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SERITI Kriel

Kriel Colliery

Design Strategies to Combat FOG Incidents at Kriel Colliery

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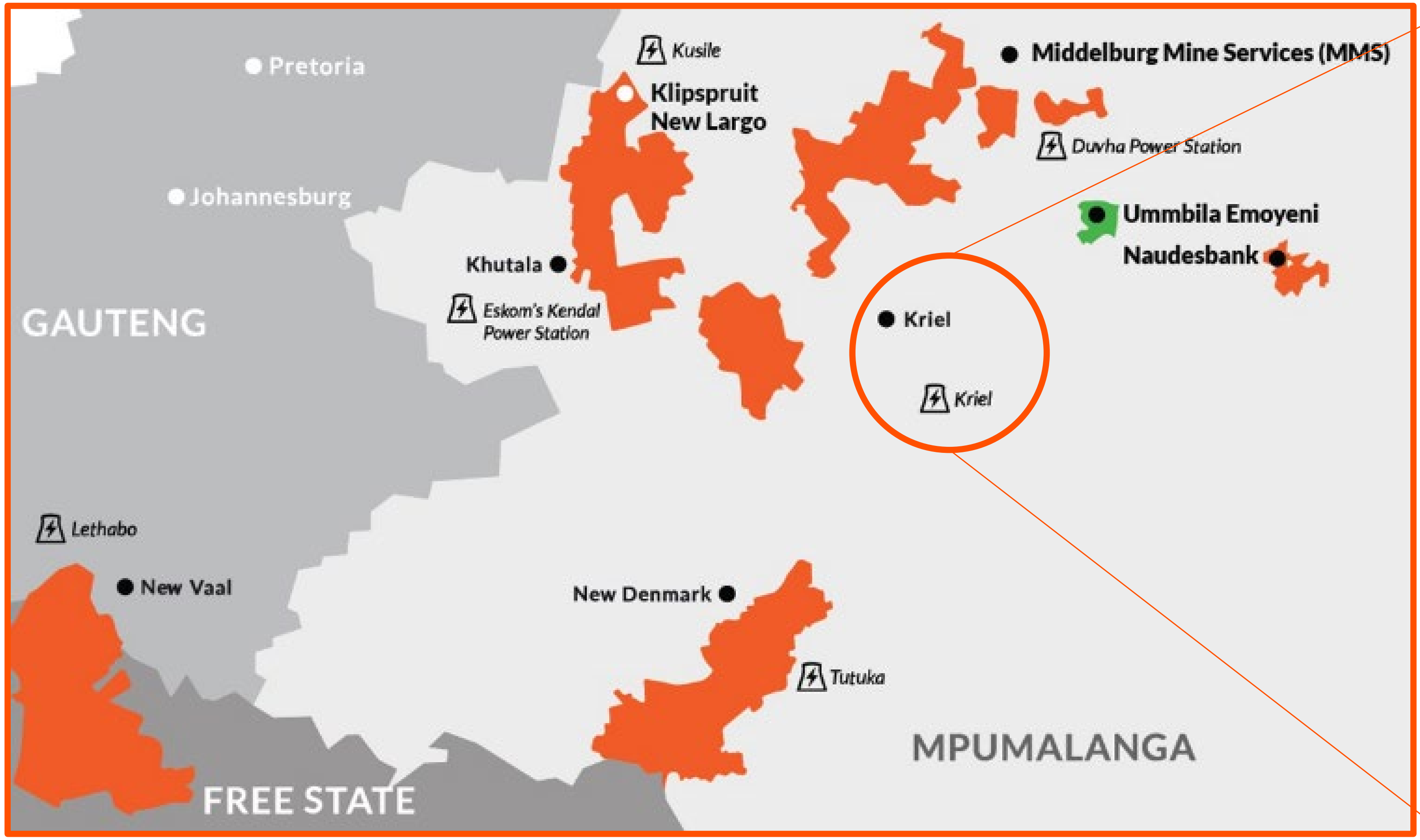
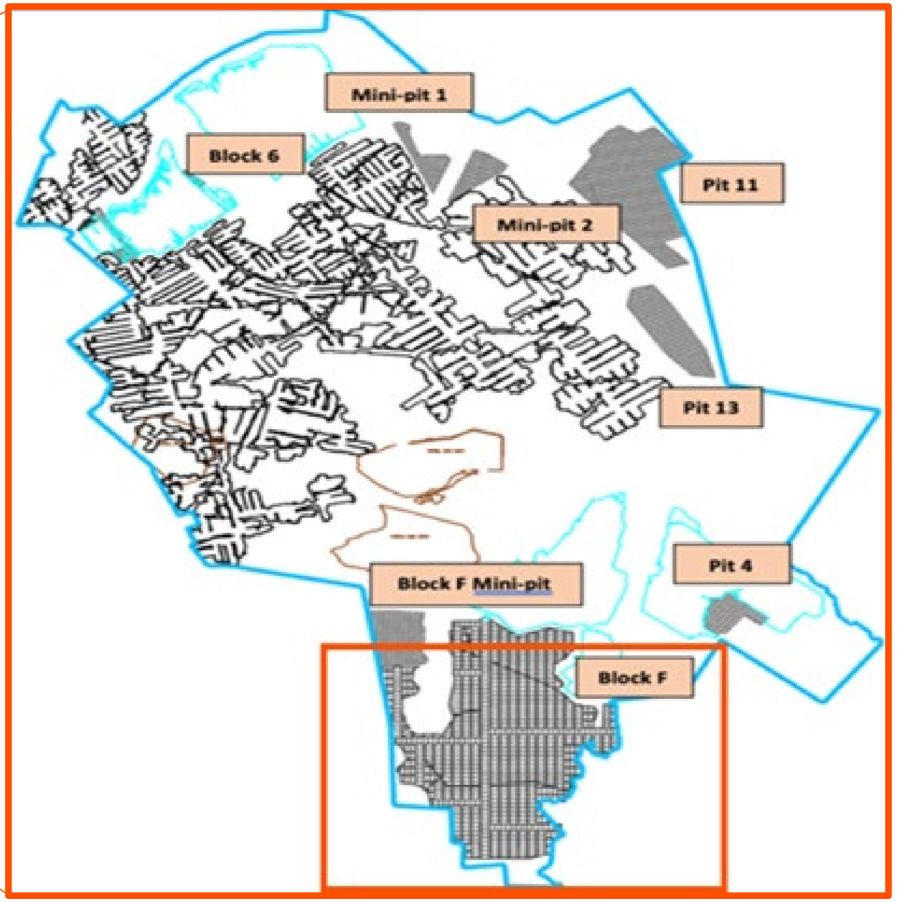
Content

- Introduction
  - Kriel Colliery Locality
  - Block F 18-months Plan
- Block F Local Geology
  - Block F Geological Complexity
  - Generalized Stratigraphy
- Block F FOG Incidents
  - FOG Incidents Stats
  - FOG Intersection Failures
  - FOG Learnings and changes
- Engineering Design Process and Strategies
  - Data Collection
  - Concept Formulation (Model)
  - Design Strategies
    - Empirical Support Design at the Fault
    - Strategy for Undermining the river at Fezela

Introduction: Kriel Colliery Locality





- New Vaal
- Klipspruit New Largo
- Khutala
- Middelburg Mine Services

- New Denmark
- Kriel
- Naudesbank

SERITI Green

- Ummbila Emoyeni

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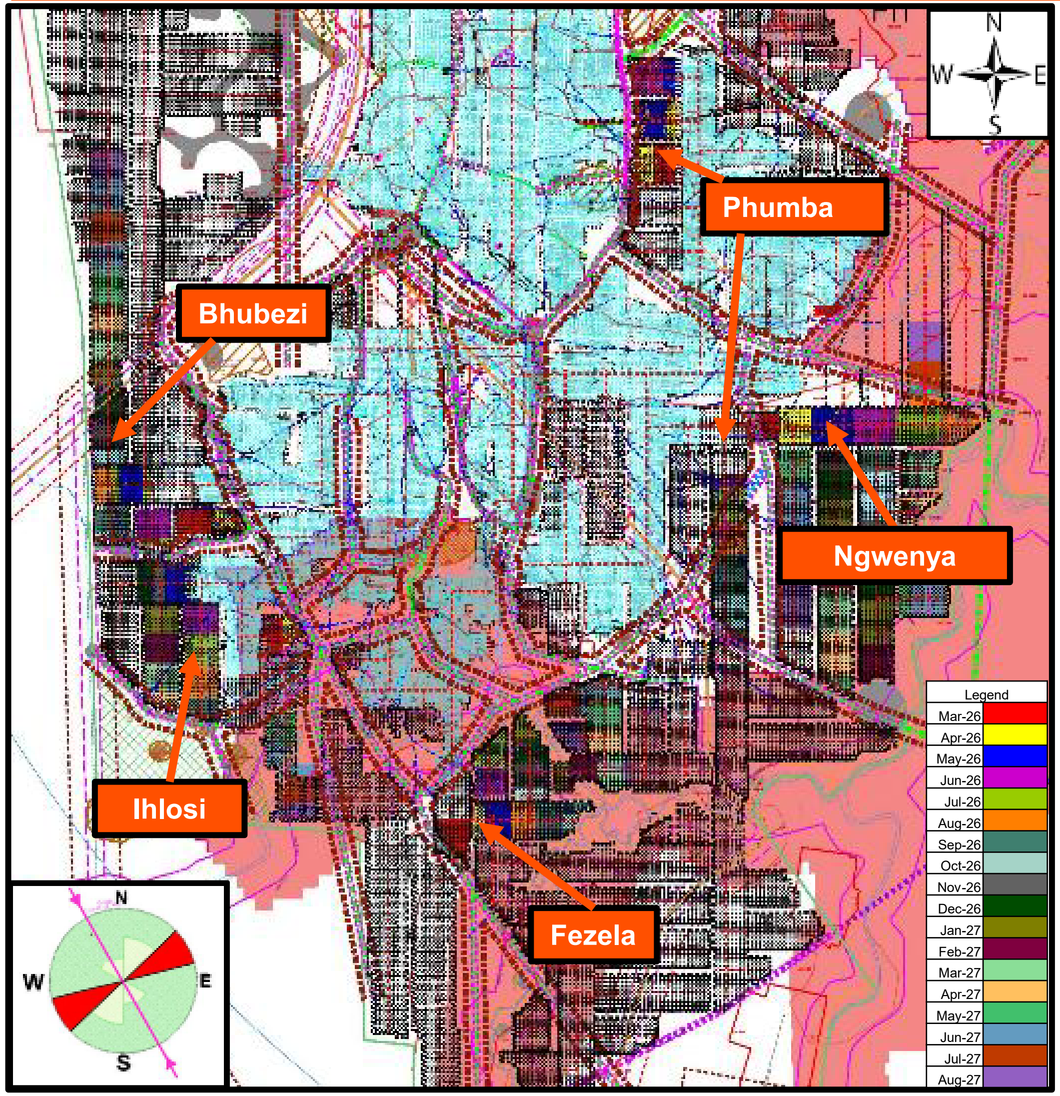
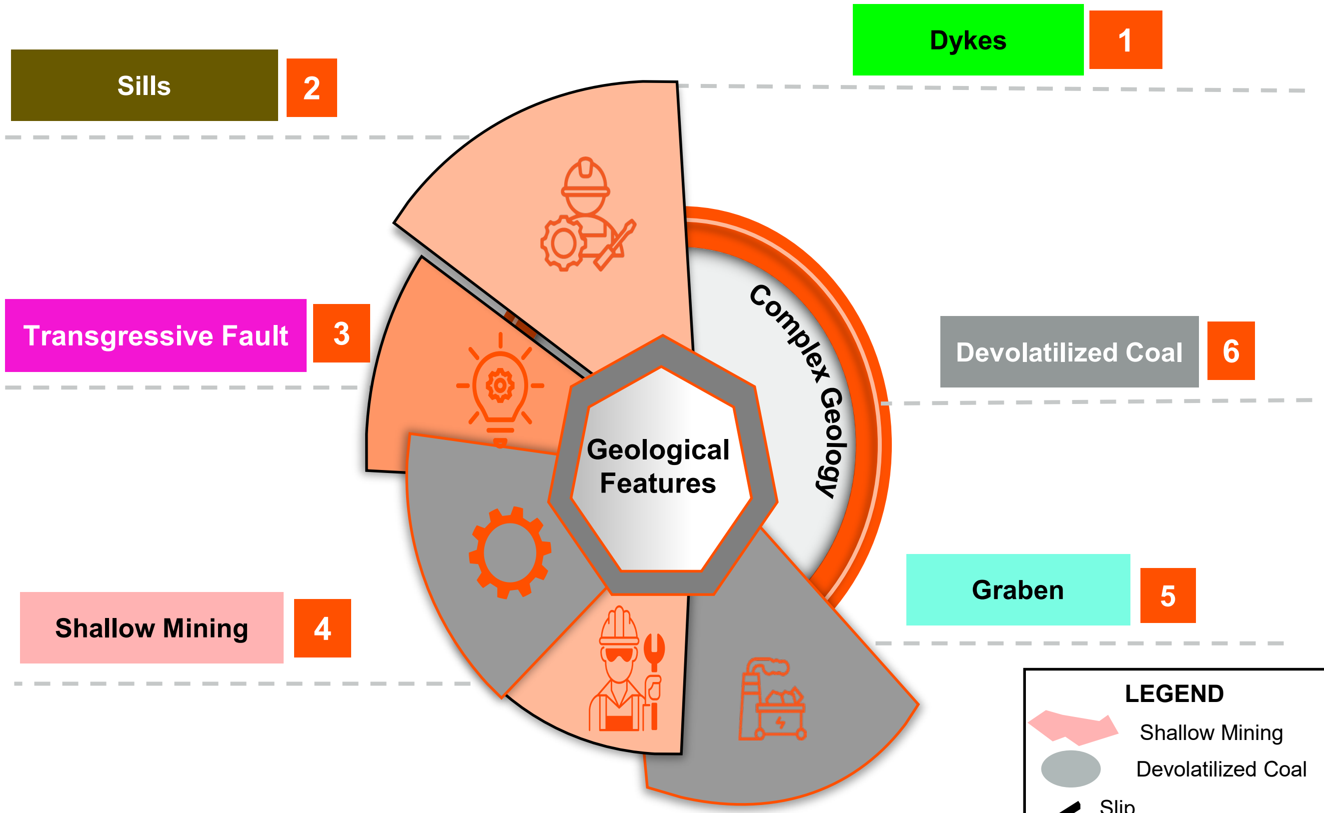
Introduction: Block F 18-months Plan

