ISP Mining at Tau Lekoa Mine

SANIRE
SOUTH AFRICAN NATIONAL INSTITUTE OF ROCK ENGINEERING

Turning Challenges Into Opportunities

OHMS

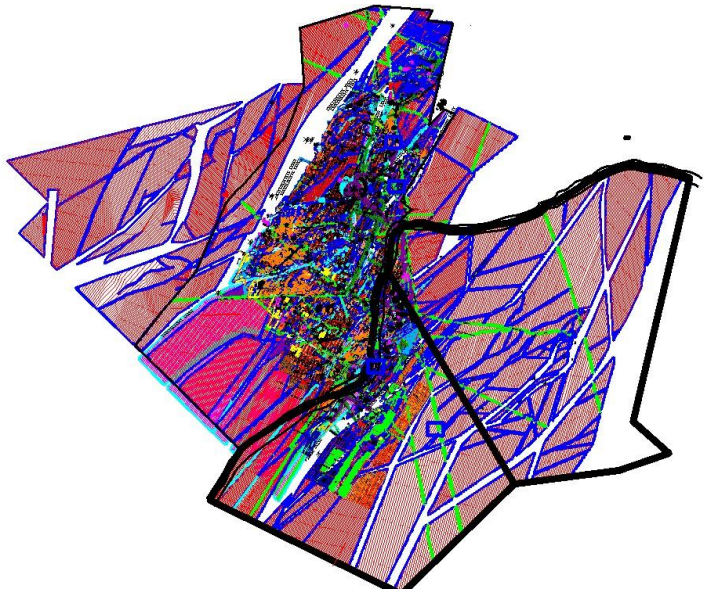
CW van der Westhuizen

CONTENT

- Introduction & Overview
- ISP Potential
- ISP Design Methodology
- Rock Mass Characteristics
- Review of Crush Pillar Design at Tau Lekoa Mine
- Inter-Pillar Stable Span Assessment
- ISP Pillar System
- ISP Support, Process and Sequencing
- Results

INTRODUCTION AND OVERVIEW OF TAU LEKOA MINE

- The mining industry is constantly facing the challenge of sustainability, with Tau Lekoa Gold Mine (TLM), being no different as it is nearing its operational live.
- Tau Lekoa Mine (Vaal Reefs 10 Shaft) was sunk from 1985 to 1989 to a depth of 1743m below surface.
- Consists of twin shafts : man-&-material, rock & ventilation (MM&RV)
- 6 Levels to access the ore-body
- Stoping takes place from 900 to 1650m below surface
- First gold in 1991
- Reef Mining VCR (Ventersdorp Contact Reef) & Denny's Reef.
- Current Employees = approx. 1600



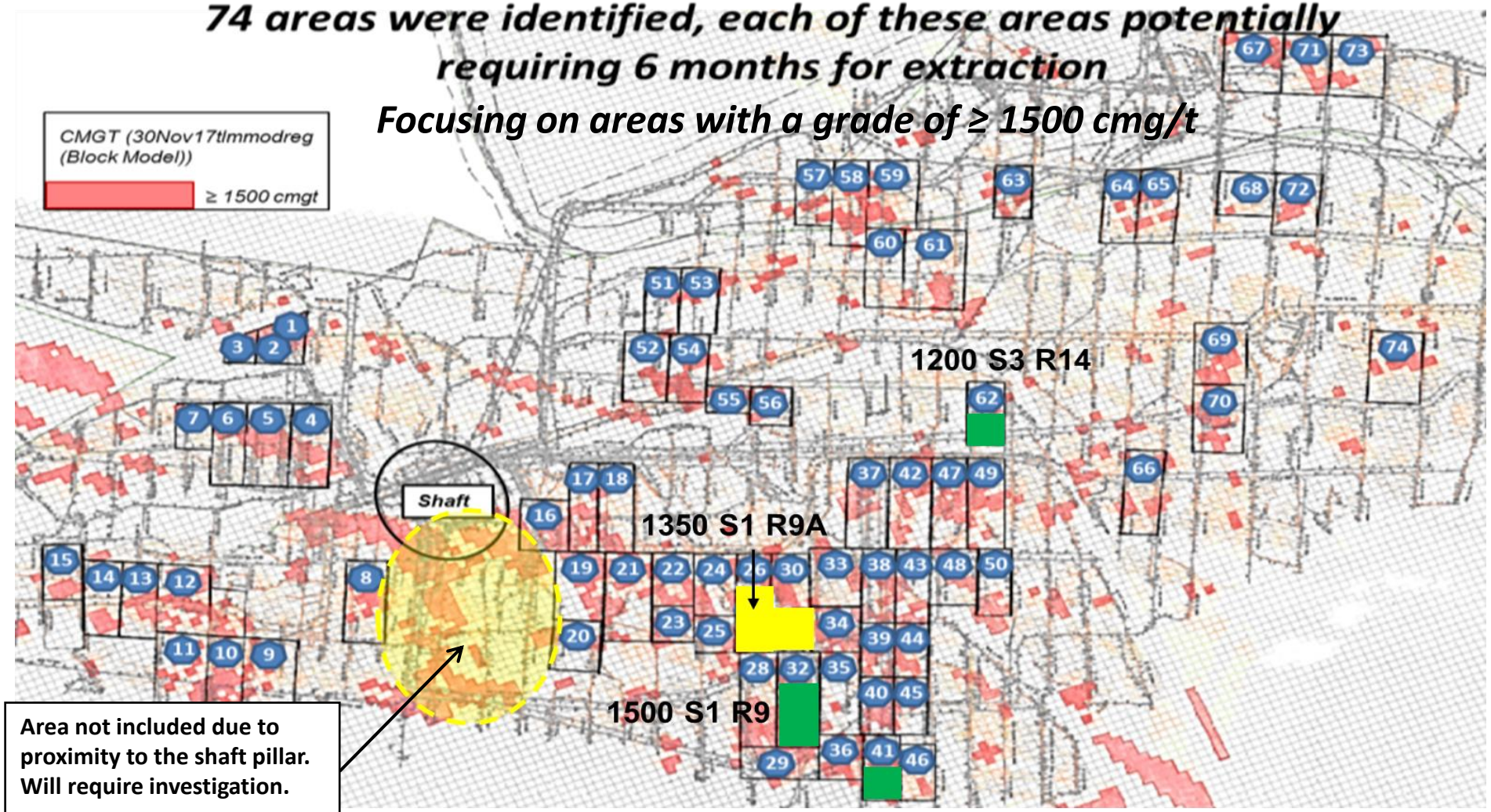
INTRODUCTION AND OVERVIEW OF TAU LEKOA MINE

- In 2017, during reconnaissance inspections to some Isolated Blocks of Ground (IBG), it was observed that several of the strike crush pillars were not in contact with the hanging wall and, no visible deformation or Falls of Ground (FOG's) were observed within these areas.
- Typical pillar designs are based on width:height ratio which led to the question WHY the 7m x 3m strike pillars.
- From what could be gathered was that it was left for ore and ventilation control between adjacent panels.
- This led to the hypothesis that the in-stope strike pillar could be safely reduced to 3m x 3m pillars.
- The benefit of the pillar reduction:
  - Gold lockup in multitude of high grade In-stope Strike Pillars (ISP) can be extracted which would supplement the business plan, create incremental value and potentially extent the live of mine (LOM)

