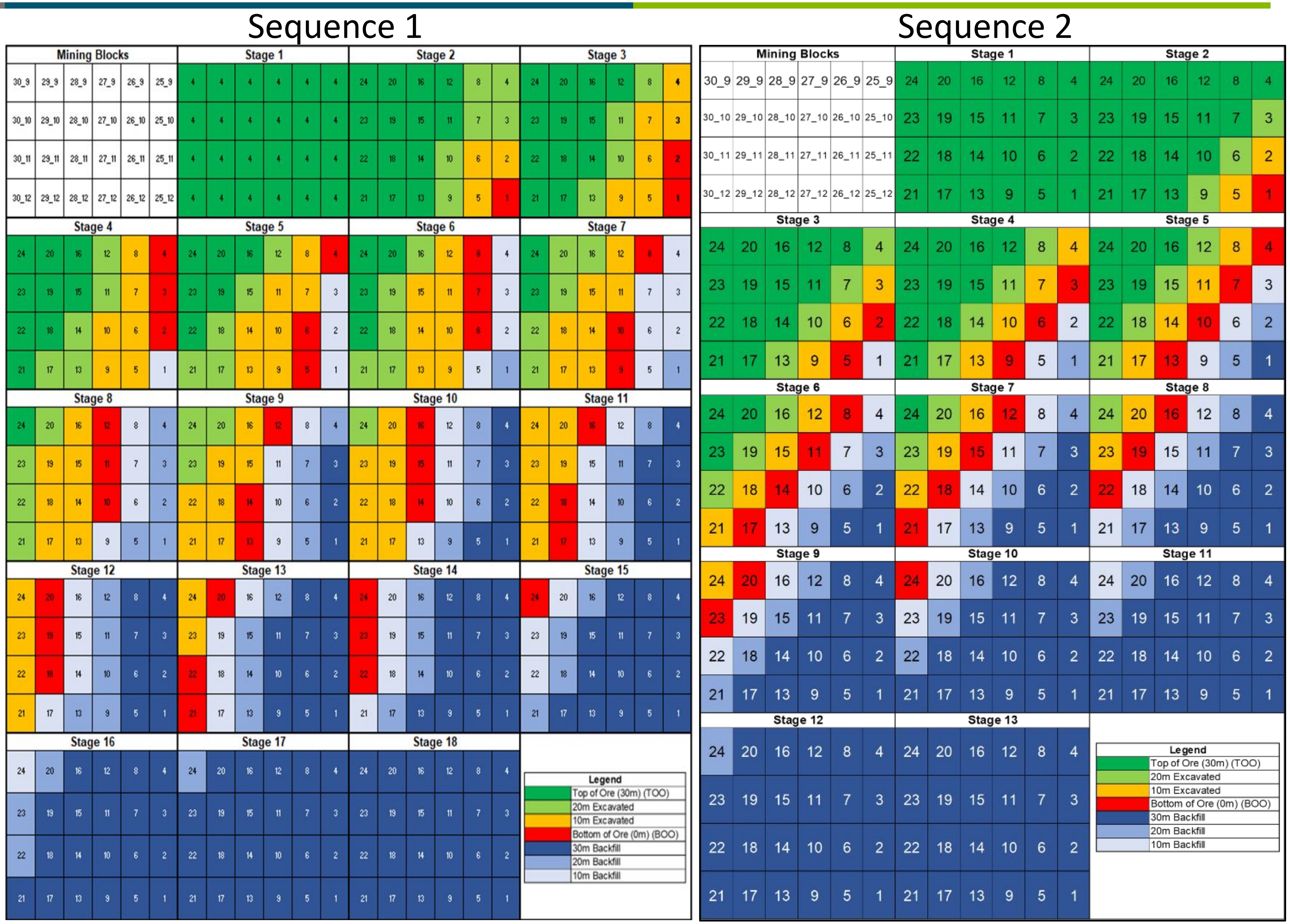
- What was modelled?
  - Strip mining sequence (Sequence 1)
  - Checkerboard mining sequence (Sequence 2)

- What was assessed?:
  - Maximum allowable mining block length before aquitard deformation exceeded thresholds (similar displacement control principles from 2D modelling)
  - Evaluate different excavation sequences
  - Assessed how sequence and geometry influenced cumulative and permanent aquitard damage