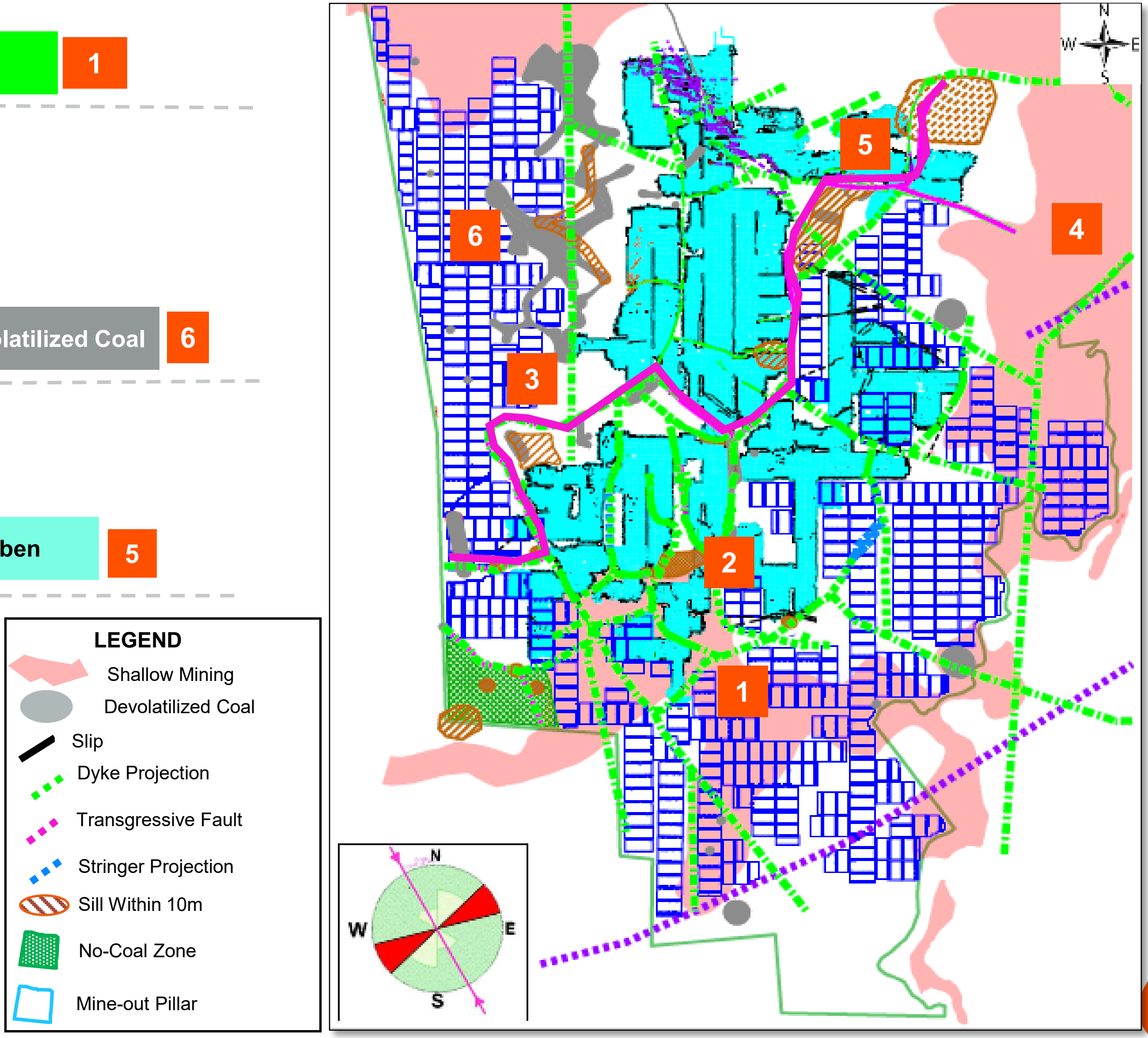


Geotechnical Areas per Section:

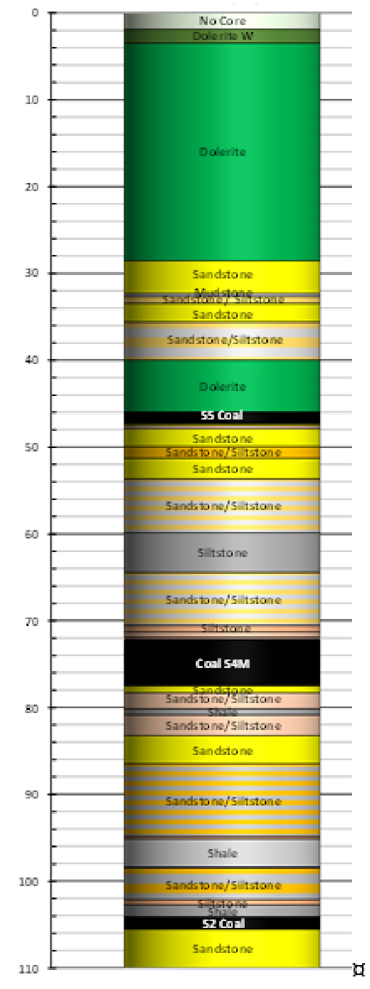
- **Phumba** – Mining tertiary panels from the main BF-N8 panel. The section is mining the north-eastern reserves within proximity to a 5.9m to 8m throw **normal fault**.
- **Ngwenya** – Currently opening pit-room towards the eastern side. This section will be mining adjacent to a panel where a large **FOG** occurred and towards shallow mining area (depth below surface < 40m).
- **Fezela:** Developing further south to access the reserves on the southern side of the **river**. The ground in this area is predominantly **shallow** (depth to seam floor < 40m below surface).
- **Ihlosi –** mining the south-western reserves of Block F within proximity to a **"No Coal Zone"** which is associated with **major geological structures** such as dolerite dykes, sill and normal fault. The area is also considered **shallow mining area** associated with surface water bodies (in-channel non-perennial streams, River).
- **Bhubezi** – developing an access on the up-throw side of a normal fault to the western reserves. Area associated with devolatilised ground due to a major dolerite sill on the floor of the No.4 Seam coal.

Local Geology: Block F Geological Complexity

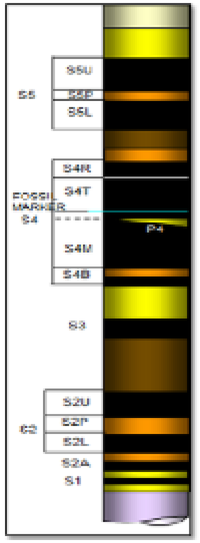


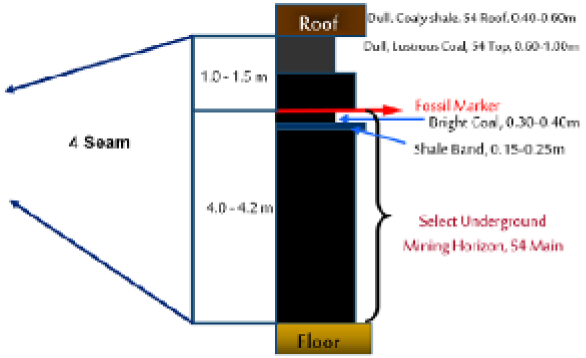


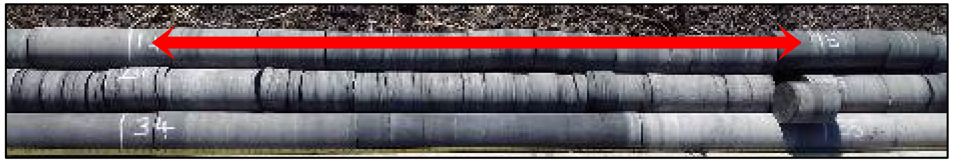
Geology: Generalized Stratigraphy

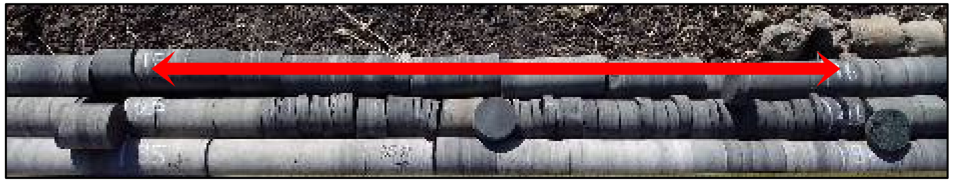


Depth (m)	Thickness (m)	Rock Type, lithology
0 m to 28.5 m	28.5 m	No drill core available for 1st metre. Weathered dolerite progressing into intact dolerite sill (D1) of ±25 m in thickness.
28 to 40 m	12 m	Partially weathered into fresh, intact laminated sandstone with siltstone & sandstone layers.
40 to 46 m	6 m	Dolerite sill (D2).
46 to 47.5 m	1.5 m	No.5 Coal Seam
47.5 to 72.2 m	30 m	Fresh, intact laminated sandstone with siltstone & sandstone layers.
72.2 to 77.5 m	5.5 m	**No.4 Seam Horizon;** Coal, plies and cleated.
77.5 to 104.2 m	26.7 m	S4 Floor and S4S2 interburden, interlaminated, sandstone, siltstone in No.4 floor with varying amounts of interbedded siltstone, carbonaceous layers and sandstone.
104.2 to 105.6 m	<1 m	**No.2 Seam Horizon;** Thin coal seam.
105.1 to 110.9 m	5 m Plus	S2 Floor, Sandstone with a coarse grain sandstone.









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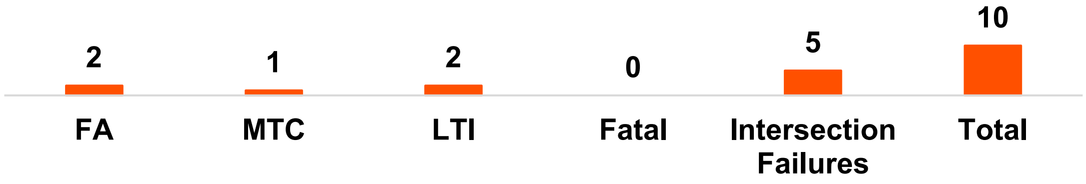
FOG: Block F FOG Incident Stats

Kriel UG FOG Incidents Stats (2021 - 2026)



- FAC:
  - 1 x FAC Bhubezi 18/11/2022
  - 1x FAC Fezela 11/02/2026
- MTC – 1 x MTC Bhubezi 24/04/2023
- LTI:
  - 1 x HPI 3 / 4, LTI Ihlosi 16/12/2023
  - 1 x HPI 3 / 4, LTI Ngwenya 19/02/2025
- Intersection failures:
  - Fezela FOG 17/01/2024
  - Fezela FOG 08/06/2024
  - Ngwenya FOG 08/07/2024
  - Phumba FOG 04/09/2025

Kriel UG FOG Incidents Stats FY26 (April 2025 - March 2026)

- FAC:
  - 1x FAC Fezela 11/02/2026
- Intersection Failures:
  - Phumba FOG 04/09/2025

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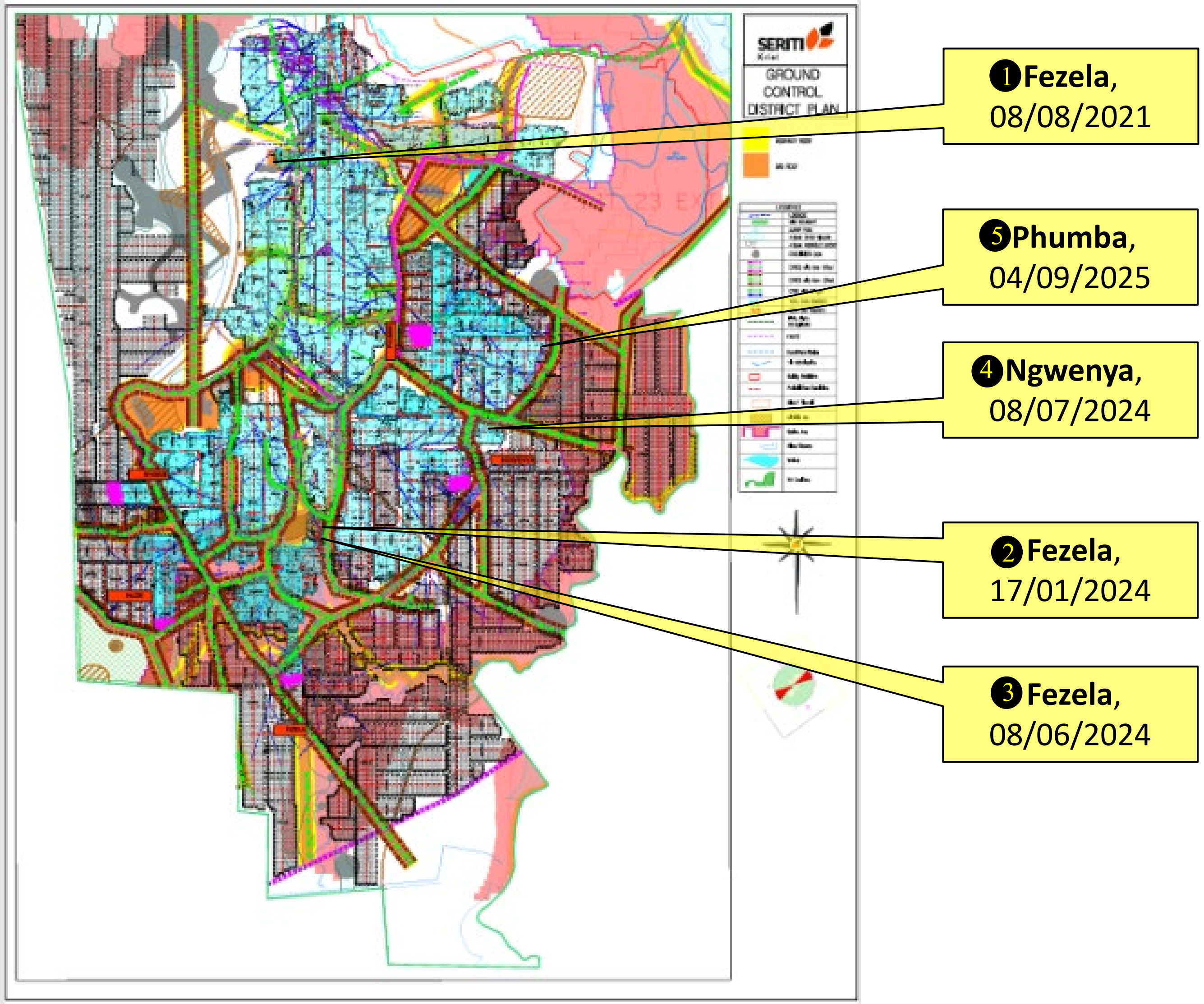
FOG: Block F Intersection Failures