ISP POTENTIAL

74 areas were identified, each of these areas potentially requiring 6 months for extraction

Focusing on areas with a grade of ≥ 1500 cmg/t



ISP POTENTIAL (CALCULATED REVENUE)

Estimated ISP Project Value

Estimated number of In-stope Strike Pillars		
Levels	6	*Levels*
Crosscuts per Level	20	*Crosscuts*
Gullies per Raise	16	*Gullies*
Strike Pillars per Gully	20	*Pillars*
Estimated number of Pillar (TLM)	38400	*Pillars*
Halved due to accessibility	19200	*Pillars*
Halved due to grade	9600	*Pillars*

← **25% of pillars**

Pillar Parameters		
Size (3m x 7m)	21	m^2
Extraction Stoping width	150	*cm*
Relative Density	2750	kg/m^2
Tons per pillar	86.625	*tons*

Potential Gold		
Grade (cm.g/t)	1000	*cm.g/t*
Grade (g/t)	6.67	*g/t*
Gold Price (R/kg)	R 900 000.00	*R/kg*

← **Lower grade used**

← **Lower Gold Price**

Potential Production and Revenue (TLM)		
Total tons of Pillars	**831600**	*tons*
Total Gold in Pillars	**5544**	*kg*
Total Rand Value (Revenue)	**R 4 989 600 000.00**	

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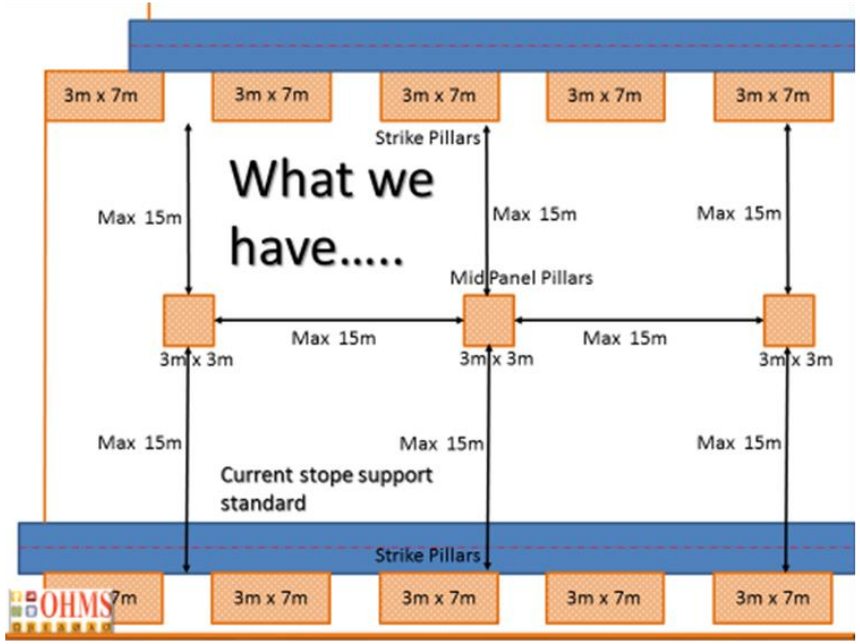
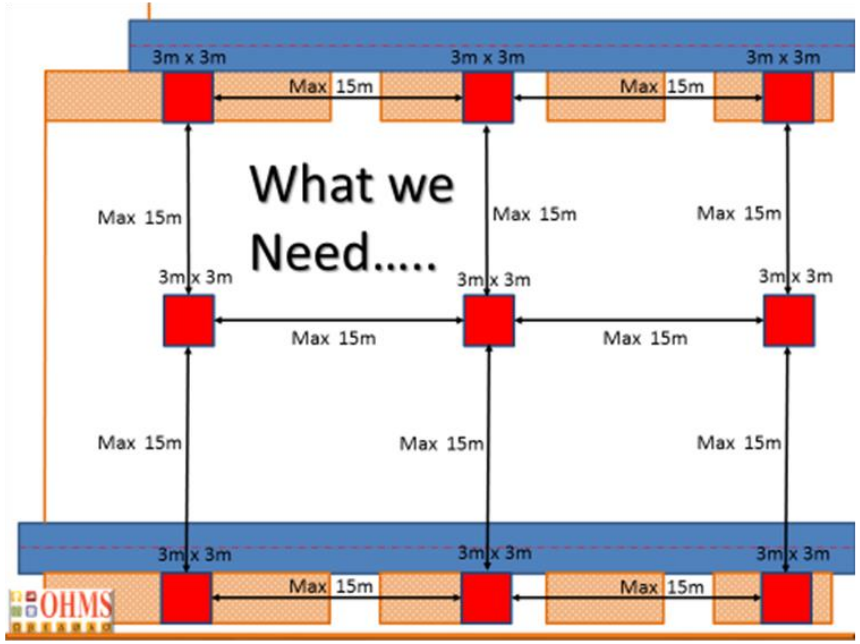
CONCEPT

The intent is to reduce the current redundant portions of the in-stope strike pillars that was previously utilized for ventilation and ore control purposes, without changing or altering the current in-stope pillar design spans.

