Extraction of the Kloof Main Shaft Pillar Complex - Geotechnical Investigations and Monitoring

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ABSTRACT

The extraction of the Main Shaft pillar at Kloof Gold Mine is expected to be one of the most challenging rock engineering projects in recent years. The scale, scope and complexity of the project are particularly unique. The extraction will directly affect four vertical shafts and indirectly affect a further three shafts. Most of these shafts intersect the notoriously unstable Western Area Formation which was responsible for the major collapse and de-commissioning of a shaft at Western Areas Gold Mine. In addition to these shafts, twenty-nine critical excavations are housed within the pillar and seventy-seven potentially unstable hotspots have been already identified within these excavations. The risks associated with this shaft pillar extraction are being managed through comprehensive investigations and a monitoring programme. The initial results from this programme are presented in this paper.

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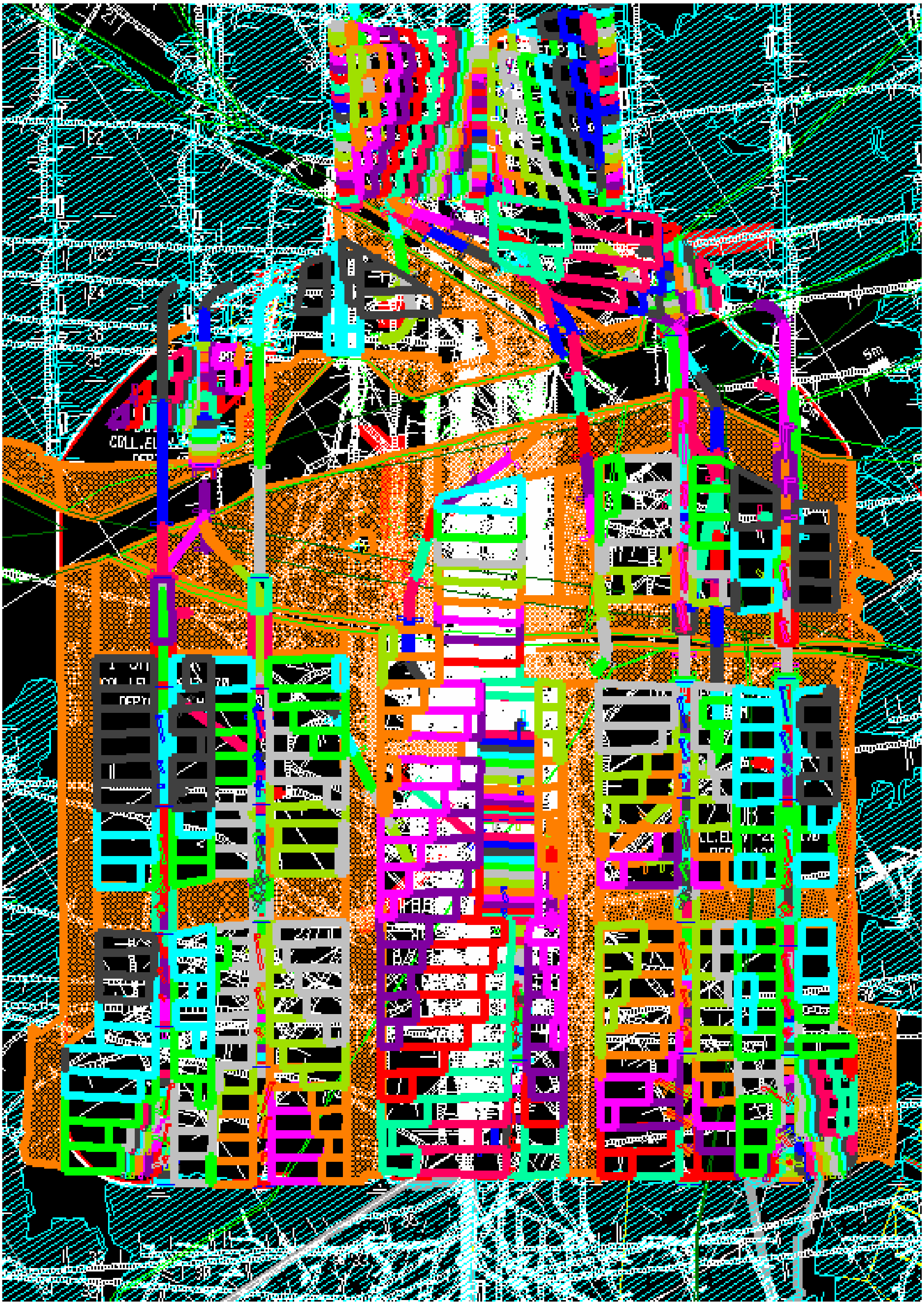
1 OVERVIEW OF THE SHAFT COMPLEX