Kriel Block F Intersection Failures Update

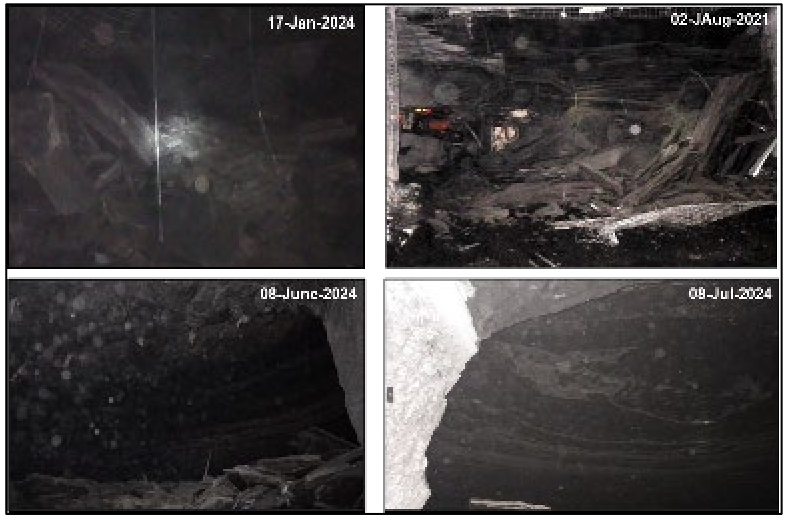


One (1) significant FOG event:

- Fezela BF-W4 - 08 August 2021

Three (3) significant FOG events:

- Fezela BF-1 - 17 January 2024
- Fezela BF-1 - 08 June 2024
- Ngwenya BF-E7 - 08 July 2024
- Phumba BF-E11 - 04 September 2025



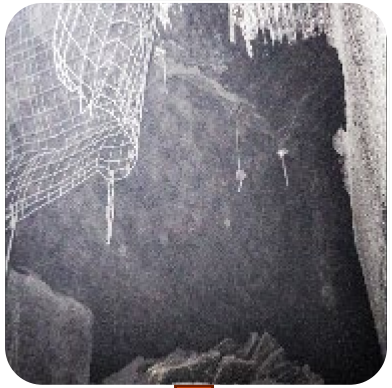
Intersection Failures (FOG): Learnings and Changes

02 Aug 2021

- Spin-to-stall to reverse spin bolts.
- Introduced 2.8m x 20mmØ roof bolts installed using a 1350mm x 23mm Ø Fasloc dualspeed resin.

17 Jan 2024

- 5 RMDs for intersections created in poor ground
- Review of NPHI with new information from UDD.



08 June 2024

- 40m zoning around dykes on GH Plans.
- Increase in frequency of SEPTs.

06 July 2024

- Reduce bord width from 7.2m to 6.5m mine wide.
- Change support pattern from 1.4m x 2m pattern to a 1.5m x 1.5m grid spacing.
- Convert roof bolters from dry to wet drilling.
- Onboarding of contractor to install 6m fully grouted anchors.

05 September 2026

- Limiting panel span when approaching the dyke.
- Increased use of cable anchors within the 10m zone of dykes.

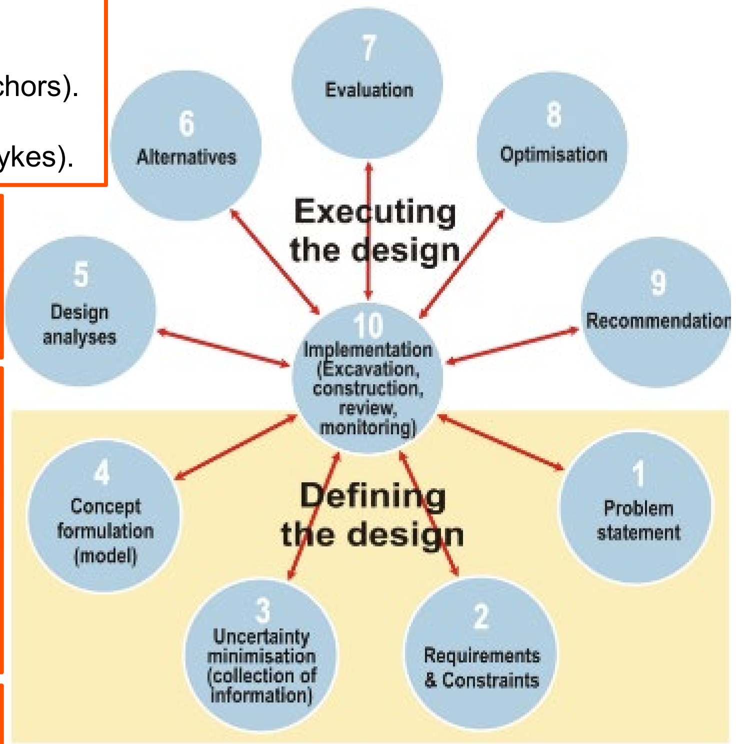
Engineering Design Process

9. Recommendation:
- Pillar design layout strategies
- Roof monitoring strategies (1 RMD/ 5 RMDs)
- Specialized reinforcement (6m fully grouted cable anchors).
- Secondary support installation (2.8m x 20mm bolts)
- Panel span and number of roadways going through dykes).

8. Optimisation:
- Risk based approach to the 40m zone of the dykes and devolatilised ground.
- Declaration of Special Areas

7. Evaluation:
- Compliance to Design (Survey Scanner).
- Pull tests (SEPTs).
- Third Party Audit (Saxum Mining)
- TARPs
- Operational Management System (OMS Audits)
- Critical control Verification (CCV)
- Risk Assessments

6. Alternatives:
- Do not mine Devolatilised ground.
- Avoid mining within 40m of dykes



(Stacey, 2005)

1. Problem statement:
- Clarity of design objectives (e.g. Rock Engineering service function).
- Design stable mine excavations to safeguard the lives and safety of all mine employees.

2. Requirements and Constrains:
- **Objectives:**
  - Safety factor requirements.
  - Required Beam thickness (coal beam > 0.5m)
- **Constrains**
  - Size of machines
  - Mining height,
  - Bord width

3. Uncertainty Minimisation (collection of Data):
- **Geology:**
  - UDD
  - Surface Exploration drilling
  - Sonic wireline geophysics (UCS, E, v)
- **Geotech:**
  - Geotechnical logging and sampling
  - Impact splitting Index Tests (ISP)
  - In-situ stress (rose diagram and measurements)

5. Design Analyses:
- **Pillar Design:**
  - Salamon and Munro (1967) pillar strength formula
  - Overlap Reduction (van der Merwe and Mathey, 2013).
  - Shallow Mining Guidelines
- **Support Designs:**
  - Analytical Methods - beam building
  - Empirical Methods - ISP index

4. Concept Formulation (Model):
- Mode of Failure (tensile or shear)
- Failure Mechanisms (beam buckling, hydraulic pressure, skin failure/slabbing)
- Mohr Coulomb or Hoek-Brown criteria
- Rock Mass classification systems (RQD, MRMR, GSI and Q).

Data Collection: Geotechnical Logging

Information obtained from a logging a geotechnical borehole

1. Geological Information

- Rock and soil types
- Strata thickness and layering
- Presence of dykes, sills, faults

2. Ground Conditions

- Rock quality and strength
- Weathered or devolatilised zones
- Fractures, joints, and weak planes

3. Hydrogeological Data

- Water table level and Phreatic zone
- Limit of weathering
- Waterlogged zones

4. Mining & Stress Indicators

- Evidence of stress-related fractures
- Areas prone to slabbing or roof failure
- Core discing

5. Sampling

- Uniaxial compressive strength tests with elastic moduli.
- Brazilian tensile strength.
- Weatherability tests

Data collection: Impact Splitting

Nominal Core Size	Approx. Diameter (mm)	Chisel drop Height (mm)
TNW	60.5	102
BQ	36.1	36
NQ	47.3	62
HQ	63.2	111

$$h_d = \frac{A}{28.27}$$

Where A = cross sectional area of core (mm^2)

The individual unit ratings for each zone is determined from the following equations:

If $f_s \leq 5$ $R = 4 f_s$

If $f_s > 5$ $R = 2 f_s + 10$

Where f_s = fracture spacing (cm)

The unit ratings are weighted according to their height into the roof using the following equation to determine a weighted roof rating (R_w):

$$R_w = R.2(2-h)t$$

where h = mean height above the roof (m), T = thickness of unit (m) and R = individual unit rating

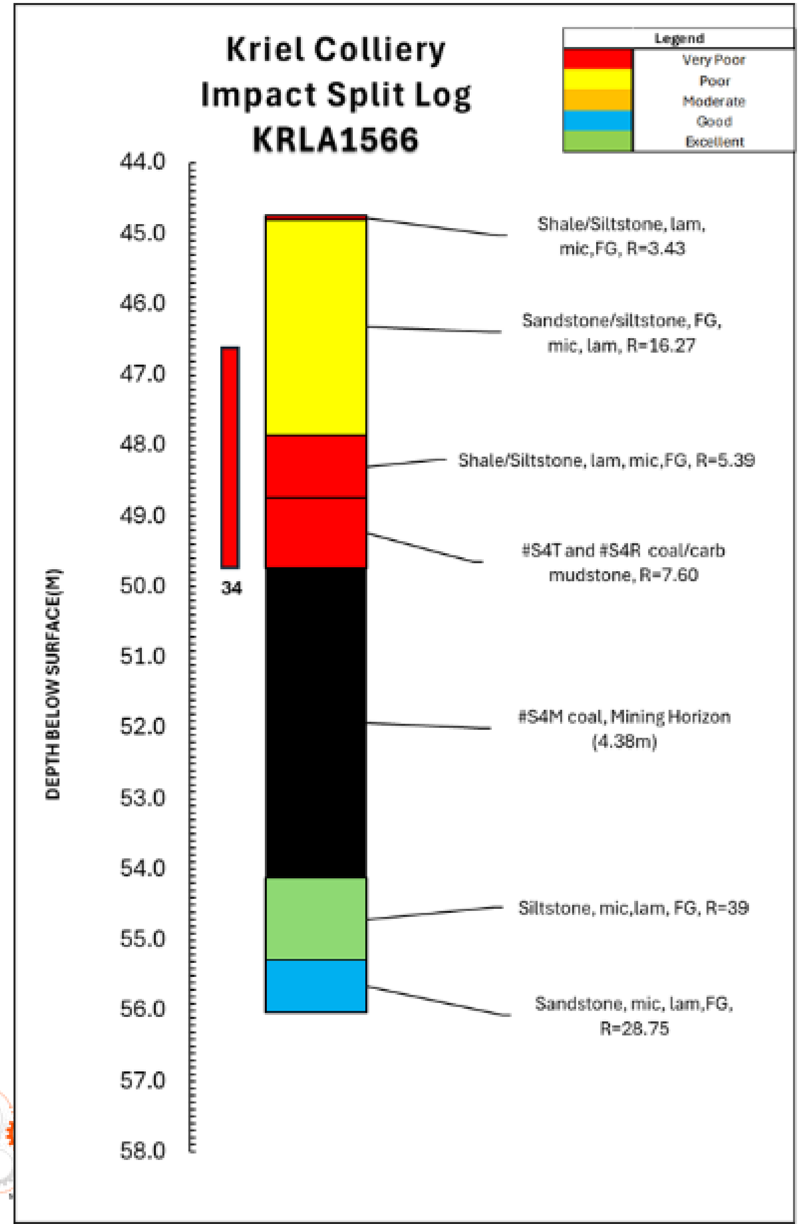
Why impact split ?

- To predict roof conditions that can be expected underground.
- To determine the propensity of the roof layers to delaminate under prevailing underground stress conditions.
- To determine the minimum systematic support requirements for the different roof conditions.

Procedure

- Select the drill core (5m section of the roof which includes the 2m of roof above the selected mining horizon.
- Divide the core into geotechnical zones that are perceived to behave similarly.
- Conduct the initial fracture count.
- Chisel = 1.5kg and blade width of 25mm.
- Chisel is dropped onto the core every 20mm intervals from a constant height.
- Conduct final fracture count.

Data Collection: Impact Splitting



Unit Rating	Rock Class	Roof Rating
<9	Very Poor	<34
10 - 13	Poor	35 - 51
14 - 19	Moderate	52 - 75
20 - 28	Good	76 - 113
29 - 42	Very Good	114 - 167
>42	Excellent	>167

Why impact split ?

- To predict roof conditions that can be expected underground.
- To determine the propensity of the roof layers to delaminate under prevailing underground stress conditions.
- To determine the minimum systematic support requirements for the different roof conditions.