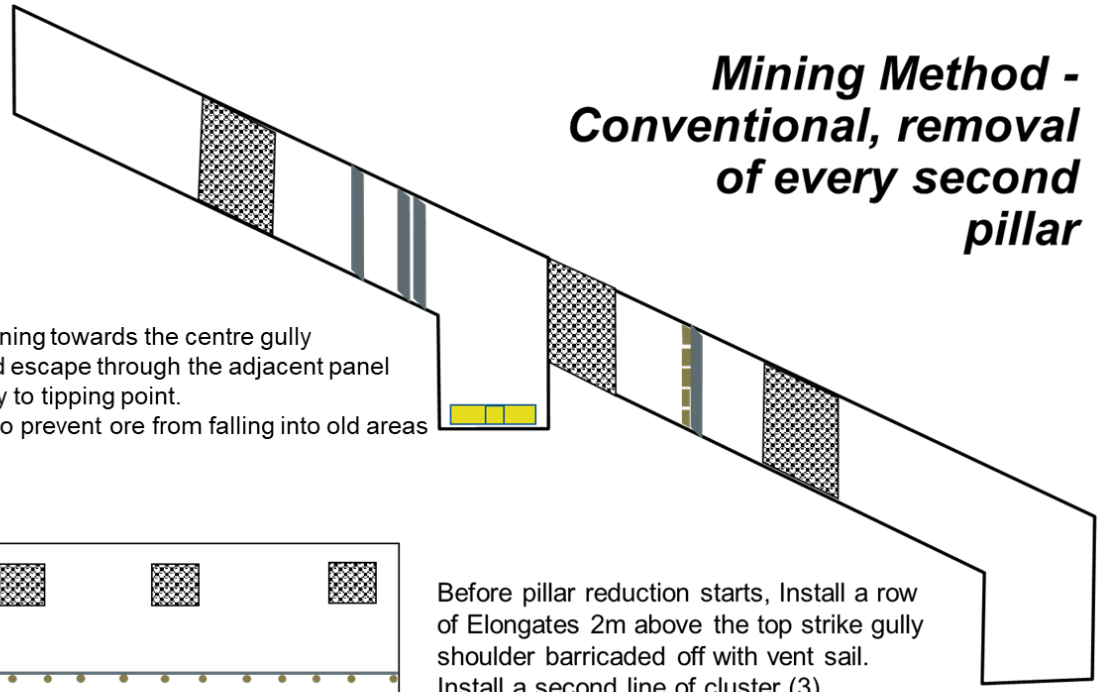




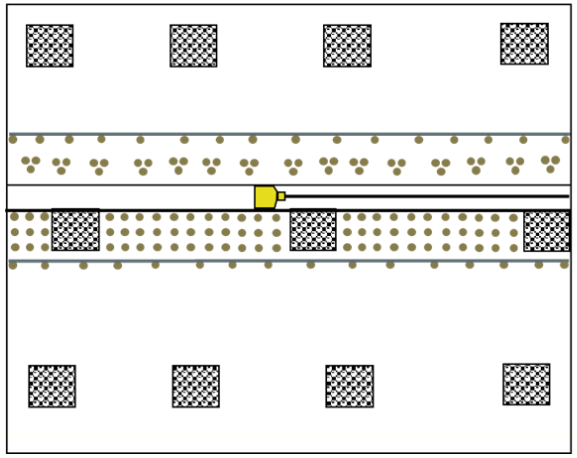
Pillar design

- To provide hanging wall stability and limit potential fallout size
- To control ventilation flow and limit loss of air volume
- To prevent ore loss due to steep deposition of the ore body

CONCEPT

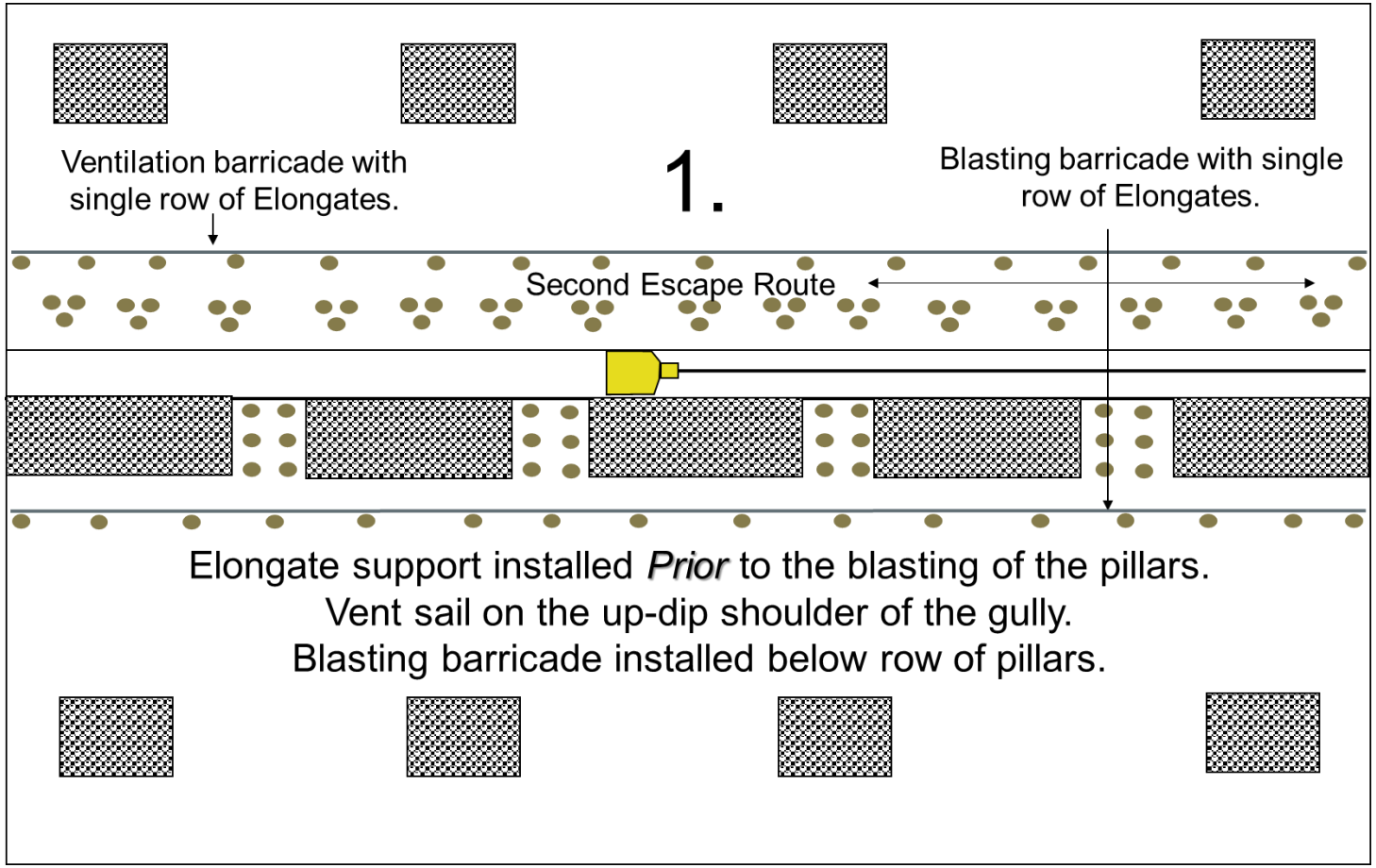


- Retreat mining, mining towards the centre gully
- Establish a second escape through the adjacent panel
- Scraper clean gully to tipping point.
- Install :barricade" to prevent ore from falling into old areas



Before pillar reduction starts, Install a row of Elongates 2m above the top strike gully shoulder barricaded off with vent sail. Install a second line of cluster (3) Elongates along the up – dip shoulder of the top strike gully. Install a line of Elongates below the targeted pillars with a blasting barricade to regulate the ore. Reduce the pillars to 3m by 3m dimensions with a maximum span of 15m apart of strike.