3D Mining Sequences

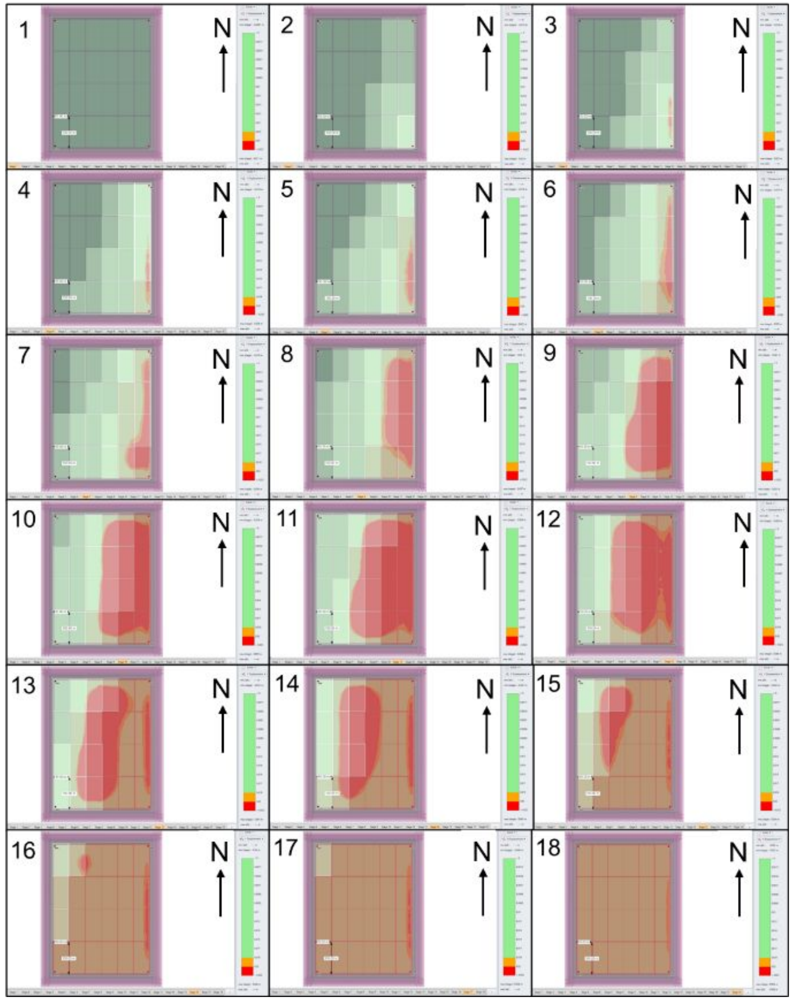
- Two Models:
  - Sequence 1 – Strip Mining
  - Sequence 2 – Checkerboard Mining
- Strip Mining = Mining block after block in a continuous linear progression
- Checkerboard Mining = Alternating blocks mined in a staggered pattern, leaving unexcavated zones between active blocks