Table 5. Roof conditions and typical systematic support

Roof condition	Max. cut-out distance (m)	Bord width (m)	Typical systematic support			
			Type	Length (m)	Pattern	Distance between rows of bolts (m)
Excellent	>18	7	M16 point anchor	0.9 or 1.2	Spot bolting false roof	N/A
Very Good	>18	6.5 to 7	M16 point anchor	1.2	Spot bolting and 5 bolts per intersection only	N/A
Good	18	6 to 6.5	M16 point anchor	1.2 or 1.5	5 bolts per intersection and 2 per row in bords	2 to 2.5
Moderate	12	5.5 to 6	M16 or M20 full column resin	1.5 or 1.8	9 bolts per intersection and 3 per row in bords	1.5 to 2
Poor	6	5 to 5.5	M20 full column resin	1.8	16 bolts per intersection and 4 per row in bords. Steel straps may be necessary	1 to 1.5
Very Poor	<6	<5	Specialised support, e.g. 1.8m M20 full column resin bolts and /or cable anchors with steel straps. Cable trusses, cluster stick packs or shotcrete may also be required	≥1.8	As dictated by conditions. Typically 5 bolts per row with steel straps. Often 9 cables in intersections.	<1

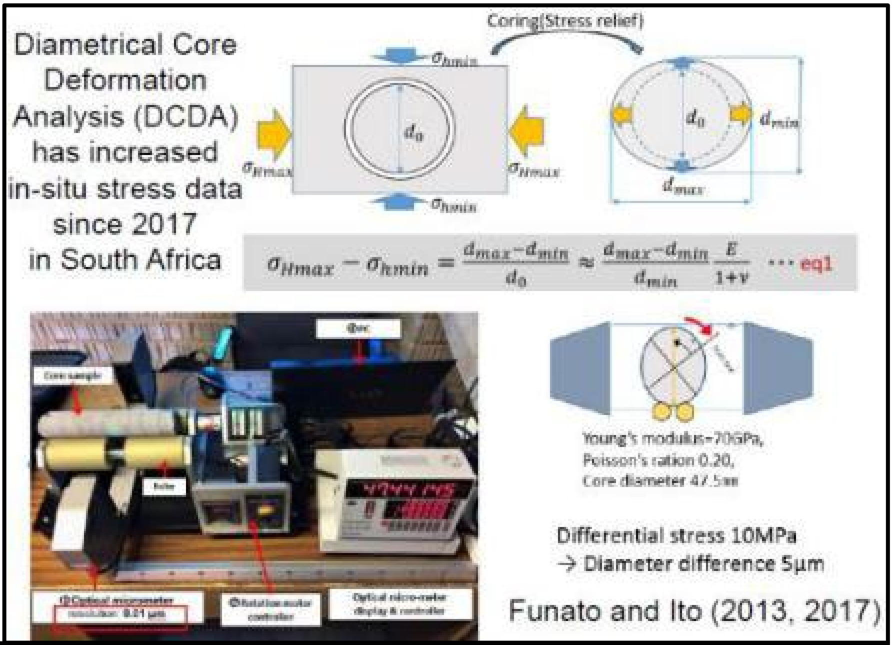
Data Collection: In-situ Stress Measurements

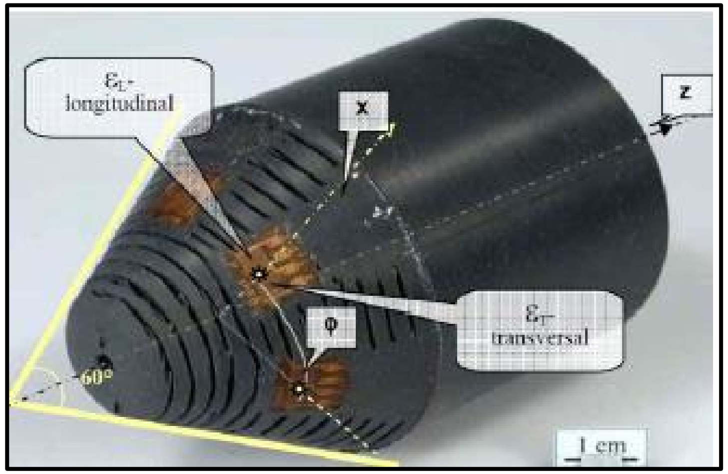
CSIR / Groundworks / Coaltech Stress measurement Project

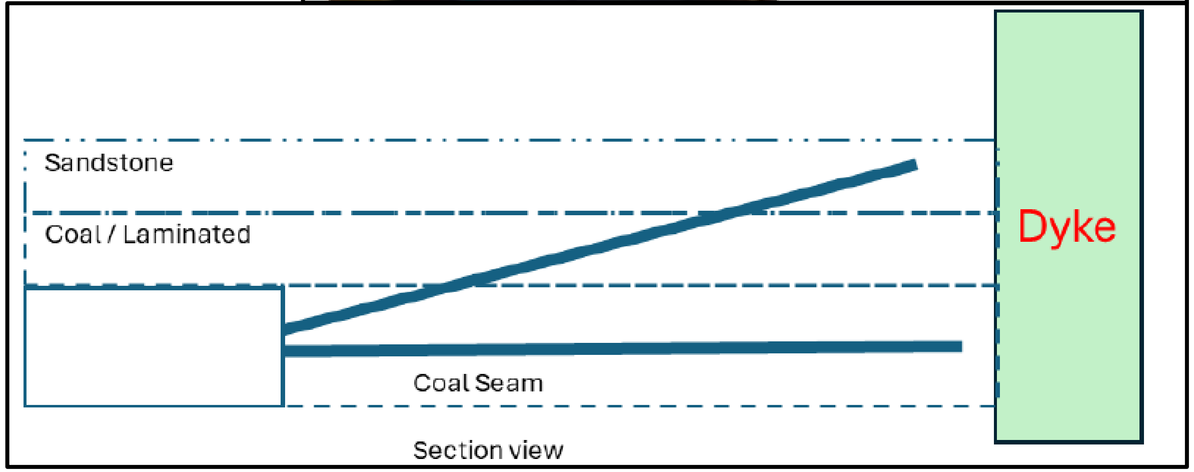
Aim:

- Measurement of the stress field components as a geologically complex area is approached with the **CCBO (Compact Conical Borehole Over-coring)** method, will contribute to quantify the impact of these structures on the magnitude and / or orientation of the field stress components.

- At the same time, correlating these measurements with measurements obtained using the **DCDA** (**Diametrical Core Deformation Analysis**)method, could allow the drilling of core in a similar rock type where stress components are required (regular basis in very geologically complex areas) and measurement of the stress component magnitudes and orientations







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Data Collection: Historic In-situ stress Data for Kriel

In-situ stress measurement, North West Shaft 4 Seam at Kriel Colliery (after G. Walker and P. Cartwright (2000))

Table 1 Test properties and location

Test No.	Elastic Modulus (GPa)	Poisson's Ratio	Depth into access hole (m)	Height above seam (m)
1:2	9.7 (est.)	0.3 (est.)	10.75	3.72
2:1	15.96	0.40	9.79	1.72
3:1	11.45	0.48	9.97	2.86

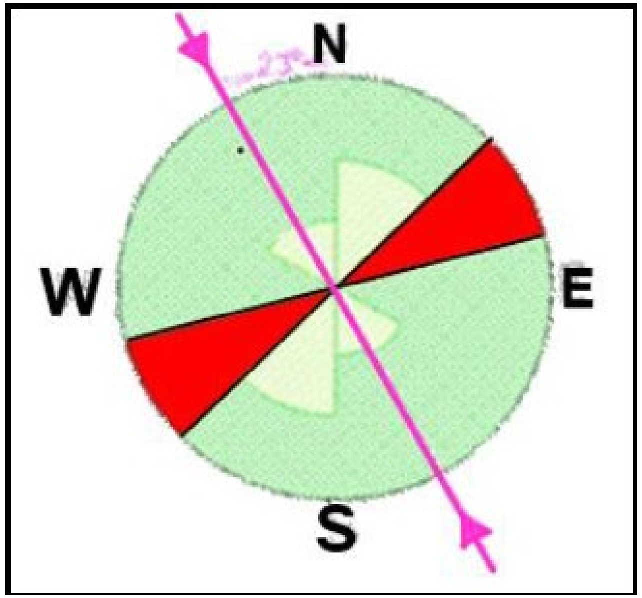
Table 2 Principal stresses

Test No.	Major			Intermediate			Minor		
	Value (MPa)	Bearing	Dip	Value (MPa)	Bearing	Dip	Value (MPa)	Bearing	Dip
1:2	3.9	55°	58°	2.9	303°	13°	1.2	206°	29°
2:1	3.9	195°	7°	3.0	288°	23°	0.4	89°	66°
3:1	4.3	177°	17°	2.7	063°	52°	2.2	278°	32°

Table 3 Horizontal and vertical stress components

Test No	Maximun horizontal stress component (MPa)	Bearing of maximum horizontal stress	Minimum horizontal stress component (MPa)	Vertical stress component (MPa)
1:2	3.0	291°	1.8	3.2
2:1	3.9	010°	2.6	0.9
3:1	4.1	359°	2.4	2.7

Stress Rose Diagram



- The historic data gave us a good tool to use in planning the mining layout and panel directions relative to the major principal stress directions.
- During the mining of the Block F shaft, panels mining in the east west directions tend to encounter stress related problems compared to panels advancing in a north-south directions.

Data Collection: In-situ Stress Estimation

An improved method for estimating in situ stress in an elastic rock mass and its engineering application (Q. Pei *et al,* 2016)

Site Stress Measurements Data

Measurement site	σ_V (MPa)	σ_H (MPa)	σ_h (MPa)	K-ratio	H
Site 1	1.67	3.0	1.8	1.80	66.7
Site 2	0.92	3.9	2.6	4.23	36.9
Site 3	1.78	4.1	2.4	2.31	71

input Parameters

β	8.50E-06	per degrees celcius	
G	0.0287	degrees cel. Per m	
Erm (MPa)	3233.33	5320.00	3816.67
v	0.30	0.40	0.48
Gemma	0.025	Mpa/m	

	$\frac{\sigma_H+\sigma_h}{2\sigma_V}-\frac{\nu}{1-\nu}$	$\frac{\beta E_{rm} G}{(1-\nu)\gamma}(1+\frac{1000}{H})$
	1.011	7.21E-01
	2.856	2.43E+00
	0.908	1.08E+00
ξ	**1.1788**	
η	**0.0714**	

Estimated In-situ stress

input Parameters

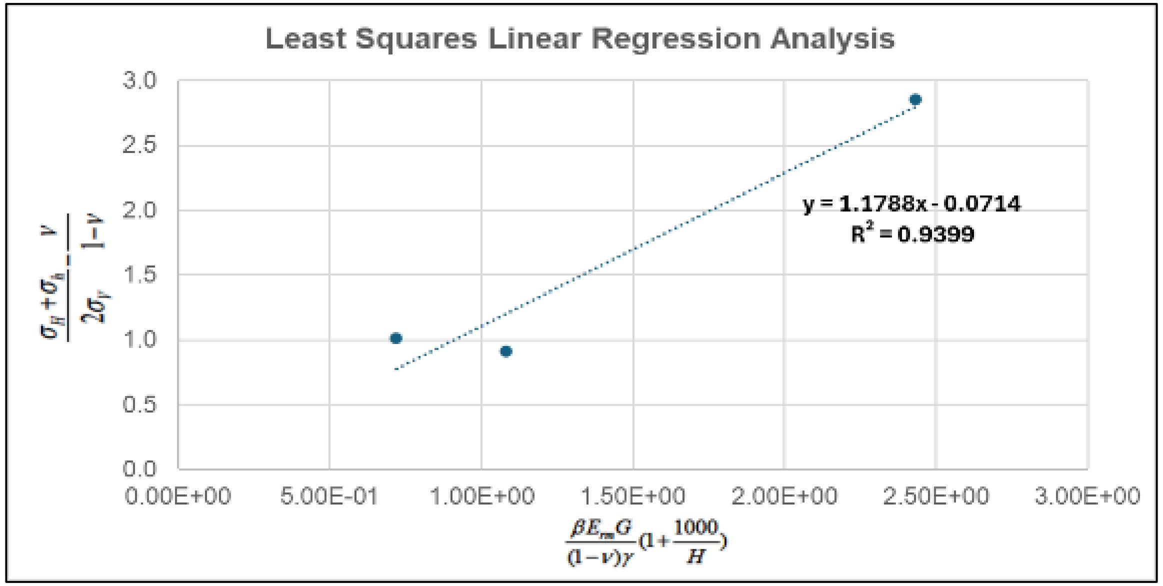
β	8.50E-06	per degrees celcius
G	0.0287	degrees cel. Per m
Erm (MPa)	3131	Mpa
v	0.33	
Gemma	0.0272	Mpa/m
H	25.93	m
λ	0.49	

σ_V (MPa)	σ_H (MPa)	σ_h (MPa)	k-ratio
0.71	2.29	1.33	3.25

Rock type	β (10^{-6} /°C)
Granite [29]	6–9
Limestone [29, 30]	3.7–10.3
Sandstone [29]	5–12
Marble [29]	3–15
Conglomerate [30]	9.1
Dolomite [30]	8.1
Breccia [30]	4.1–9.1
Schist [29]	6–12

Average = 8.50E-6 was used

$$\left.\begin{aligned}\sigma_H &= \lambda\sigma_V + 2\beta E_{rm} G\xi(H+1000) + 2\eta(1-\nu)\\ \sigma_V &= \gamma H\\ \sigma_h &= \lambda\sigma_V + 2\lambda\beta E_{rm} G\xi(H+1000) + 2\eta\nu\end{aligned}\right\}$$



$$\frac{\sigma_H+\sigma_h}{2\sigma_V} = \frac{\nu}{1-\nu} + \frac{\beta E_{rm} G}{(1-\nu)\gamma}\left(1+\frac{1000}{H}\right)\times\xi+\eta$$

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Data Collection: In-situ Stress Estimation