EXTRACTION SEQUENCE



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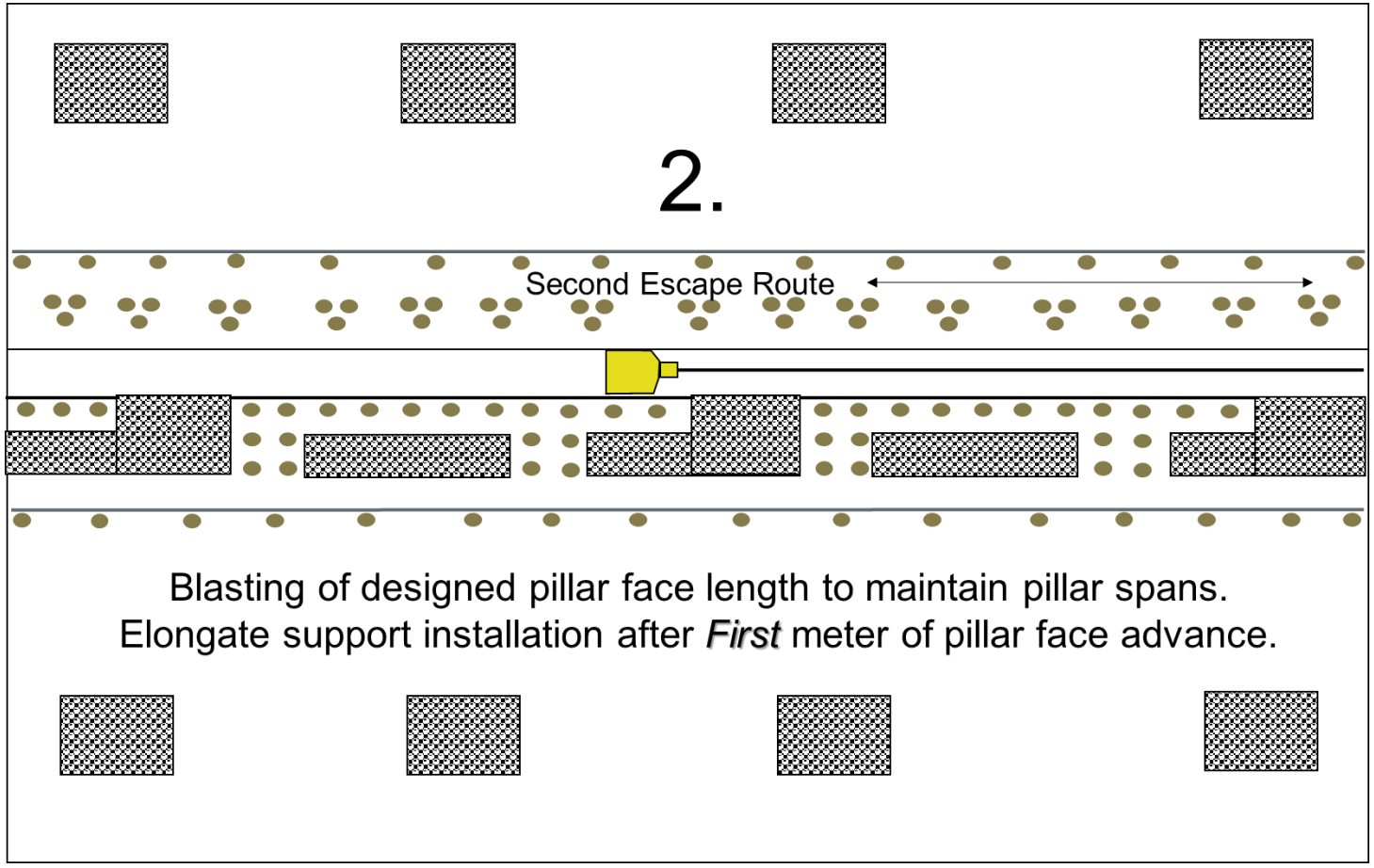

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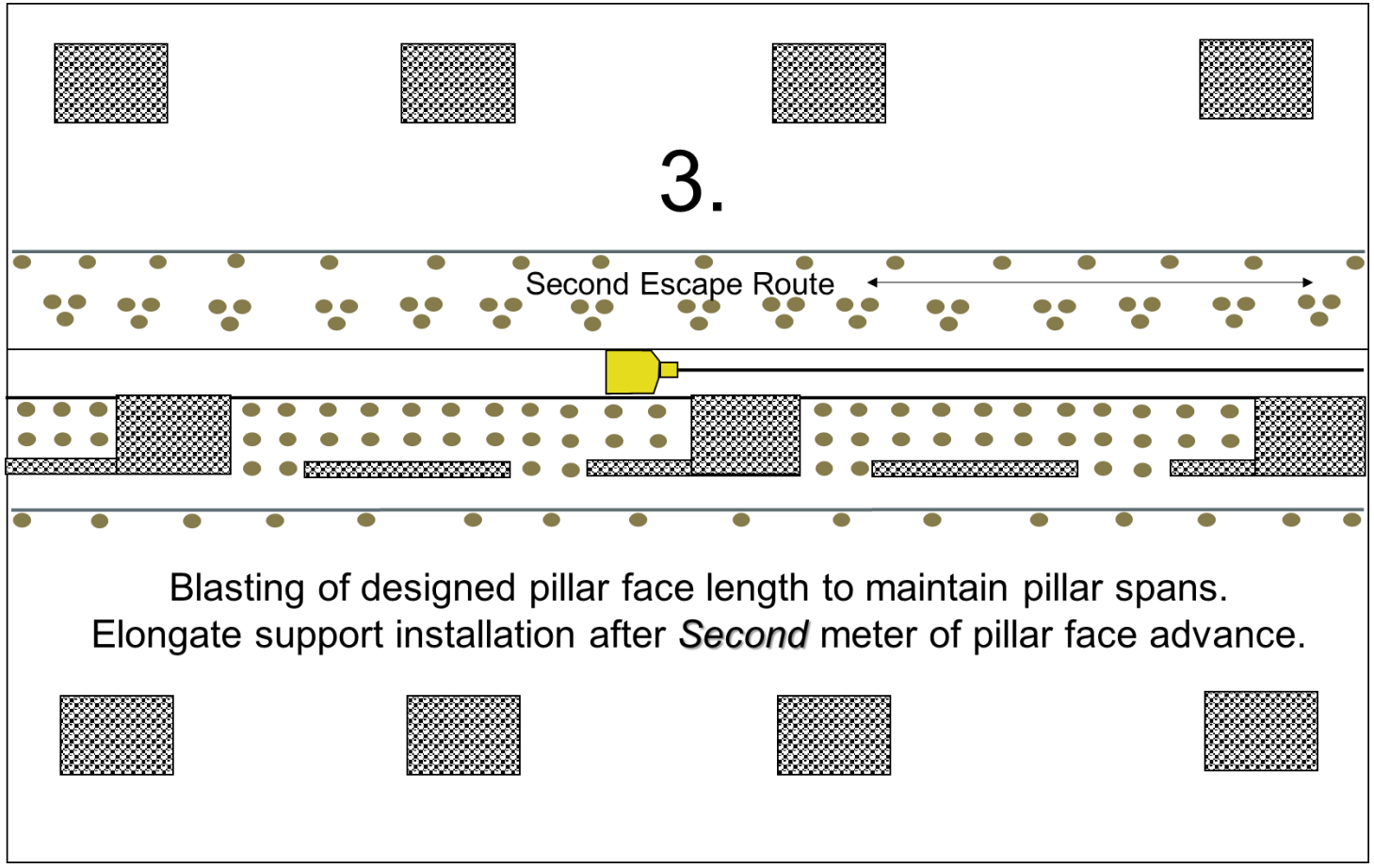