The shaft pillar at Kloof Main Shaft Complex protects three production shafts and a ventilation shaft. The number of production panels on the Ventersdorp Contact Reef (VCR) is diminishing. Therefore, reducing the shaft pillar will subsequently increase the current production profile. Elsburg Quartzite underlies the VCR which has a uniaxial compressive strength (UCS) of 150Mpa. Approximately 90% of the hangingwall rock comprises low UCS (± 80MPa) friable Westonarea Formation (WAF). Previous drilling indicates that the WAF is 5 to 10 m thick. Overlying the WAF is Alberton Lava with a UCS ranging between 220MPa to 320MPa.

Three geological features traverse the shaft pillar and influence the design at Kloof Main Shaft: 1) A near vertical intrusive dyke to the northwest with a down-throw of 85m to the north; 2) A near vertical intrusion (Venterspost Dyke) with a down throw of 30m to the northwest and approximately 50m wide; 3) The Shaft Fault with an up-throw of 17m to the north which intersects the 1 Sub Vertical Shaft. The area between the Venterspost Dyke and the Shaft Fault has great complexities with localized strike changes. Previous drilling has shown that a zone of intense flat faulting and areas of reef eliminations and duplications exist between 27 and 28 level. Each geological feature was assessed for possible seismic activity arising from mining by plotting the mining steps against the expected magnitude. This assessment clearly showed a direct proportional relationship between the two parameters. The stress conditions along the northwest contact Ventersdorp Dyke will increase as the top section of the shaft pillar is mined. The seismic hazard will also increase as the pillar is reduced.



2 EXTRACTION AND SUPPORT

The modelling results highlighted the following critical areas; haulages that intersect the reef plane; areas where the WAF is exposed; the 24 to 26 level reef and waste passes; areas where the ventilation raises expose the WAF, 22 level hoist chambers and 24 level pump chamber (even though it will be abandoned). Other large excavations around the shaft area will not be affected by the extraction of the pillar.

The proposed extraction of the shaft pillar will be by a mini-longwall (overhand) mining method with two 30m dip pillars on either side of the shaft and four 40m strike stability pillars. Spans on strike and dip pillars should not exceed 200m. Bracket pillars 20m in width will stabilise major geological features. The extraction sequence is summarised in Table 1.

Table 1. Extraction sequence.

Phase	Extraction Process	Duration
01	Block to the northwest of Venterspost Dyke will be extracted	6 months
02	South-eastern corners of the pillar	6 months
03	Mining of the inner-cut, on-reef through the shaft barrels	12 months

Results from strain and displacement analysis (Mungur, 2003), indicate that the shaft barrels should be reinforced 73m above and 61m below 1SV shaft reef elevations and 70m above and 64m below 2SV shaft reef elevation. The Main Shaft bottom is 40m above the reef plane. Reinforcement is required 25m above Main Shaft bottom to prevent the effect of stress relaxation once area below this shaft is extracted.

A backfill mix will be pumped into the wide raises that will be re-entered after being stopped for long periods as well as into the inner cut. The backfill will be pumped as mining advances, leaving an unfilled span of 1m on the idle faces. Permanent and temporary support will be installed as per mine standard. Support resistance and energy absorption requirements based on Kloof's Code of Practice are 28.5kN/m^2 and 18.6kJ/m^2, respectively.