Contouring of the k-ratio obtained from estimated in-situ stress data

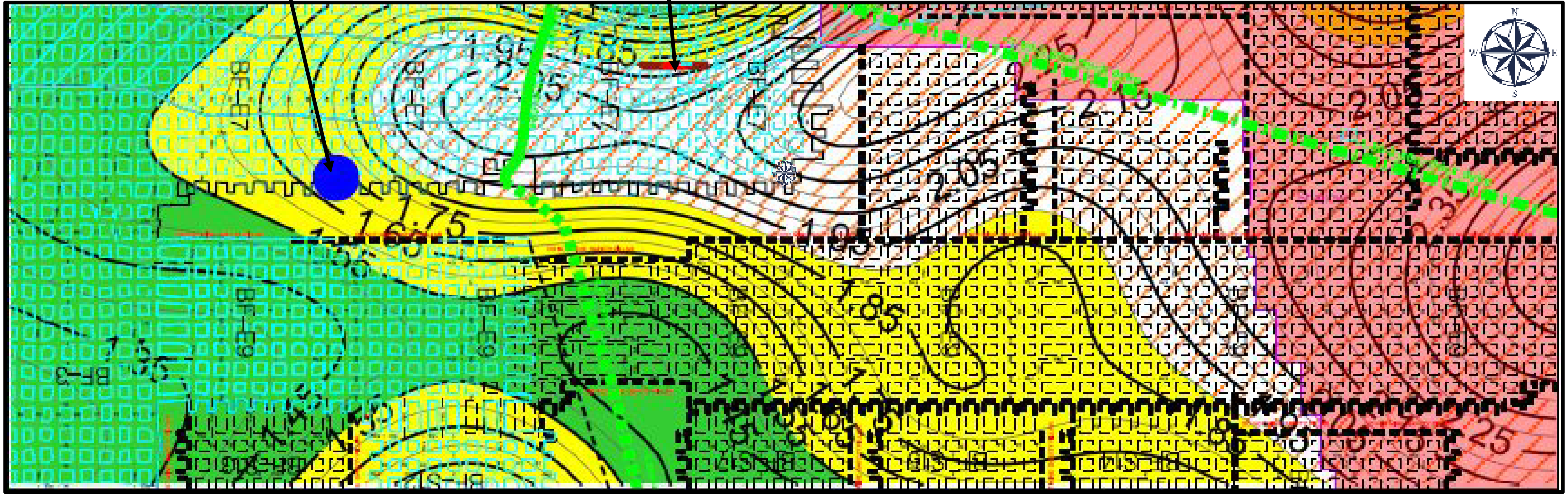
Stress Measurement site
K-ratio = 1.6 – 2.2

FOG at a k-ratio = 1.9

1.25 -1.55

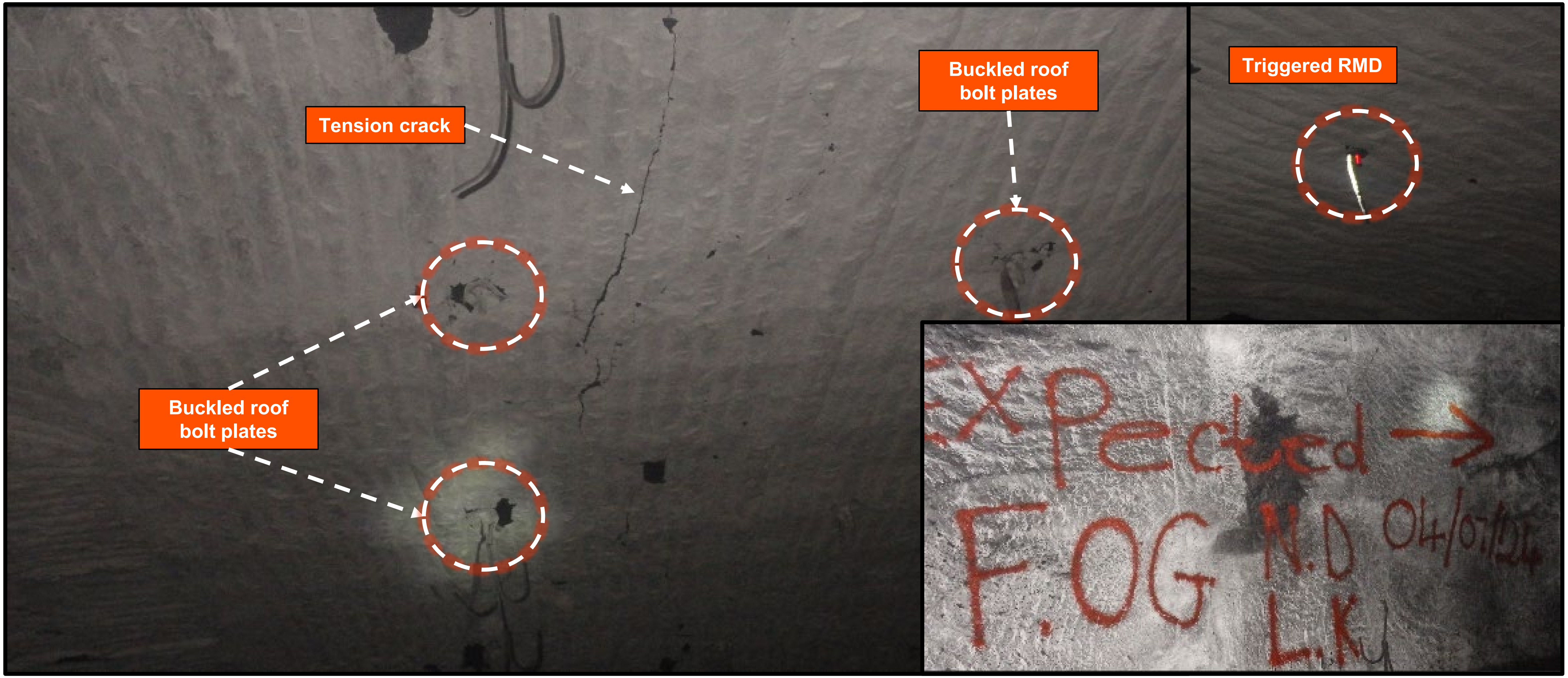
1.55 – 1.9

>1.9



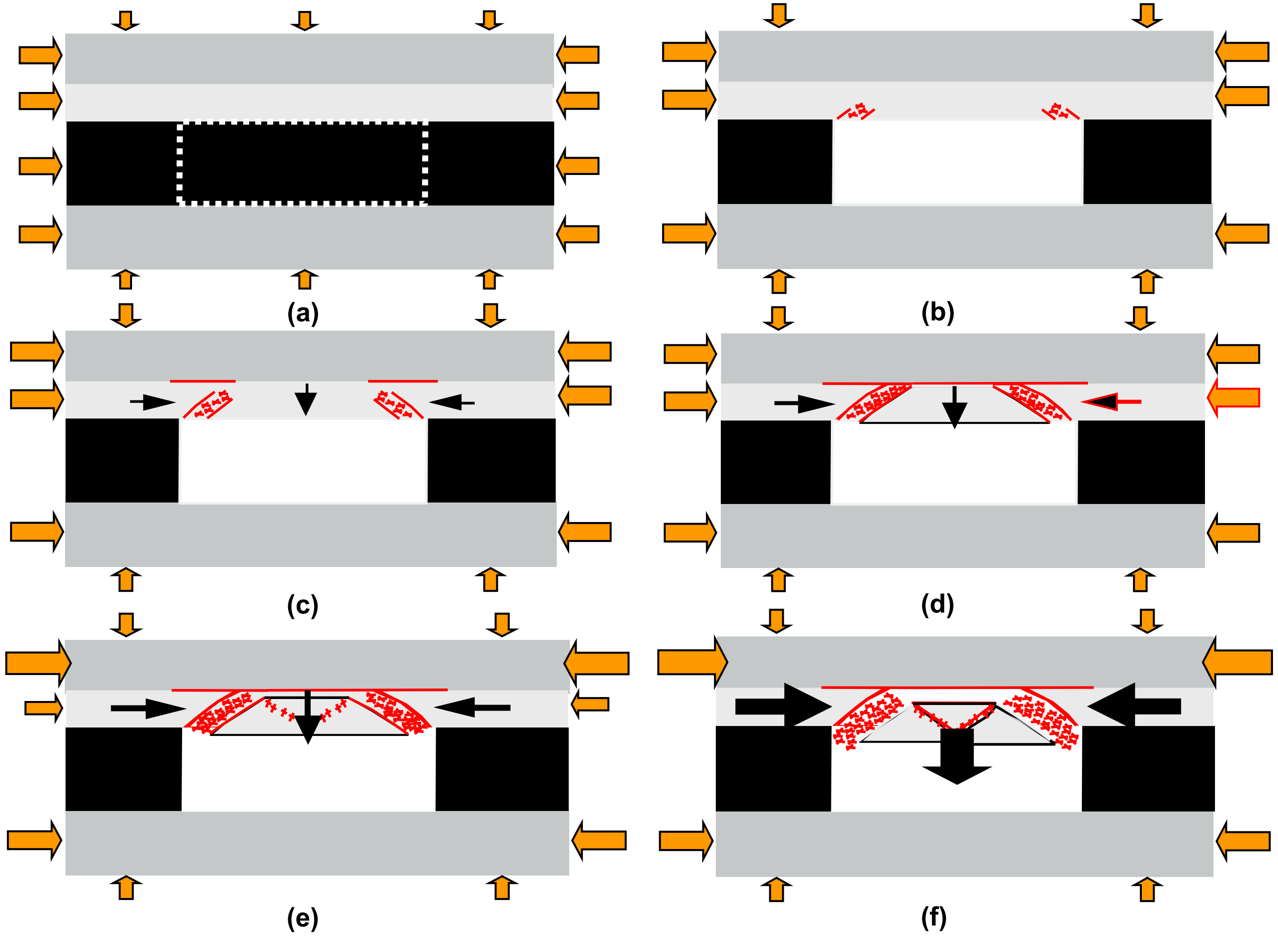
Concept Formulation: Failure Modes

04/07/2026 Ngwenya section Panel BF-E7 FOG Road L1 Split 58

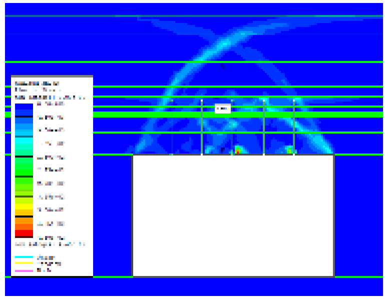


Concept Formulation: Failure Mechanisms

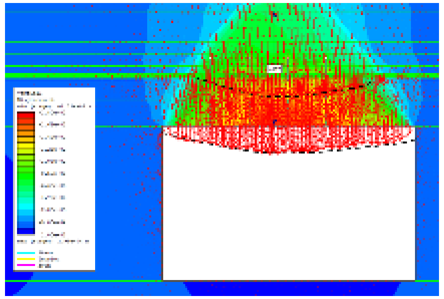
Failure Mechanism



Max Shear strain



Max vertical displacement



Beam buckling:

- Failure initiates from the corners (max. shear at corners).
- Bolts on the edges were too far from pillar sidewall in a bord width of 7.2m.
- Simplified RS2 simulations provided reasonable estimates of the possible failure mechanism.
- **Major contributing factors:**
  - **Complex geology (dyke-sill interaction)**
  - **Water features on surface (rivers and wetlands)**
  - **Increase in the k-ratio/ horizontal stress concentration within the transition zone into shallow mining.**