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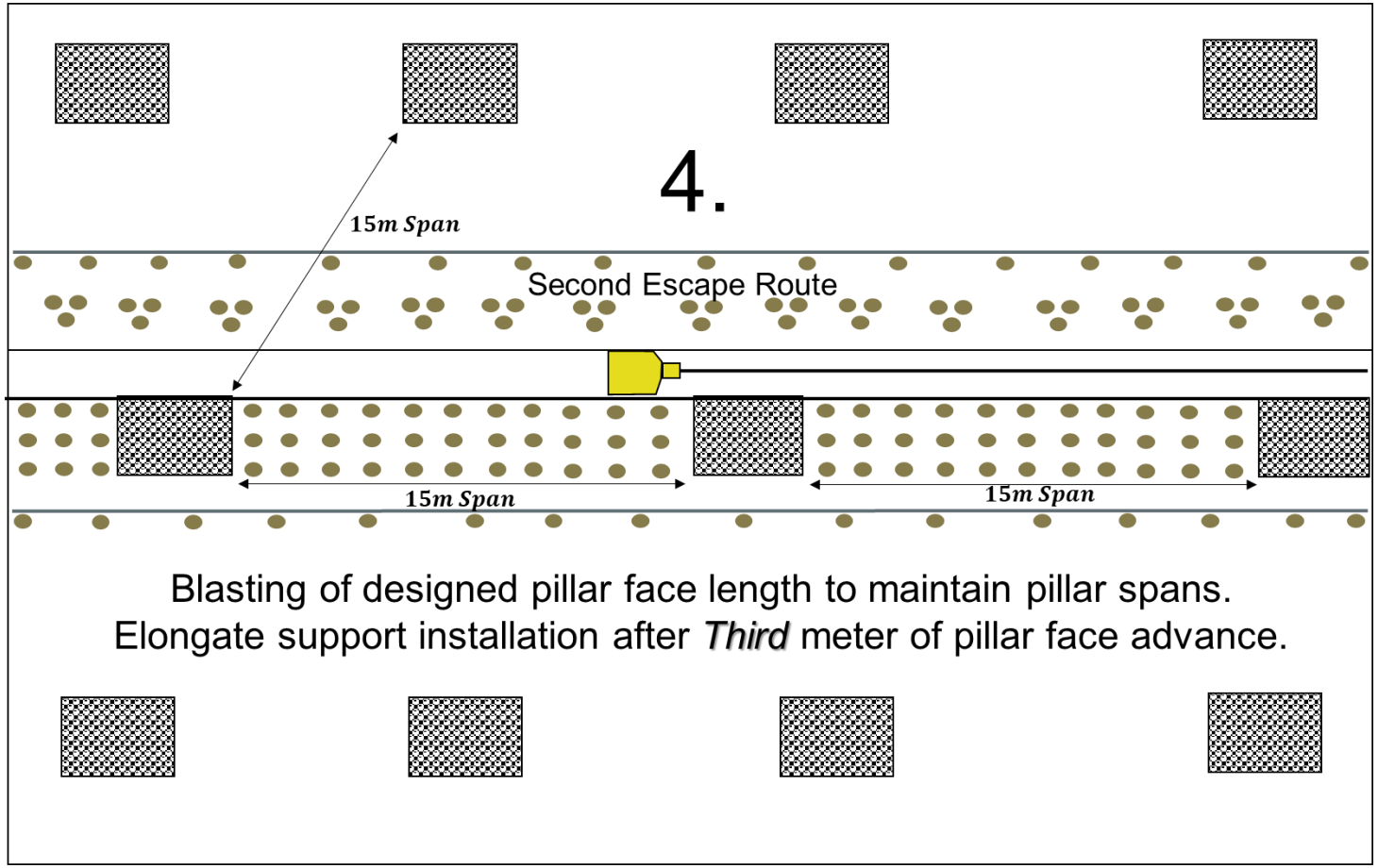

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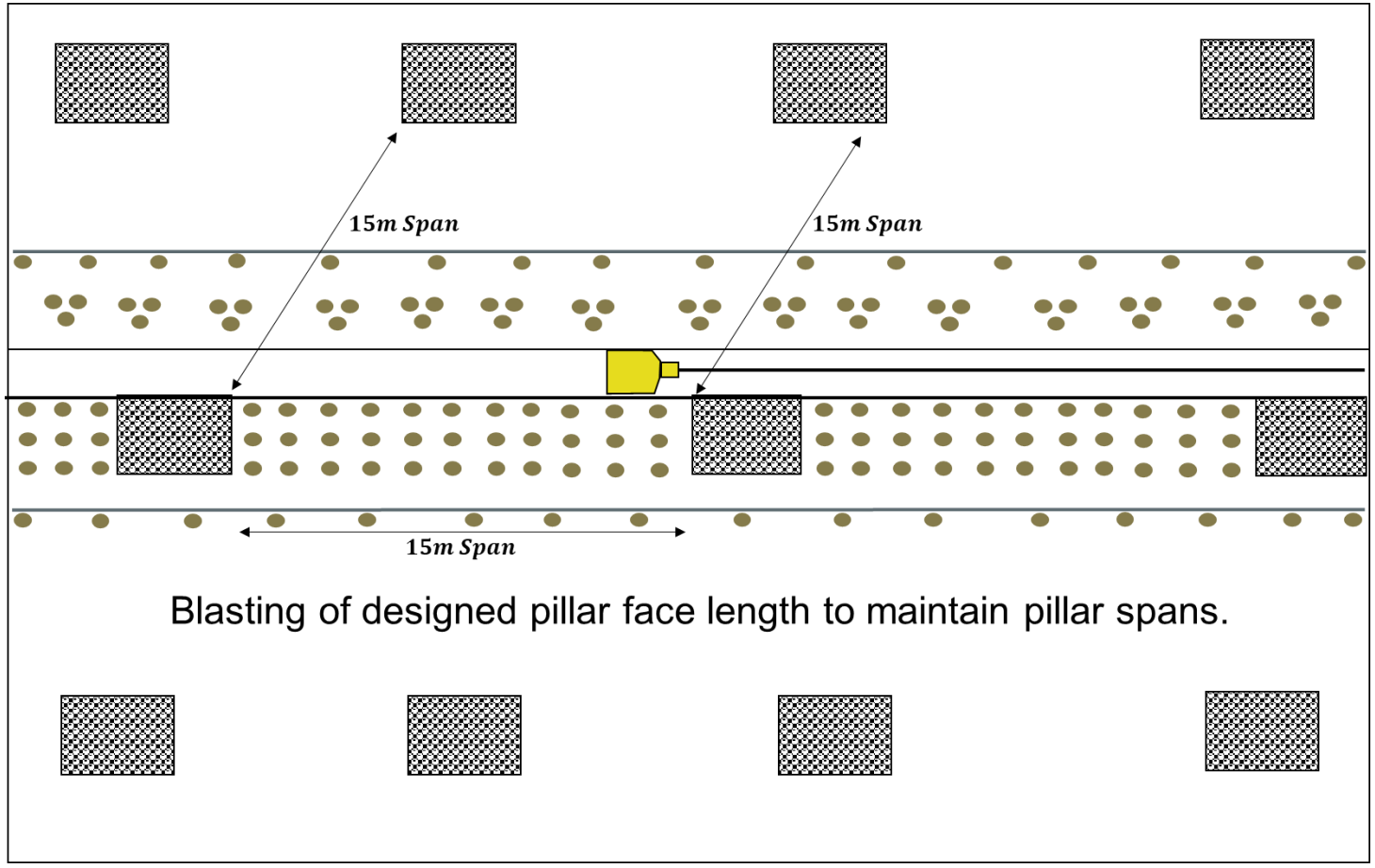
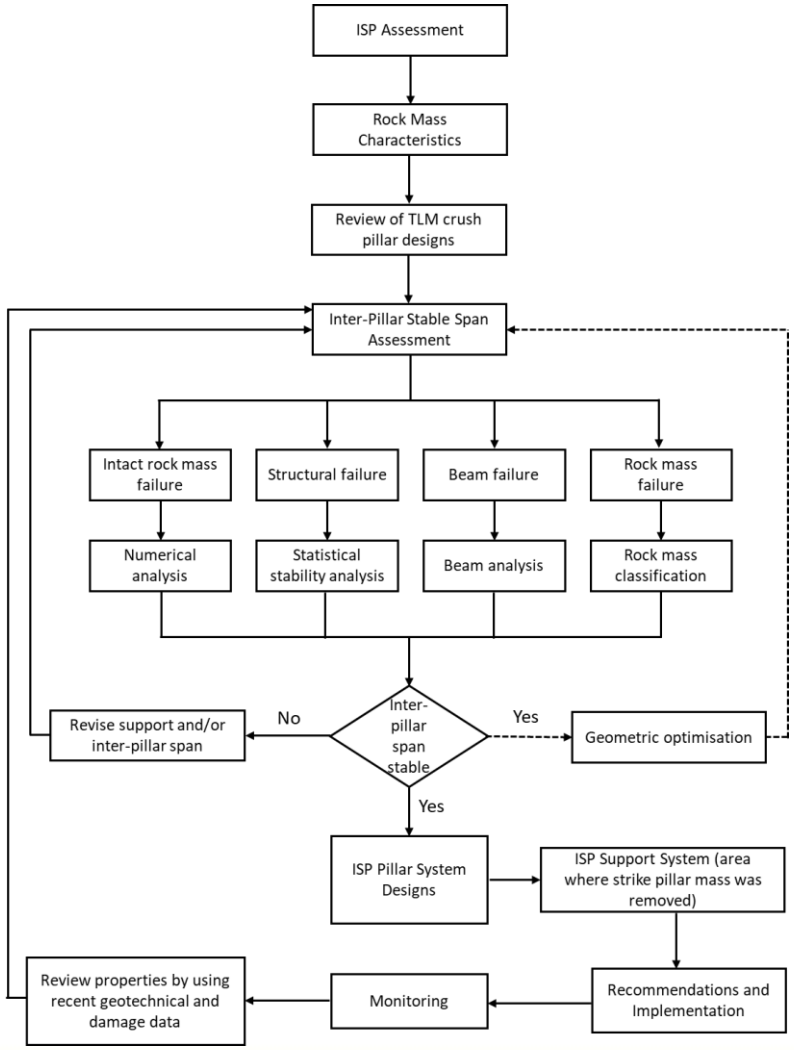