Haulages that expose WAF (23 level; 24 level and 25 level) will be supported with ringsets because the maximum stress (>84MPa) far exceeds the strength of the WAF. In order to prevent rock falls, all haulages in the shaft pillar area will be supported with wire mesh and lace. WAF deteriorates when exposed to water, resulting in bulking and subsequent damage to the shaft chase lining. Therefore dry zones will be maintained around the reef planes by means of wetcrete or void filled ring sets. Water sumps will be installed on either side of the WAF areas and water will be trapped and pumped away from the WAF.

3 RISK MANAGEMENT

In view of the potential risks of a shaft extraction of this magnitude, it is essential that the best possible geological and geotechnical information is available, supplemented with routine monitoring. The initial requirements to manage these risks are summarised in Table 2.

The design, support and monitoring of underground excavations are influenced by the geological environment. Figure 3 illustrates the relationship between geological input parameters, rock engineering design and other relevant processes. The remainder of this paper presents the results obtained to date for the planned investigations and monitoring.

Table 2. Risk management actions.

Step	Objective	Methodology
1	Determine chronology of previous events and assess current damage to excavations.	Site investigations Geotechnical assessments
2	Monitoring changes in rock mass behaviour	Weekly shaft examination to include checkpoints to investigate lining; brattice wall in 1SV# and steelwork. Regularly repeat baseline assessments. Comprehensive, real-time instrumentation programme.
3	Monitor seismic damage	Log seismic events on mine network.
4	Predict and design	Gather data from monitoring program, experience from neighbouring mines and rock mass data will be used to back analyse any unexpected damage and re-calibrate the numerical model.
5	Risk Management and control	A comprehensive risk assessment should be done on all risks associated with mining of the shaft pillar.