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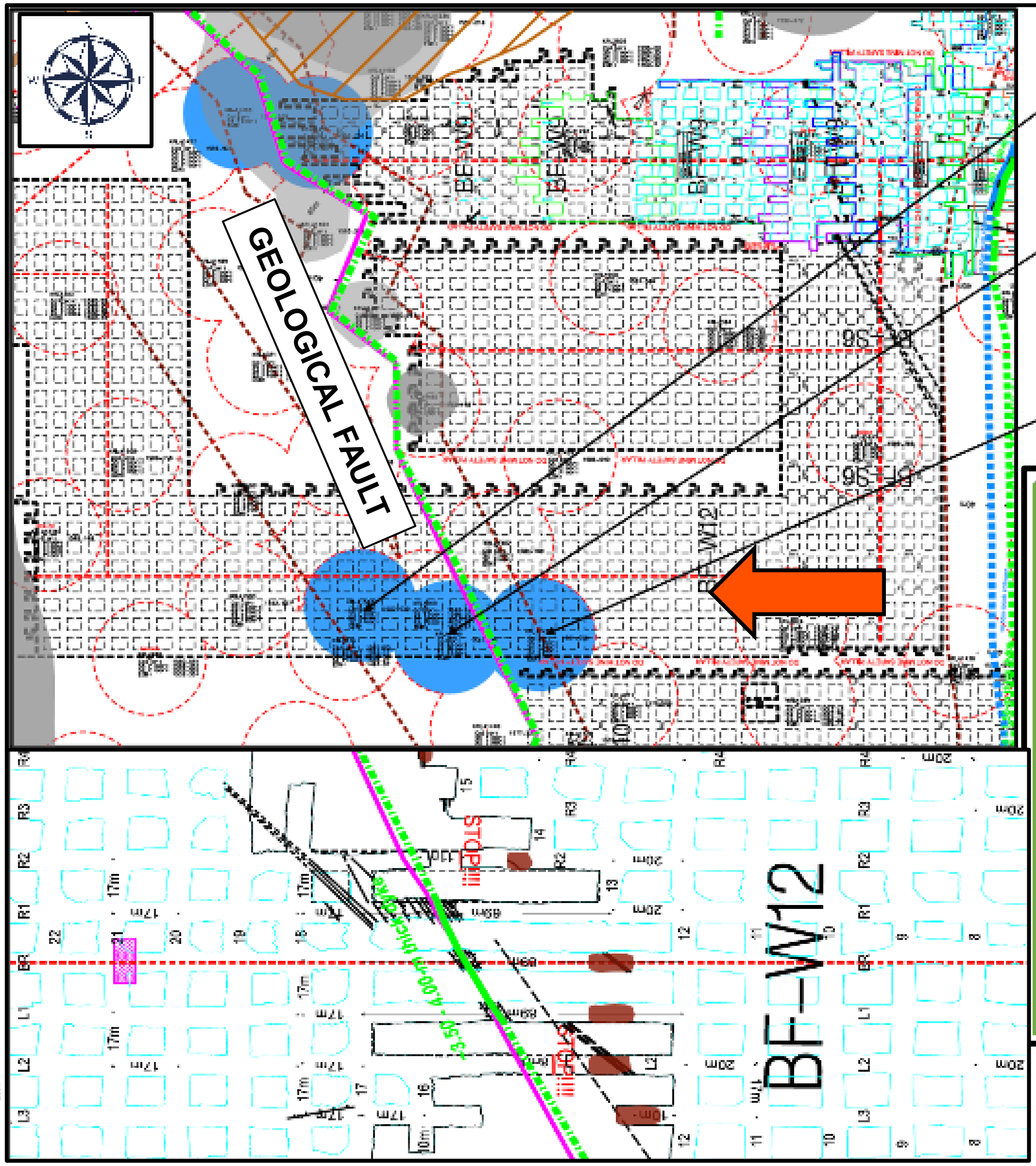
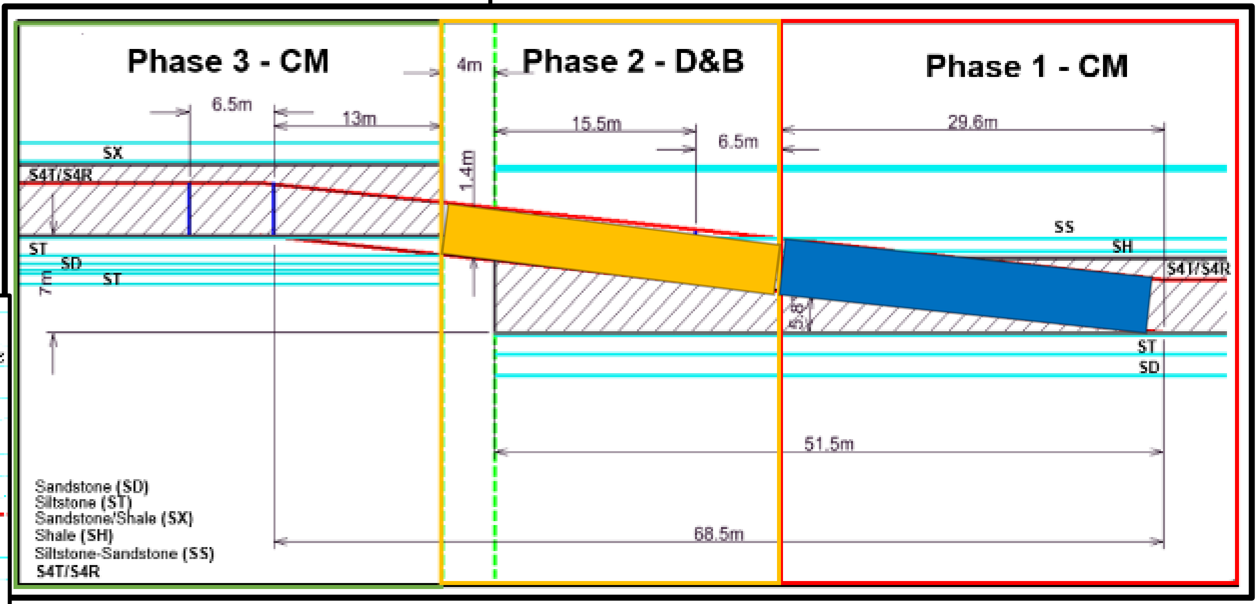
Design Strategies: BF-W12 Fault Development (Empirical Designs)





Design layouts

- The mining layouts had to change once the presence of a major geological structure was confirmed.
- Splitting for ventilation purposes was initially planned but was abandoned due to sufficient use of fans with ducting.

Design Analysis: Empirical Support Design at the Fault

Borehole	Geotech Zone	Depth (m)	Thickness (m)	RQD	Jn	Jr	Ja	Jw	SRF	Q-Rating	Classification
KRLA1497		43.84		%						RQD/Jn x Jr/Ja x Jw/SRF	
KRLA1497	Sandstone/Siltstone, FG,Lam	44.79	0.95	100.0	2.0	1.00	1.00	0.66	5.00	6.60	Fair
KRLA1497	Sandstone, FG,massive	45.80	1.01	100.0	2.0	1.50	1.00	0.66	5.00	9.90	Fair
KRLA1497	Sandstone, MG-CG, Lam	46.04	0.24	100.0	2.0	1.50	1.00	0.66	5.00	9.90	Fair
KRLA1497	Sandstone, FG, x-lam	47.35	1.55	100.0	2.0	3.00	3.00	0.66	5.00	6.60	Poor
KRLA1497	Sandstone/Shale, interlam	47.67	0.32	43.8	2.0	1.00	1.00	0.66	5.00	2.89	Fair
KRLA1497	Shale/Sandstone, interlam	49.06	1.39	77.3	2.0	1.00	3.00	0.66	5.00	1.70	Poor
KRLA1497	Coal/Shale, #S4R	49.74	0.68	83.8	3.0	1.00	1.00	0.66	5.00	3.69	Poor
KRLA1497	Coal, S4T	50.80	1.06	53.8	3.0	1.00	1.00	0.66	2.50	4.73	Fair
Borehole	Geotech Zone	Depth (m)	Thickness (m)	RQD	Jn	Jr	Ja	Jw	SRF	Q-Rating	Classification
KRLA1498		38.67		%						RQD/Jn x Jr/Ja x Jw/SRF	
KRLA1498	Sandstone, FG, massive	39.90	1.23	96.75	2.0	3.0	1.0	0.66	5.00	19.16	Good
KRLA1498	Sandstone, FG, lam	41.52	1.62	82.41	2.0	1.5	3.0	0.66	5.00	2.72	Poor
KRLA1498	Shale/Sandstone, FG, lam	41.92	0.40	61.25	2.0	1.0	1.0	0.66	5.00	4.04	Fair
KRLA1498	Sandstone, CG, Lam	42.02	0.10	100.00	2.0	3.0	4.0	0.66	5.00	4.95	Fair
KRLA1498	Shale/Sandstone, FG, lam	43.12	1.10	60.91	2.0	1.0	1.0	0.66	5.00	4.02	Fair
KRLA1498	Sandstone,MG-CG, Lam	43.22	0.10	100.00	2.0	1.5	4.0	0.66	5.00	2.47	Poor
KRLA1498	Coal/Shaly #S4R	43.92	0.70	50.71	2.0	1.5	3.0	0.66	5.00	1.67	Poor
KRLA1498	Coal #S4T	44.60	0.68	82.35	3.0	1.5	3.0	0.66	5.00	1.81	Poor
Borehole	Geotech Zone	Depth (m)	Thickness (m)	RQD	Jn	Jr	Ja	Jw	SRF	Q-Rating	Classification
KRLA1503		38.12		%						RQD/Jn x Jr/Ja x Jw/SRF	
KRLA1503	Sandstone, FG, massive	38.75	0.63	100.00	2.0	1.5	1.0	0.66	5.00	9.90	Fiar
KRLA1503	Sandstone, FG, lam	39.91	1.16	100.00	2.0	3.0	1.0	0.66	5.00	19.80	Good
KRLA1503	Shale/sandstone, interlam	40.04	0.13	100.00	2.0	3.0	1.0	0.66	5.00	19.80	Good
KRLA1503	Sandstone, CG,lam	41.65	1.61	100.00	2.0	1.5	3.0	0.66	5.00	3.30	Poor
KRLA1503	Shale/Siltstone, FG, interlam	42.04	0.39	100.00	2.0	1.0	3.0	0.66	5.00	2.20	Poor
KRLA1503	Sandstone, MG-CG, lam	43.38	1.34	64.93	2.0	1.0	3.0	0.66	5.00	1.43	Poor
KRLA1503	Coal/Shaly #S4R	44.00	0.62	53.23	3.0	1.0	3.0	0.66	5.00	0.78	Very Poor
KRLA1503	Coal #S4T	44.85	0.85	65.29	2.0	1.0	3.0	0.66	5.00	1.44	Poor

Q-Rating System

- In the vicinity of the fault (Phase 1 zone) the rating varied between poor and fair.
- Similarly within the Phase 2 zone the Q-rating overall indicated a Fair rock mass.
- Poor rock mass conditions within the laminated sandstone zone were evident during excavation and was as a result of jointing in the vicinity of the fault and friable roof conditions created by blasting.

Design Analysis: Empirical Support Design at the Fault

Borehole	Geotech Zone	Depth (m)	Thickness (m)	ESR	Excavation Category	Excavation span/height	De	Max Unsupported Span
KRLA1497		43.84				(m)		(m)
KRLA1497	Sandstone/Siltstone, FG,Lam	44.79	0.95	1.3	C - Access tunnels	6.5	5.00	5.53
KRLA1497	Sandstone, FG,massive	45.80	1.01	1.3	C - Access tunnels	6.5	5.00	6.50
KRLA1497	Sandstone, MG-CG, Lam	46.04	0.24	1.3	C - Access tunnels	6.5	5.00	6.50
KRLA1497	Sandstone, FG, x-lam	47.35	1.55	1.3	C - Access tunnels	6.5	5.00	5.53
KRLA1497	Sandstone/Shale, interlam	47.67	0.32	1.3	C - Access tunnels	6.5	5.00	3.97
KRLA1497	Shale/Sandstone, interlam	49.06	1.39	1.3	C - Access tunnels	6.5	5.00	3.22
KRLA1497	Coal/Shale, #S4R	49.74	0.68	1.3	C - Access tunnels	6.5	5.00	4.38
KRLA1497	Coal, S4T	50.80	1.06	1.3	C - Access tunnels	6.5	5.00	4.84

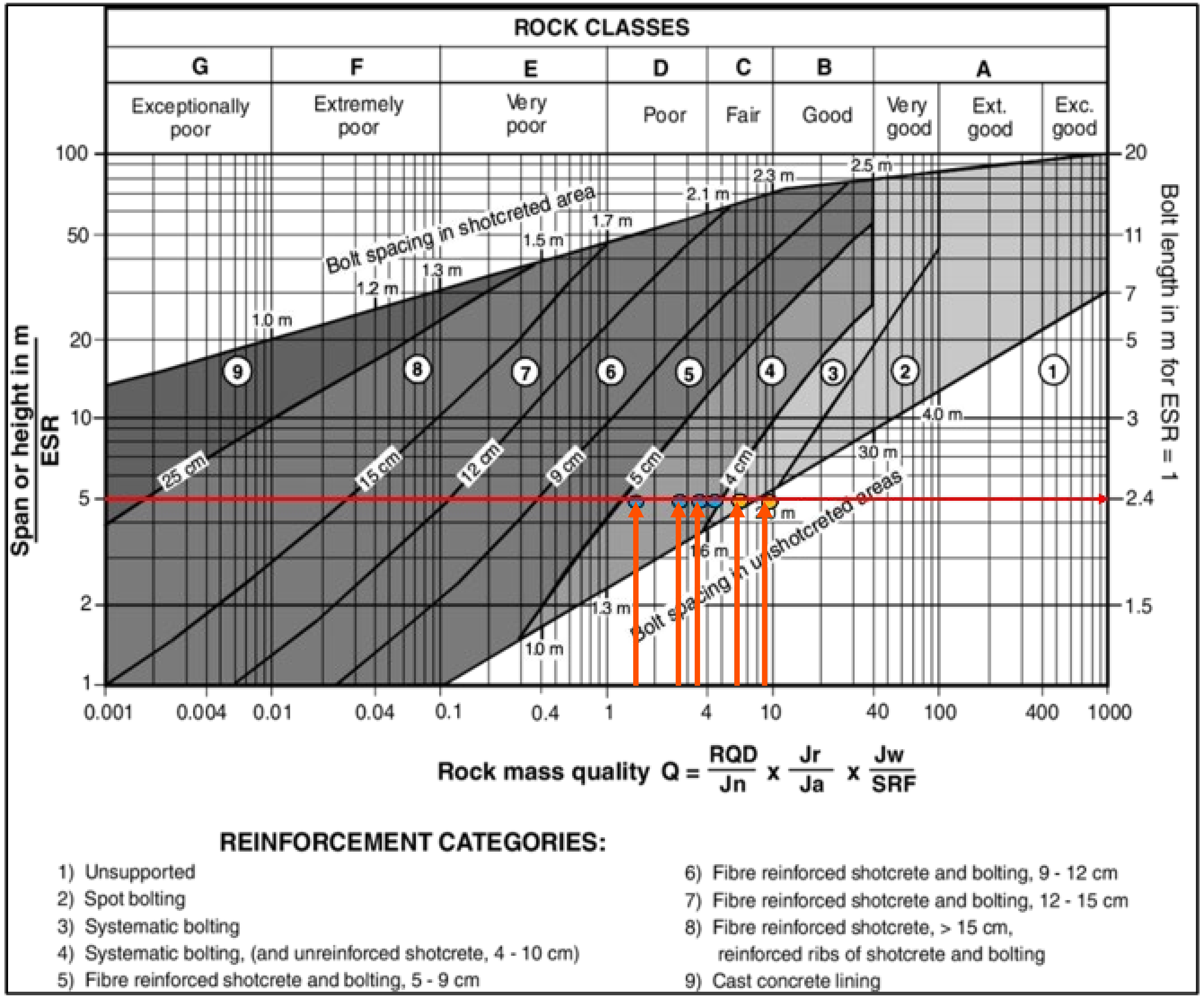
Borehole	Geotech Zone	Depth (m)	Thickness (m)	ESR	Excavation Category	Excavation height	De	Max Unsupported Span
KRLA1498		38.67				(m)		(m)
KRLA1498	Sandstone, FG, massive	39.90	1.23	1.3	C - Access tunnels	6.5	5.00	8.47
KRLA1498	Sandstone, FG, lam	41.52	1.62	1.3	C - Access tunnels	6.5	5.00	3.88
KRLA1498	Shale/Sandstone, FG, lam	41.92	0.40	1.3	C - Access tunnels	6.5	5.00	4.55
KRLA1498	Sandstone, CG, Lam	42.02	0.10	1.3	C - Access tunnels	6.5	5.00	4.93
KRLA1498	Shale/Sandstone, FG, lam	43.12	1.10	1.3	C - Access tunnels	6.5	5.00	4.54
KRLA1498	Sandstone,MG-CG, Lam	43.22	0.10	1.3	C - Access tunnels	6.5	5.00	3.74
KRLA1498	Coal/Shaly #S4R	43.92	0.70	1.3	C - Access tunnels	6.5	5.00	3.19
KRLA1498	Coal #S4T	44.60	0.68	1.3	C - Access tunnels	6.5	5.00	3.30