Blasting of designed pillar face length to maintain pillar spans.

ISP DESIGN PROCESS DIAGRAM



ROCK MASS CHARACTERISTICS

- During this assessment the following were considered:
- Orebody Information
  - Reef Dip (VCR dips on average 27°)
  - Reef Strike (NE-SW)
  - Reef Thickness (0.1m – 3.0m)
  - Reef Depth (900 – 1650m below surface)
- Stratigraphy & UCS
  - Hanging wall consists of Lava with Ave. UCS of 250MPa
  - VCR Reef with Ave. UCS of 182 MPa
  - Footwall consists of GE Quartzites with Ave. UCS of 121MPa
- Joint Information
  - Five (5) joint sets present at Tau Lekoa Mine (Used in structural assessment – Jblock).
- Seismicity
  - Tau Lekoa Mine is considered seismically active
  - Seismic History of area to be mined to be considered

REVIEW OF TAU LEKOA MINE CRUSH PILLAR SYSTEM

- The crush pillar system was intended to cater for the tensile zone between the regional pillar system but to control significant wedge and dome collapses (up to 5m).
- Pillar layout was achieved through iterative design processes.
- Peak and Residual Strengths determined making use of the Ryder and Ozbay (1990) technique. The outcome of this assessment indicated a
  - Peak strength = 80MPa and a;
  - Residual strength = 10 MPa (for a crush pillar with a width-to-height ratio of 1.5)
- Subsequent work was done by M Dunn using descriptive statistics for pillar measurements over a 20-month period and the Point Estimate Method used in combination with the Ryder and Ozbay equation and Tributary-area method (TAT) to calculate the pillar strengths, stresses and factor of safety.

REVIEW OF TAU LEKOA MINE CRUSH PILLAR SYSTEM

Description	Strike Pillars	Mid-Panel Pillars
Peak Strength	123.1 ±33.8MPa	111.9 ±30.7MPa
Residual Strength	9.9 ±2.7MPa	9.0 ±2.5MPa
Average Pillar Stress (APS)	107 ±28.6MPa	145 ±37.4MPa
Factor of Safety (FOS)	1.23 ±0.48	0.83 ±0.32

- The exercise conducted by M Dunn was repeated using a newer data set collected from 120 pillars in various working places over a 24 months period (2019-2021). The following results were obtained:

Description	Reduced Strike Pillars & Mid-Panel Pillars (3m x 3m)
Peak Strength	111.9 ± 30.7MPa
Residual Strength	9.0 ± 2.5MPa
Average Pillar Stress (APS)	150.8 ± 37.16MPa
Factor of Safety (FOS)	0.79 ±0.30.

REVIEW OF TAU LEKOA MINE CRUSH PILLAR SYSTEM

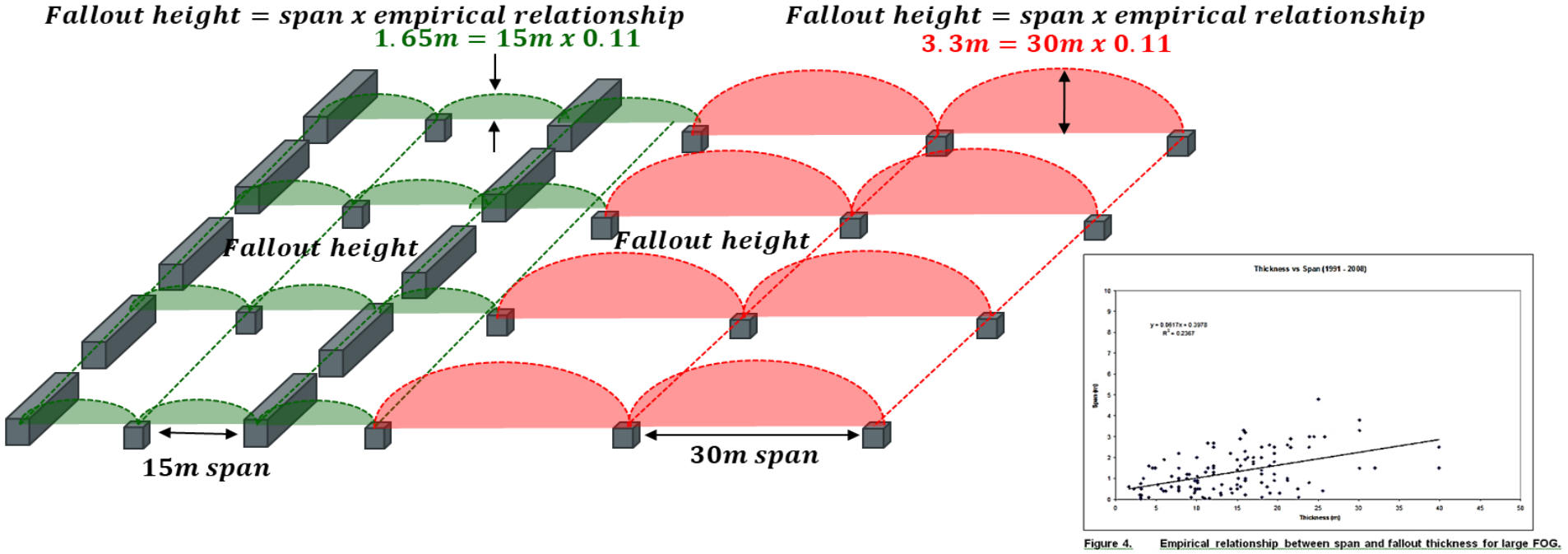


Figure 4. Empirical relationship between span and fallout thickness for large FOG.