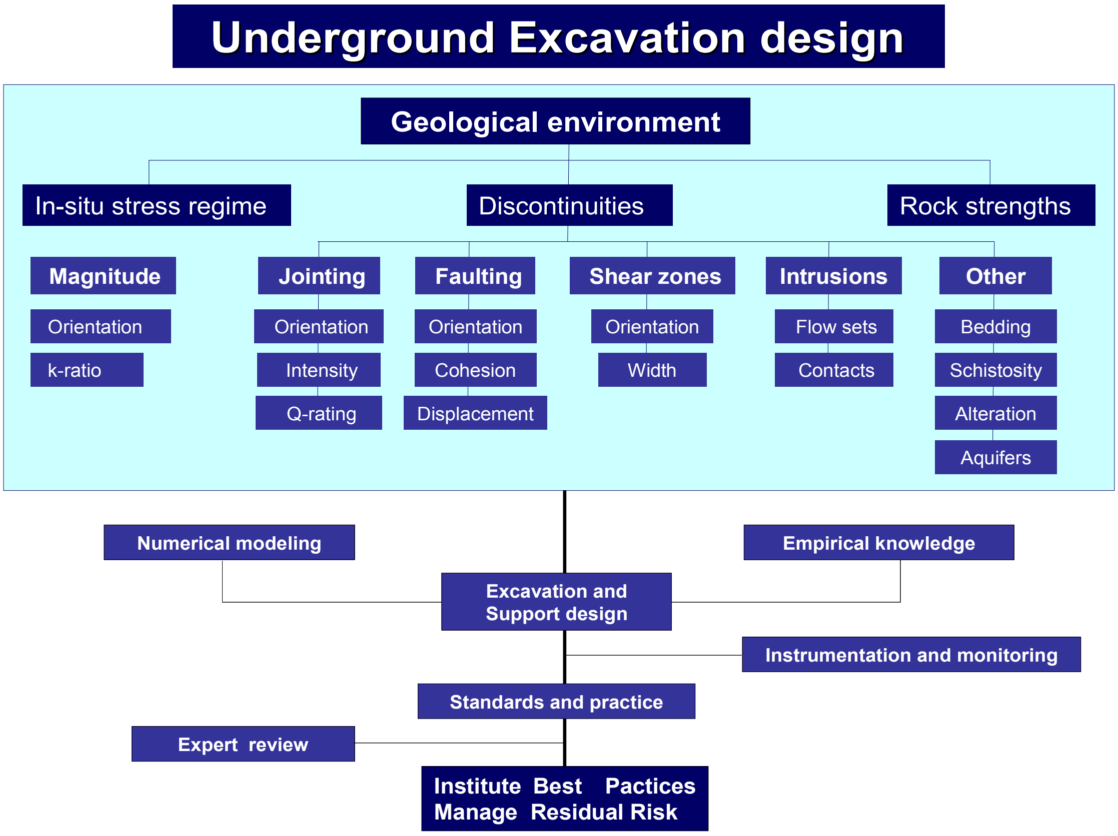


Figure 3. The relationship between geological environment and rock engineering design processes.

4 GEOTECHNICAL INVESTIGATIONS

4.1 Scope of Work

Current geotechnical information within the Kloof Main shaft area is insufficient to guide the instrumentation, monitoring and numerical modelling that need to be undertaken to assist in safe and profitable extraction of the pillar. Collection and interpretation of detailed geotechnical information are required to interpret the envisaged instrumentation data and to calibrate and enhance the credibility of numerical modelling results. The results of the geotechnical investigation will be integrated into the instrumentation and monitoring programme during extraction of the shaft pillar.

The first step was to conduct a literature and report survey of current information in order to identify and collate relevant reports, to assess their usefulness and to identify information gaps. This included an evaluation of existing information on the properties and in-situ behaviour of the WAF. The geomechanical properties and potential instability of the WAF is of particular concern as some excavations at both Driefontein and Kloof are showing signs of early stress induced damage. The response and possible influence of geological discontinuities and the effect of seismicity on critical excavations also needs to be taken into consideration. A graphical representation of the overall programme is depicted in Figure 4.