Borehole	Geotech Zone	Depth (m)	Thickness (m)	ESR	Excavation Category	Excavation height	De	Max Unsupported Span
KRLA1503		38.12				(m)		(m)
KRLA1503	Sandstone, FG, massive	38.75	0.63	1.3	C - Access tunnels	6.5	5.00	6.50
KRLA1503	Sandstone, FG, lam	39.91	1.16	1.3	C - Access tunnels	6.5	5.00	8.58
KRLA1503	Shale/sandstone, interlam	40.04	0.13	1.3	C - Access tunnels	6.5	5.00	8.58
KRLA1503	Sandstone, CG,lam	41.65	1.61	1.3	C - Access tunnels	6.5	5.00	4.19
KRLA1503	Shale/Siltstone, FG, interlam	42.04	0.39	1.3	C - Access tunnels	6.5	5.00	3.56
KRLA1503	Sandstone, MG-CG, lam	43.38	1.34	1.3	C - Access tunnels	6.5	5.00	3.00
KRLA1503	Coal/Shaly #S4R	44.00	0.62	1.3	C - Access tunnels	6.5	5.00	2.35
KRLA1503	Coal #S4T	44.85	0.85	1.3	C - Access tunnels	6.5	5.00	3.01

Max Unsupported Span

- A maximum unsupported span calculated from the Q-rating in Phase 1 zone was 4.84 m.
- A maximum unsupported span calculated from the Q-rating in Phase 2 zone was 8.58 m.
- **For the final design, a maximum unsupported span of 6 m was adopted for Phase 1 while cutting with a CM.**
- **A maximum unsupported span of 2.5 m per blast advance was adopted for Phase 2 where drilling and blasting was conducted.**

Design Analysis: Empirical Support Design at the Fault



(Grimstad and Barton Chart, 1993)

Q-Rating Support Requirements

- **Q-Rating Support Requirements:**
  - Systematic support using 2.4m bolt length.
  - Bolt spacing varied between 1.3m to 1.5m for Phase 1
  - Bolt spacing varied from 1.8 to 2m for Phase 2.
  - 4-10 cm thick shotcrete for Phase 1 zone required.
- **Final Support Design:**
  - Systematic support using 2.8m bolts on a 1.0 m x 1.0 m grid spacing.
  - Bolts installed in conjunction with welded mesh to provide area coverage support.

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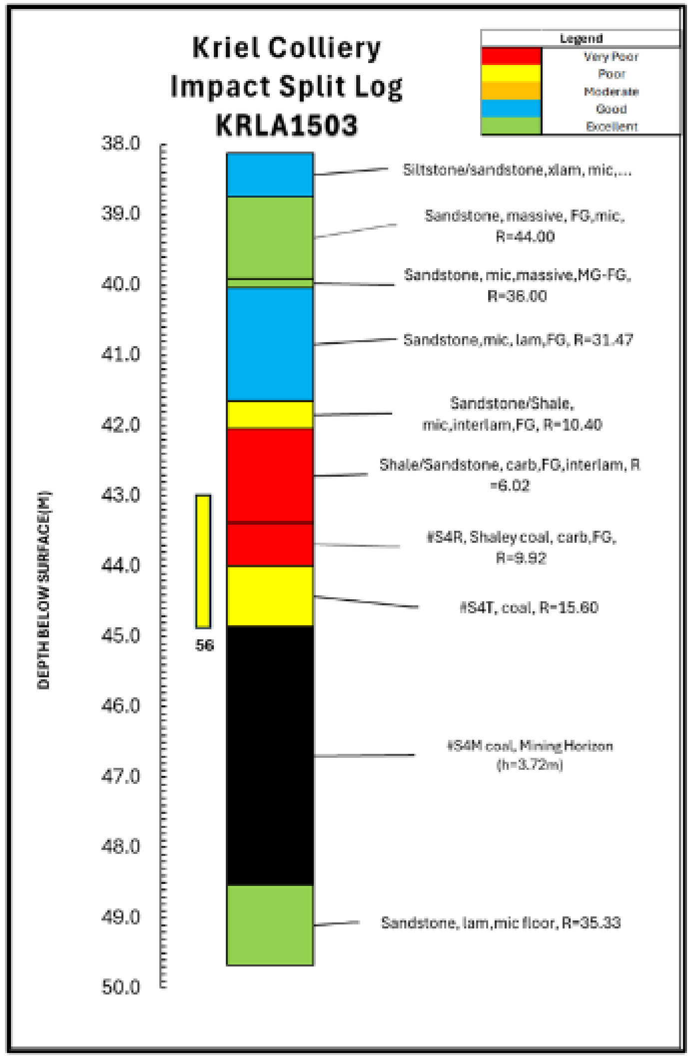
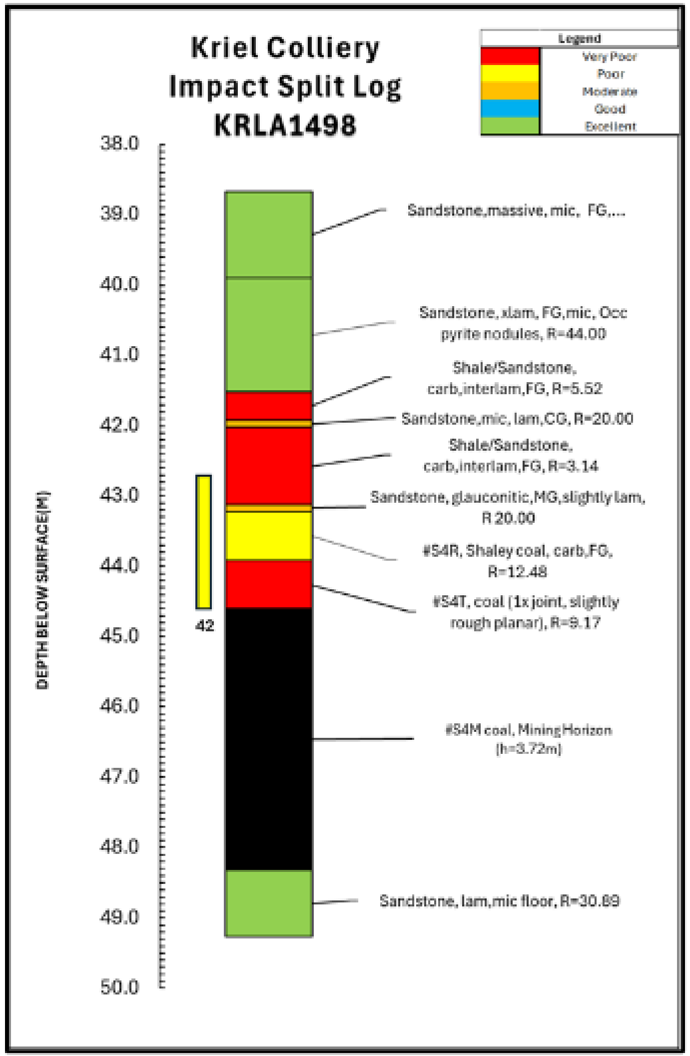
Design Analysis: Impact Splitting Support Design at the Fault

Some distance after the fault



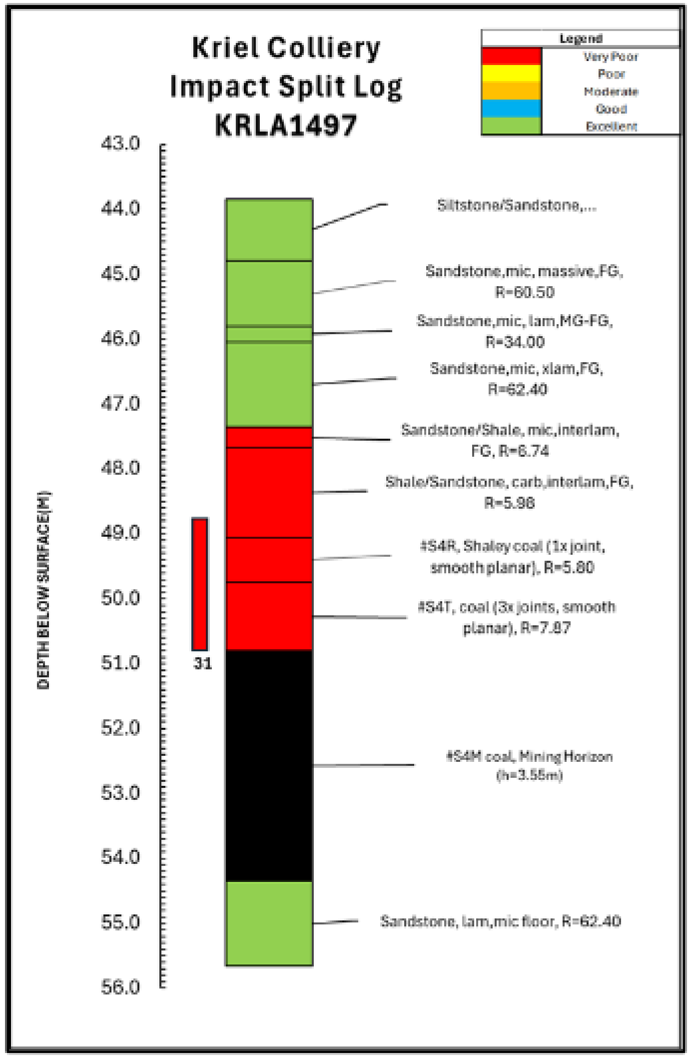
Roof rating = 56 (poor)

Immediately after the fault



Roof rating = 42 (poor)

Before the Fault



Roof rating = 31 (very poor)

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Design Analysis: Impact Splitting Support Design at the Fault

Unit Rating	Rock Class	Roof Rating
<9	Very Poor	<34
10 - 13	Poor	35 - 51
14 - 19	Moderate	52 - 75
20 - 28	Good	76 - 113
29 - 42	Very Good	114 - 167
>42	Excellent	>167

Table 5. Roof conditions and typical systematic support

Roof condition	Max. cut-out distance (m)	Bord width (m)	Typical systematic support			
			Type	Length (m)	Pattern	Distance between rows of bolts (m)
Excellent	>18	7	M16 point anchor	0.9 or 1.2	Spot bolting false roof	N/A
Very Good	>18	6.5 to 7	M16 point anchor	1.2	Spot bolting and 5 bolts per intersection only	N/A
Good	18	6 to 6.5	M16 point anchor	1.2 or 1.5	5 bolts per intersection and 2 per row in bords	2 to 2.5
Moderate	12	5.5 to 6	M16 or M20 full column resin	1.5 or 1.8	9 bolts per intersection and 3 per row in bords	1.5 to 2
Poor	6	5 to 5.5	M20 full column resin	1.8	16 bolts per intersection and 4 per row in bords. Steel straps may be necessary	1 to 1.5
Very Poor	<6	<5	Specialised support, e.g. 1.8m M20 full column resin bolts and /or cable anchors with steel straps. Cable trusses, cluster stick packs or shotcrete may also be required	≥1.8	As dictated by conditions. Typically 5 bolts per row with steel straps. Often 9 cables in intersections.	<1

Roof Rating Support Requirements

- **Final Design Adopted:**
  - Maximum bord width of 6.5 m and excavation height of 3.8 m.
  - maximum cut-out distance of 6 m.
  - Five (5) 2.8 m x 20 mm full-column resin bolts.
  - Bolt spacing of 1.0 m and row spacing of 1.0 m.
  - Bolt installed concurrently with welded mesh.
  - **3 x fully grouted long anchors per row, installed at a bolt spacing of 1.5 m and row spacing of 2.0 m.**