The inter-pillar spacing has been derived from back analysis of large falls of ground, dome or wedge collapses. There appeared to be a relationship between the fallout height (thickness) and the span. By plotting these two parameters against each other, an empirical relationship has been determined. The fallout height was initially estimated to be 0.125 times the span. Following work on a modified database indicated that the fallout height or thickness to be 0.11 times the span.

INTER-PILLAR STABLE SPAN ASSESSMENT

- During the inter-pillar stable span assessment the following four assessments were conducted:
  - Rock Mass Failure Assessment
    - More than 200 rock mass classifications were completed across the mine for the lava hanging wall.
    - This assessment concluded in that a span of 15m will be stable based on the rock mass classification data which were collected and analyzed for Tau Lekoa Mine
  - Structural Failure
    - To identify keyblocks and assess probabilistic failure potential, the JBlock software program was utilized (Esterhuizen, 1996). The JBlock software program was specifically designed to assess the potential occurrence of gravity-driven rock falls. By considering factors like the spacing, orientation, and length of discontinuities, the software enables the simulation of blocks within excavation walls.
    - The assessment concluded in the finding that the annual risk associated with mining a normal panel with an inter-pillar span of 15m and reducing the strike pillars and not exceeding an inter-pillar span of 15m was similar calculated at a probability of 0.01% for support failing under the load of keyblocks

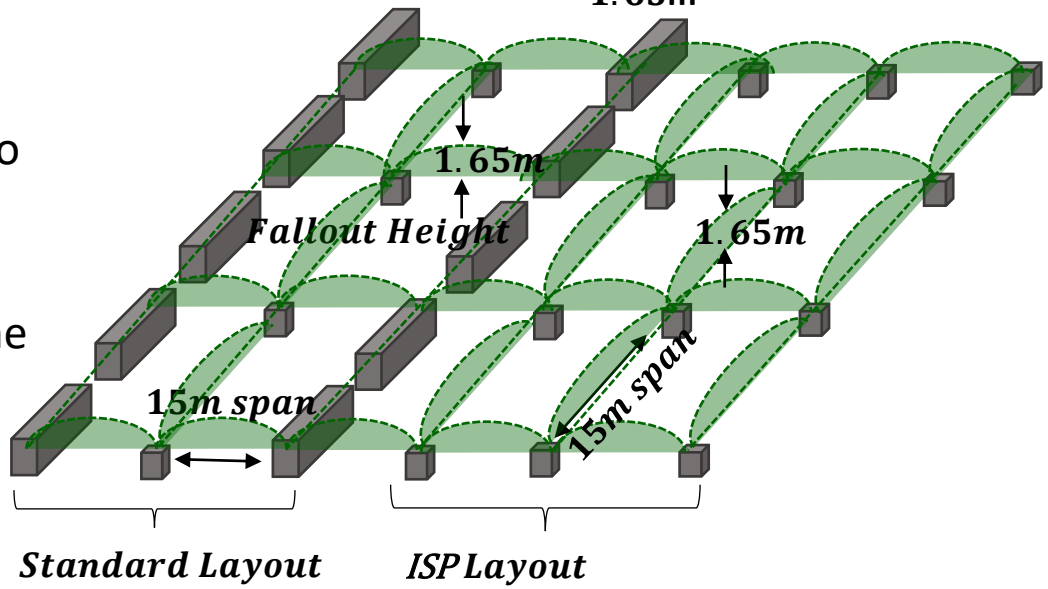
INTER-PILLAR STABLE SPAN ASSESSMENT

- Beam Failure
  - The assessment indicating that the hanging-wall strength of the Tau Lekoa Mine hanging wall lava beam would be sufficient to maintain stability for a 20 m span with a beam thickness of 0.5 m. Considering the inter-pillar design span of 15m of the ISP project sites, the hanging wall seems to be stable.
- Intact Rock Failure
  - Numerical modelling was introduced into the assessment making use of Examine2D & Map3D to develop a better understanding of the rock mass response to mining and to aid in determining the potential height of the zone of tensile failure.
  - The calculated tensile failure height ranges between 3.1m to 3.6m, which correlates well with large fall of ground database records indicating fallout heights of 3.3m or less for the 95% cumulative fallout height and an inter-pillar span of 20m (old standard).

ISP PILLAR AND SUPPORT SYSTEM

- By reducing the current Instope Strike Pillar sizes to 3m by 3m from the original 3m by 7m a designed inter-pillar span of 15m is maintained and thus a fallout height of 1.65m achieved.
- The stability of the hanging wall is not compromised due to sufficient support resistance provided by the designed residual strength of the Instope Strike Pillars.
- This is an efficient and fast option with very little delay time pertaining to the alternative of backfill or fill installation although the revenue benefit is reduced due to the remaining ore locked up in the pillars.
- The potential height of tensile failure is approximately 3.6m.
- The elongates are installed to 1m strike and dip spacing and is capable to support a hangingwall beam of approximately 6.95m.

$$Fallout\ height\ = span\ x\ emperical\ relationship$$
$$= 15m\ x\ 0.11$$
$$= 1.65m$$



- The calculated FOS is 1.92 (Elongate support system)

MONITORING

- During the reduction of the in-stope pillar in 1200 S3 Raise 14 and 1650 S1 Raise 11, a flow bed plane was identified with the aid of a borehole camera between 2.9m to 3.3m into the hanging wall and no separation along this plan was observed. During the reduction of the in-stope pillars in 1500 S1 Raise 9 no flow-bed separation was observed in the hangingwall between 2.0m to 4.0m.

- Considering the aforementioned, it was deemed necessary to continue with the drilling of 3-4 holes with a length of 3.5m to 4m to conduct borehole scans.

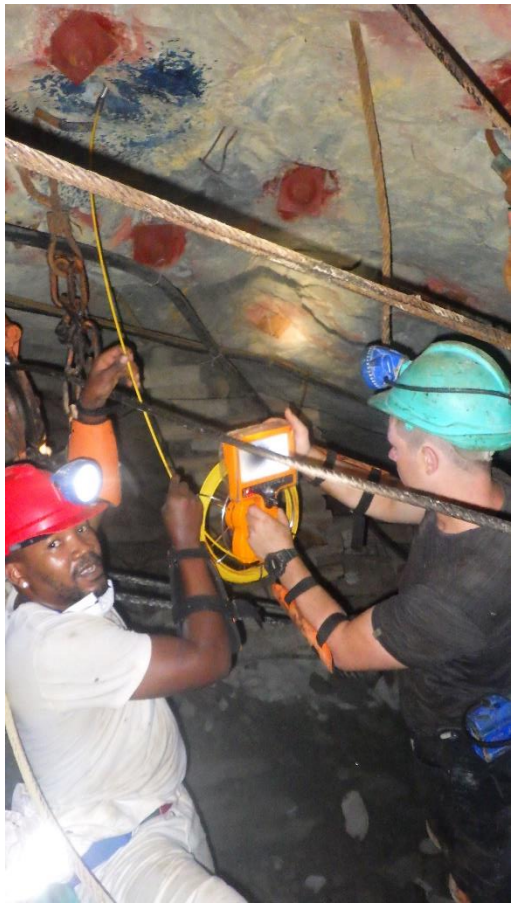
- The results from the boreholes scans will determine whether changes are to be made to the support regimes.