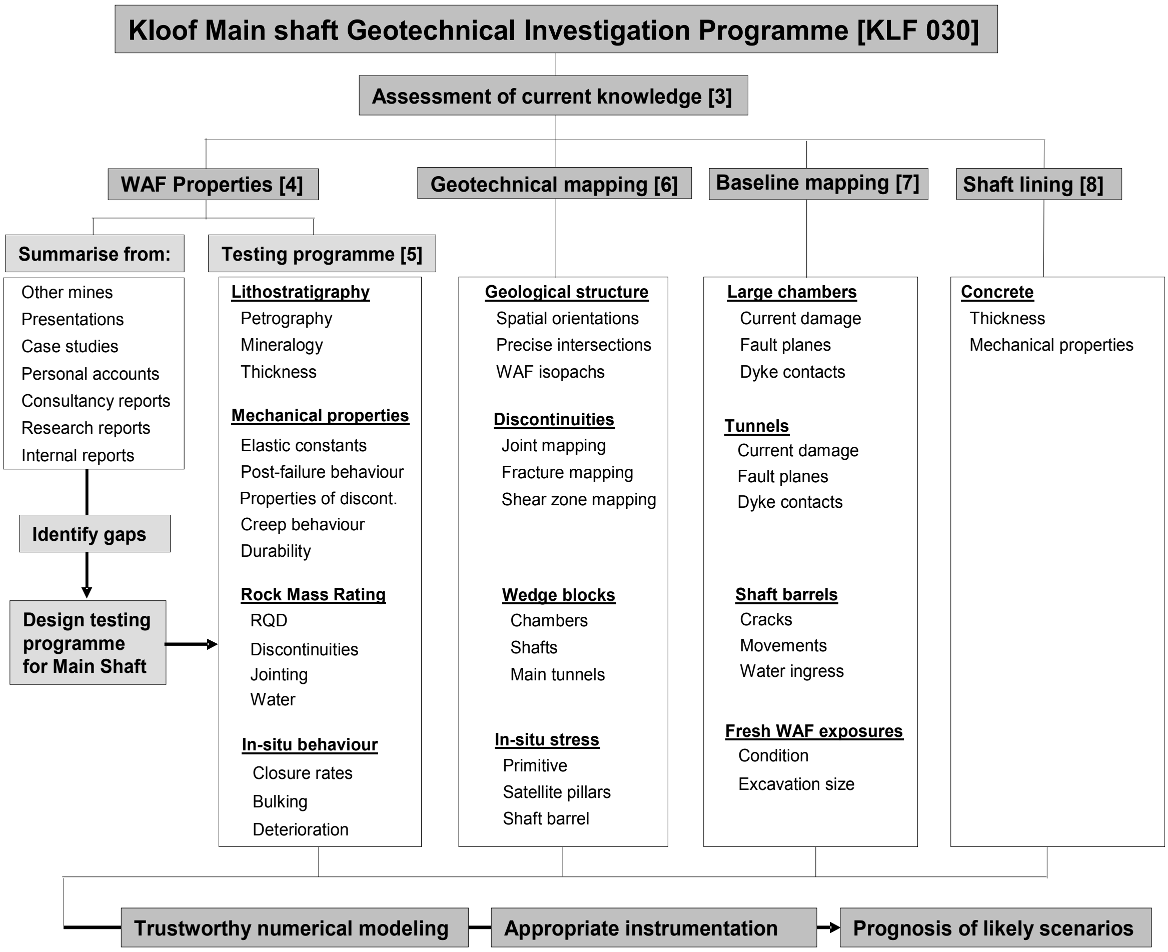


Figure 4. A summary of the geotechnical investigation programme.

4.2 Baseline Survey

A survey was conducted to record the current (baseline) conditions of critical excavations such as chambers, service excavations, shaft station areas, tunnels within the shaft pillar area and VCR intersections from 22 to 26 level and 33 level station. The shaft pillar area was mapped, marked and photographed. Plans were scanned and updated with the geological and damage information and archived on CD. Approximately 60 photographs were taken. Future digital images can be compared with the baseline conditions at regular time intervals during the shaft pillar extraction to assess and monitor changes and to provide input for numerical modelling, instrumentation and monitoring. Figure 5 is an example of the reference plan for 23 level. Figures 6 and 7 are examples of typical images that were captured. The numbered arrows refer to photograph numbers where geological structures and excavation damage were recorded.