Phase 2 and 3 zone support requirements
Boreholes KRLA1498 and KRLA1503

Phase 1 zone support requirements
Borehole KRLA1497

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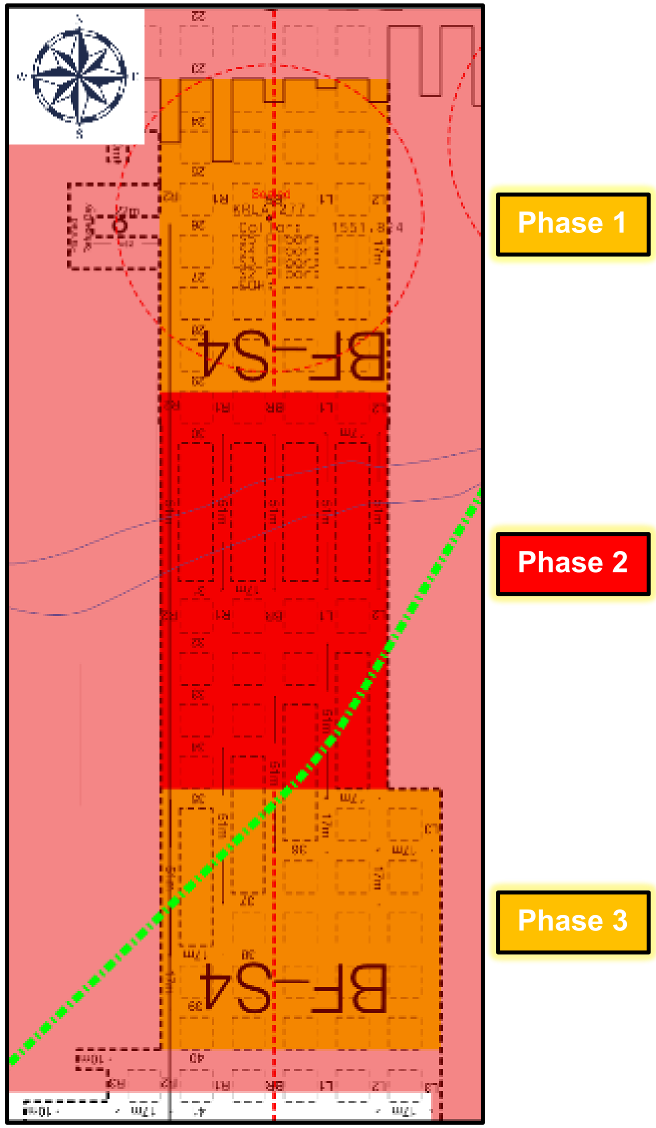
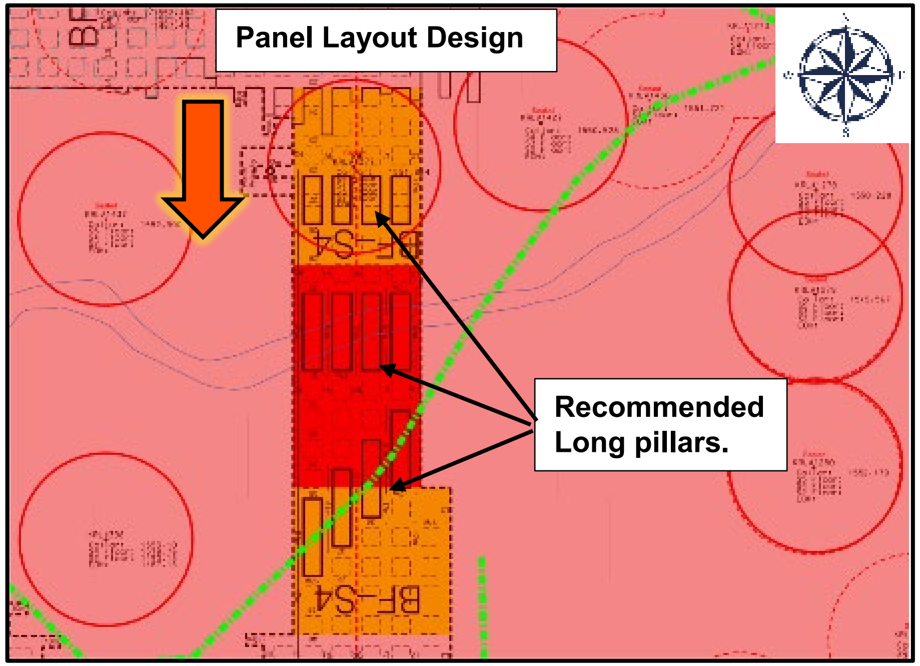
Design Analysis: Strategy for Undermining the River

Fezela Undermining the River in shallow mining areas



The planned mining ground in BF-S4 has been sub-divided into three phases as follows:

- **Phase 1** – Entering and mining within the 100 m restriction of the river. This zone will start from **split 23 to split 29** of BF-S4 panel.
- **Phase 2** – Mining within the D/2.7 restriction and directly underneath the river. Mining will also be conducted within the 40 m zone of the dolerite dyke. This phase will start from **Split 29 to Split 35**.
- **Phase 3 –** Mining outside the 100 m restriction of the river but within the 40 m zone of the dolerite dyke. This phase will start from **Split 35 to Split 40**.



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Design Analysis: Strategy for Undermining the River

Fezela Undermining the River in shallow mining areas:

Development Phase	Borehole Name	LOW (m)	Intact Hard Ovb thickness (m)	Recommended Mining height (m)	Total Ovb Comp. SD Material (m)	Percentage Comp. SD Material (%)	Immediate coal beam thickness (m)	Additional Surcharge thickness (m)	Depth to Seam Floor (m)
Phase 1	KRLA1427	6.65	19.32	3.99	7.15	27.53	1.04	0.48	Not drilled to seam floor
	KRLA1277	9.16	18.64	3.99	3.4	12.23	1.04	0.84	31.79
	KRLA1437	12.2	16.17	3.99	6.84	24.11	0.77	0.39	32.36
	Average	**9.34**	**18.04**	**3.99**	**5.80**	**21.29**	**0.95**	**0.57**	**32.08**
	Minimum	**6.65**	**16.17**	**3.99**	**3.40**	**12.23**	**0.77**	**0.39**	**31.79**
	Maximum	**12.20**	**19.32**	**3.99**	**7.15**	**27.53**	**1.04**	**0.84**	**32.36**

Development Phase	Borehole Name	LOW (m)	Intact Hard Ovb thickness (m)	Recommended Mining height (m)	Total Ovb Comp. SD Material (m)	Percentage Comp. SD Material (%)	Immediate coal beam thickness (m)	Additional Surcharge thickness (m)	Depth to Seam Floor (m)
Phase 2	KRLA1278	8.67	18.23	4.13	1.82	6.77	1.08	1.24	31.03
	KRLA1279	7.75	17.87	3.99	3.12	12.18	0.54	1.44	29.61
	KRLA1280	18.34	10.31	3.99	2.64	9.21	0.69	1.13	32.64
	Average	**11.59**	**15.47**	**4.04**	**2.53**	**9.39**	**0.77**	**1.27**	**31.09**
	Minimum	**7.75**	**10.31**	**3.99**	**1.82**	**6.77**	**0.54**	**1.13**	**29.61**
	Maximum	**18.34**	**18.23**	**4.13**	**3.12**	**12.18**	**1.08**	**1.44**	**32.64**

Development Phase	Borehole Name	LOW (m)	Intact Hard Ovb thickness (m)	Recommended Mining height (m)	Total Ovb Comp. SD Material (m)	Percentage Comp. SD Material (%)	Immediate coal beam thickness (m)	Additional Surcharge thickness (m)	Depth to Seam Floor (m)
Phase 3	KRL4398	11.49		3.99	1.59	13.84	0.57	1.05	33.34

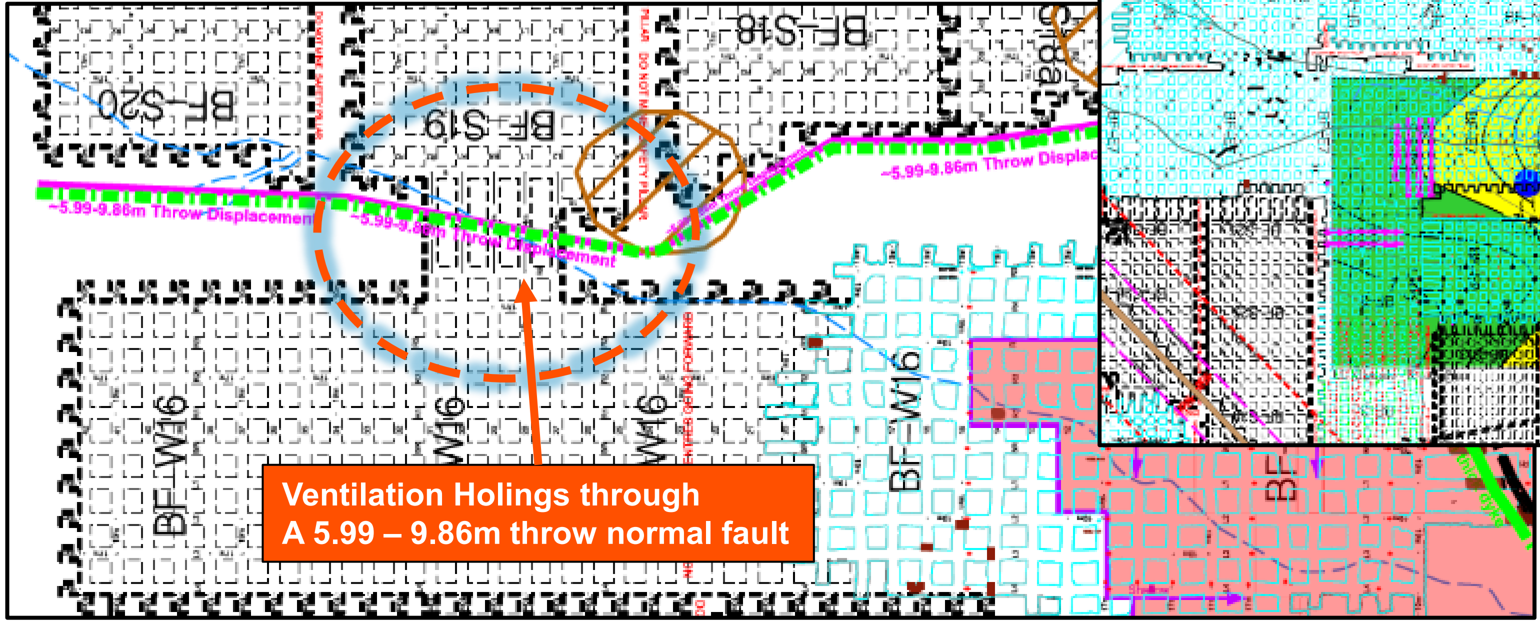
Phase 1 Support Design Strategy:
- Four (4) 1.8m x 20mm full column resin bolts per row.
- 1.0m spacing between bolts and 1.0m spacing between rows.
- 1x 4m LED RMD per intersection.

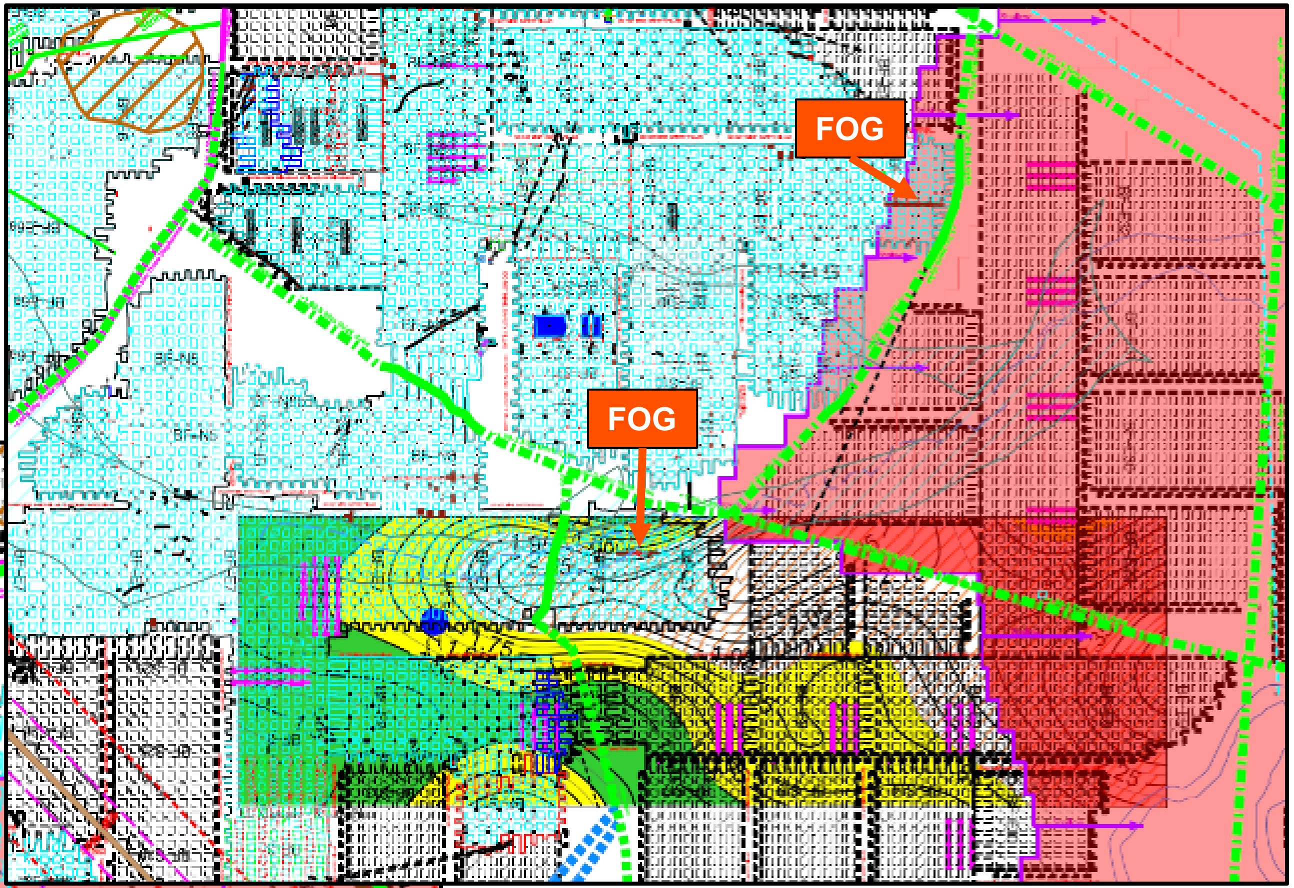
Phase 2 Support Design Strategy:
- Four (5) 2.8m x 20mm full column resin bolts per row.
- 1.5m spacing between bolts and 1.5m spacing between rows.
- Welded mesh for area coverage support.
- Five (5) 4m LED RMDs per intersection.
- Nine (9) 6m fully grouted cable anchors.

Phase 3 Support Design Strategy
- Four (5) 2.8m x 20mm full column resin bolts per row on a 1m x 1.0m grid spacing.
- Welded mesh for area coverage support.
- Ribside support with bolts and welded mesh.
- RMDs at 6m intervals in all headings.
- Systematic installation of 6m fully grouted anchors at 1.5m spacing between anchors and 2.0m spacing between rows of anchors.

Kriel Colliery Future Projects

- Expansion of the In-situ stress measurement Plan and its integration into the geotechnical hazard plan.
- Hydraulic pressure monitoring underground and the development of the hydraulic pressure TARP procedure.
- Developing the guidelines and procedures on the use of geotechnical information for mine design.
- Developing holings through a normal fault at Ihlosi BF-W16 panel to establish a return airway access for future mining of the Block F west reserves.





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Thank you