- The deformation monitoring positions to be identified along the gully planned for mining and installed.

- In addition to the above seismic monitoring are conducted.

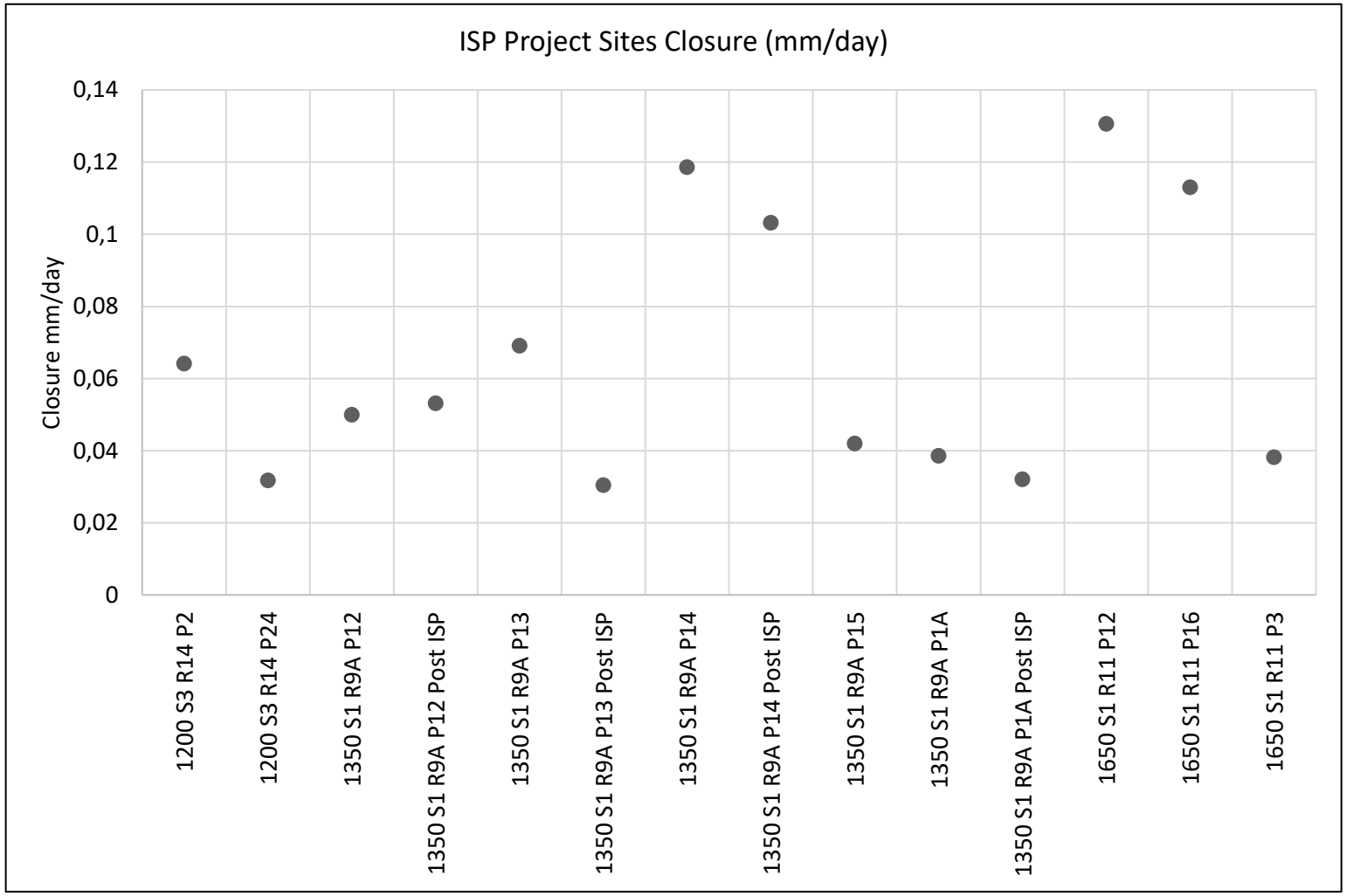
MONITORING EQUIPMENT

Borehole Camera



Closure Loggers

CLOSURE MEASUREMENT RESULTS



- No abnormal displacement or closure rates were observed nor recorded the recorded closure rates are 0.065 ±0.036mm/day
- Borehole Camera inspections did not indicate any separation into the hanging wall in the project sites.

MPBX MONITORING RESULTS

Working place	Days	Total Displacement per Head (mm)					Total HW Displacement (mm)	Displacement per day (mm/day)
		Head 1 0m-2m	Head 2 2m-4m	Head 3 4m-6m	Head 4 6m-8m	Head 5 8m-10m		
		mm	mm	mm	mm	mm		
1200 S3 R14 P2	503	0.28	0.74	0.78	0.98	0.76	3.54	0.0070
1200 S3 R14 P2	503	1.11	0.48	0.62	0.54	0.56	3.31	0.0066
1200 S3 R14 P24	455	11.68	0.34	0.53	0.64	0.85	14.04	0.0309
1200 S3 R14 P24	455	0.43	0.32	0.36	0.44	0.47	2.02	0.0044
1200 S3 R14 P24	455	0.79	0.51	0.96	0.89	0.82	3.97	0.0087
1200 S3 R14 P2	503	0.92	0.79	0.83	0.49	0.33	3.36	0.0067
1200 S3 R14 P2	503	0.46	0.57	0.9	0.71	0.67	3.31	0.0066
1200 S3 R14 P24	454	0.34	0.38	0.4	0.24	0.29	1.65	0.0036
1650 S1 R11 P16	354	0.32	0.5	0.39	3.33	4.01	8.55	0.0242
1650 S1 R11 P3	345	0.77	0.82	0.95	1.07	1.08	4.69	0.0136
1650 S1 R11 P12	352	11.88	4.59	7.47	2.91	2.77	29.62	0.0841
1650 S1 R11 P16	345	4.95	5.26	5.31	5.38	5.53	26.43	0.0766

FINANCIAL AND SAFETY RESULTS

Finances

Project Site and Date	2018	2019	2022
	1200 S3 R14	1650 S1 R10A	1500 S1 R9
Amount of Strike Pillars Reduced	67	84	76
Au (kg)	31.30	183.13	87.03
Revenue (R) Ave.	R 18 562 831.94	R 130 051 651.36	R 96 040 261.57
Total Cost	R 12 885 067.00	R 29 714 110.00	R 22 421 671.00
Profits	**R 5 677 764.94**	**R 100 337 541.36**	**R 73 618 590.57**

Safety

Project Site and Date	2018	2019	2022
	1200 S3 R14	1650 S1 R10A	1500 S1 R9
Duration to reduce the pillars (months)	12	12	12
Number of Dressings	0	0	0
Number of LTI's	0	0	0
Number of Serious Accidents	0	0	0
Number of Fatal Accidents	0	0	0

Summary

- A total of **227** In-stope Strike Pillars have been reduced successfully.
- A total of **23205.1 tons** were extracted accounting for an additional **301.459 kg** of gold which would have not been extracted if not for the ISP Mining Method
- A total additional revenue of **R 244 654 744.87** was earned between the three project sites
- Duration to reduce in-stope strike pillars is **12 months**
- **No accident or Incident** occurred