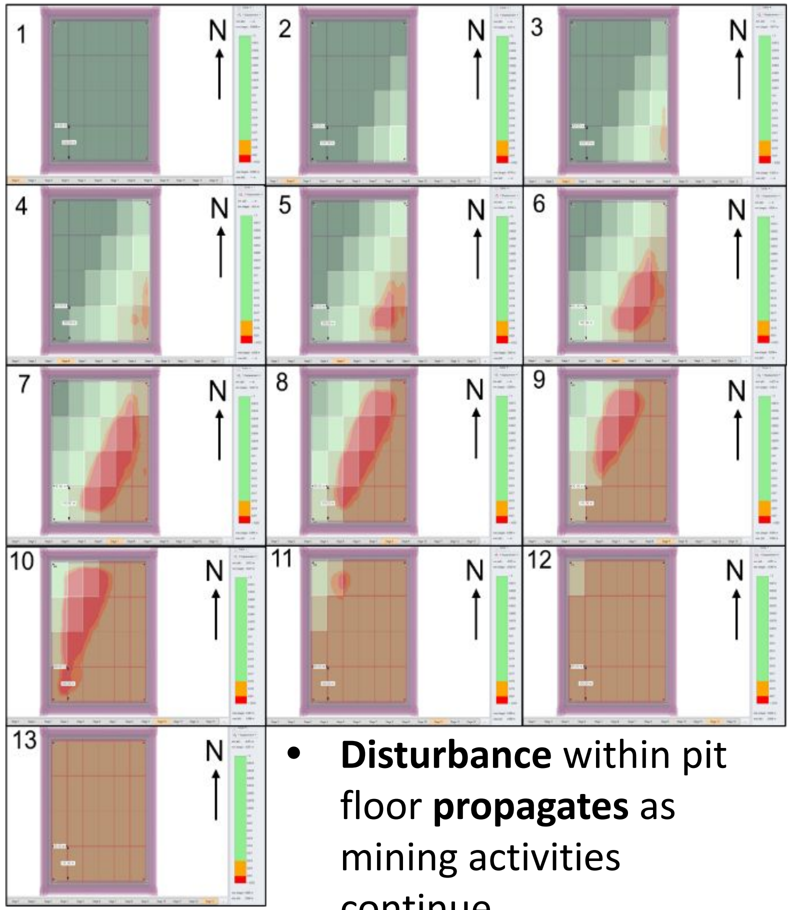


RS3 Models and Comparative analysis

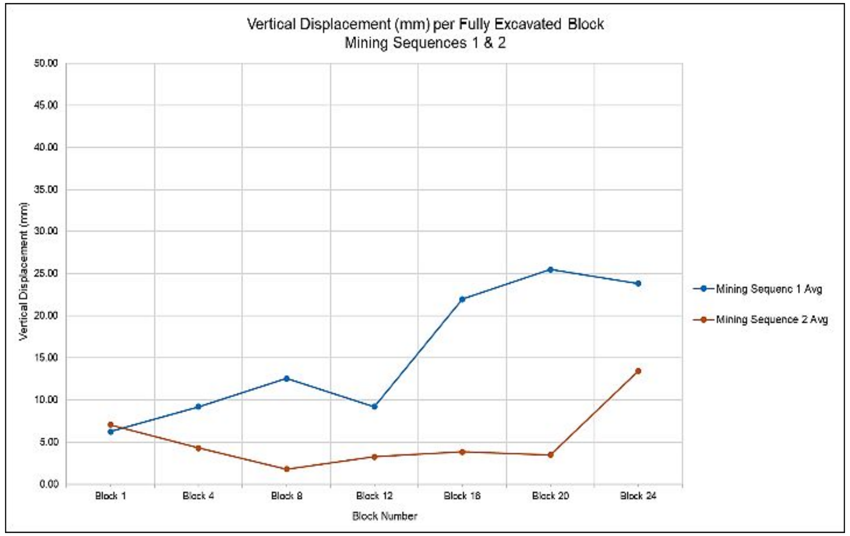
Strip Mining (1)



Checkerboard Mining(2)



- **Disturbance** within pit floor **propagates** as mining activities continue.



- <u>The checkerboard mining sequence significantly reduced:</u>
  - Cumulative deformation of the aquitard.
  - The extent of permanent damage after each mining phase.
  - The risk of creating hydraulic pathways.
- <u>Strip mining, by contrast:</u>
  - Caused progressive, concentrated deformation.
  - Increased the likelihood of permanent aquitard damage .