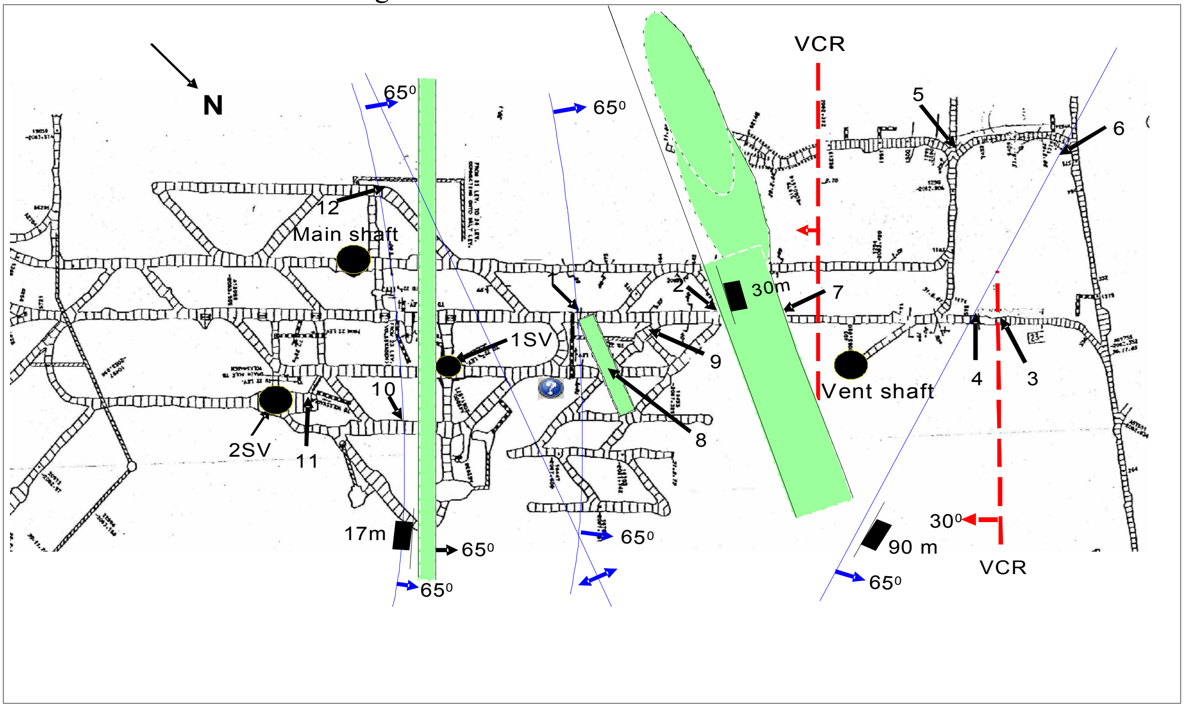


Figure 5. An example (23 level) of the baseline plan.

Figure 6. Significant bending of the kingposts on 33 level station. This area has been subjected to compression, possibly due to a previous episode.

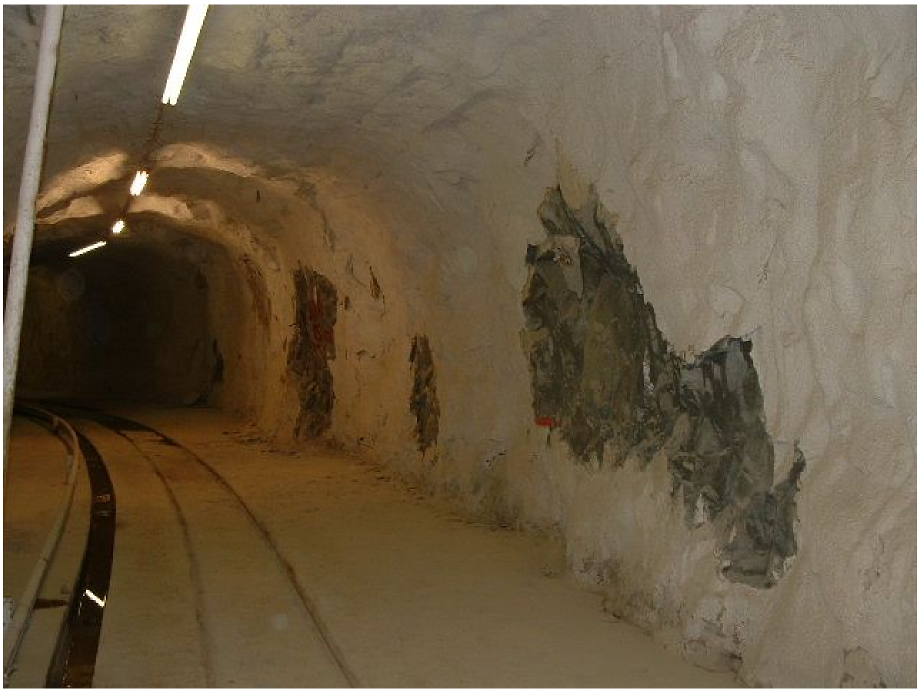


Figure 7. Haulage sidewall scaling in the shaft pillar area.

A 3-dimensional model (Figure 8), consisting of three vertical sections and five horizontal projections, was constructed to assist in the visualisation of the overall structure, their intersection with the critical excavations and stabilising pillars. The model will also be used to enhance the reliability and credibility of numerical modelling and will aid in the understanding and prognosis of future manifestations of instabilities, seismicity and rockburst damage.

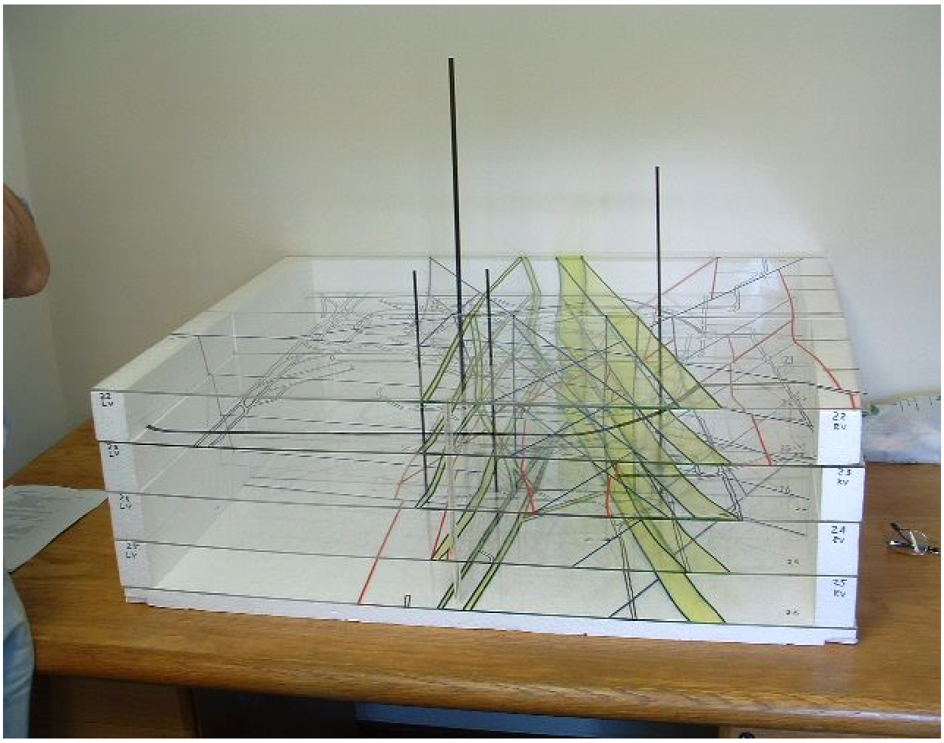


Figure 8. The 3-dimensional 1:1000 scale model of the area between 22 and 26 level.

The results from the baseline survey suggest that most damage, fracturing, and cracks that occur in the shaft pillar are associated with the intersection of geological structures such as dykes and faults. Several damaged areas are due to relatively high induced stresses that can be attributed to sub-optimal excavations positioning and design. Joints influence the damage patterns that are manifested in pronounced hangingwall and sidewall damage.

The results of the baseline survey have assisted in identifying areas where detailed numerical modelling is required to estimate possible condition deterioration during the pillar extraction phase. Areas such as geological structures and certain bullnoses and areas with large spans will be included in the instrumentation and monitoring programme. Repeat surveys and follow-up photographic imaging will be conducted at regular time intervals during the shaft pillar extraction to monitor any changes. Increases in the rate of damage deterioration will be used to prioritise areas for possible instrumentation monitoring.

4.3 Westonarea Formation

A key risk area that was identified during the shaft pillar extraction risk assessment is the depth and extent of potential migration of the WAF into the shaft barrel. The location of the WAF in 1SV shaft is shown in Figure 9.