RS3 Results and Mining Block Length

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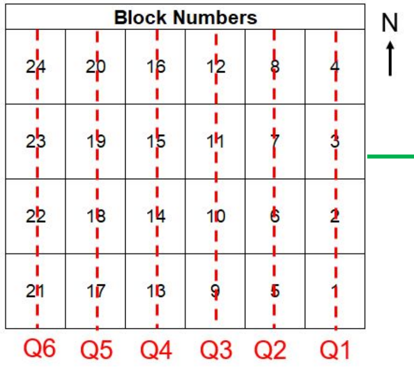
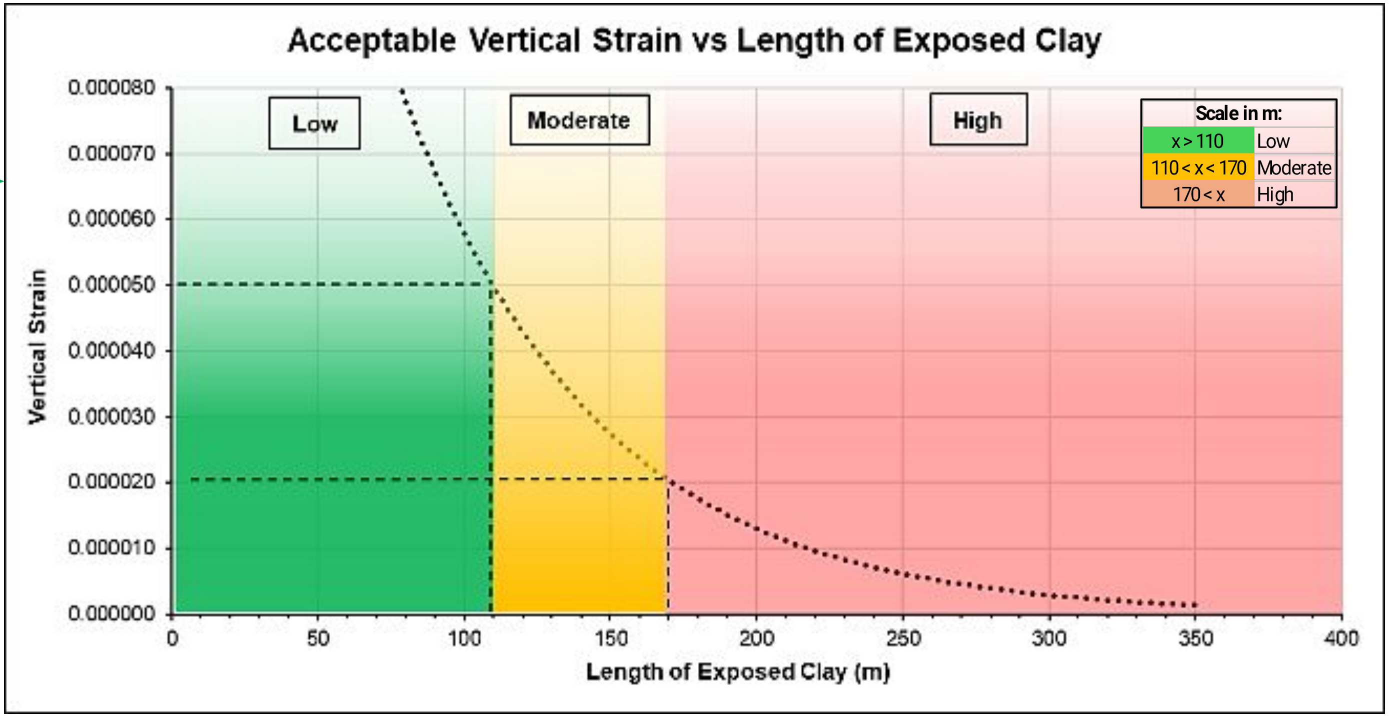
Query Lines in model for data extraction
(Sequence 1 Model used)



- This final graph summarises the overall risk associated with different mining block lengths. It categorises risk into three zones—low, moderate, and high—based on the expected deformation and probability of aquitard failure.

Acceptable Vertical strain vs. Length of exposed clay plot indicating the Low, Moderate, and High-risk regions

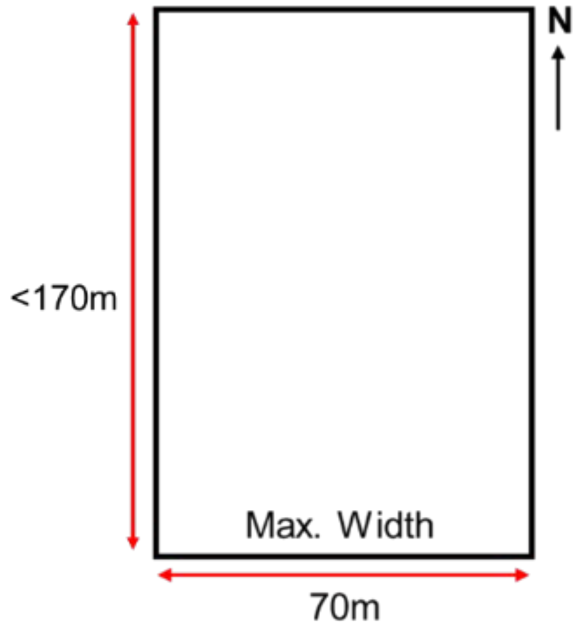


Risk level	Length of exposed clay
Low	< 110m
Moderate	110m – 170m
High	>170m

- In summary, this graph translates complex geotechnical modelling into a simple, operational guide, showing the safe, optimised, and critical ranges for mining block lengths.

In the end…

- By combining width (from 2D) with length limits (3D), we established a fully dimensioned safe mining block size.



Conclusion

- Protecting the integrity of the clay aquitard is critical to ensuring long-term pit floor stability above the confined aquifer.

- Through targeted 2D and 3D modelling, this study defined practical mining block dimensions and optimised sequencing strategies to minimise permanent damage and reduce failure risk.

- By balancing operational efficiency with geotechnical safety, a clear, risk-managed excavation approach has been developed to support safe, sustainable mining progression.

THANK YOU

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