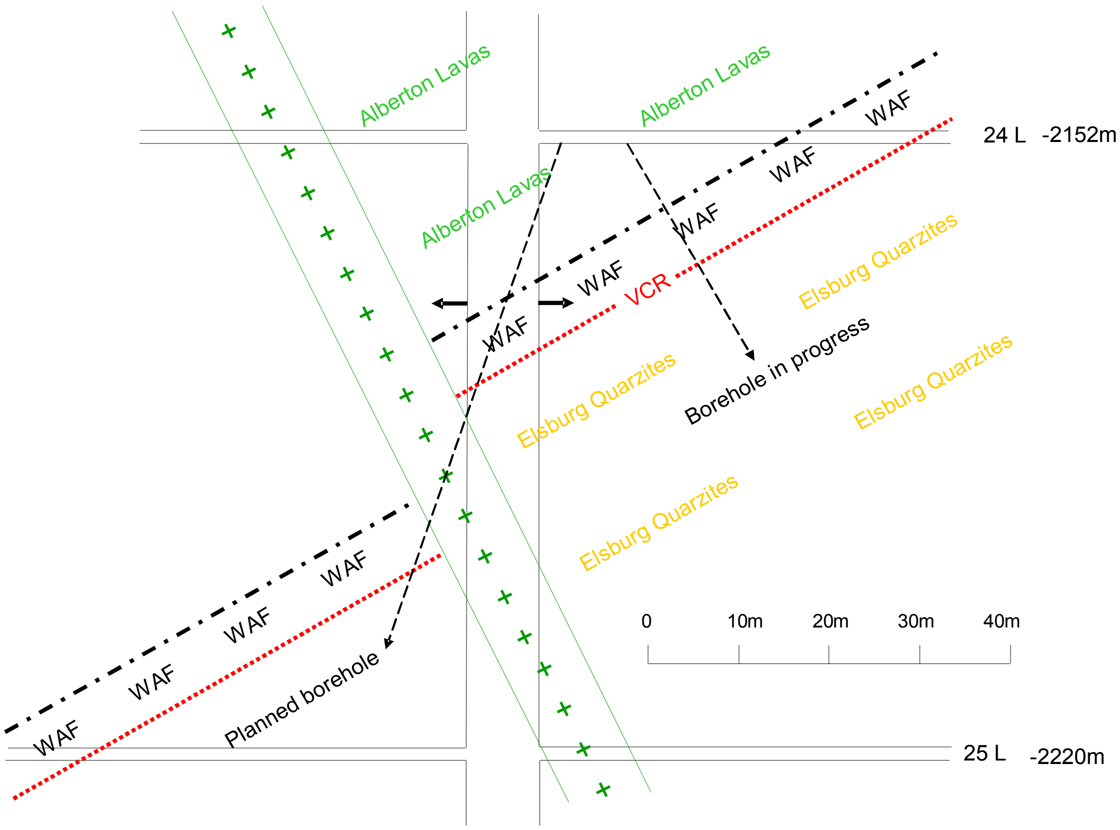


Figure 9. Location of the WAF in SV1 shaft

A summary of the characteristics of the Westonaria Formation (Table 3) indicated that it is a relatively weak rock that has poor structural integrity and in-situ stability and hence poses a risk for the long-term stability of underground excavations and mining operations. The in-situ stability is adversely influenced by exposure to water and air.

The distinctly different properties of each zone within the WAF indicated that it is not advisable to use previously published information on the WAF from adjacent mines for design purposes on Kloof Gold Mine. Accordingly, a comprehensive suite of tests is to be conducted on core samples of the WAF from drill holes with known locality and orientations from the Kloof Main Shaft pillar area. The results from these tests will provide reliable information that can be used for rock engineering, support design and numerical modelling purposes.

Table 3. Regional and site specific information on the WAF.

Properties	Units	Regional GAP 102 (2003)	WAGM (2005)	Driefontein (2006)	South Deep (2006)	Kloof Main shaft
ZONE		Not stated	1a, 1b, 2a, 2b	Not stated	Not stated	Not stated
Elastic properties						
Uniaxial CS	MPa	100 to 140	20 to 80	50 to 120	20 to 80	
Uniaxial TS	MPa	-	-	12	-	
Young's modulus	GPa	68	-	53 to 74	68	
Bulk modulus	GPa	40	-	40	40	
Shear modulus	GPa	28	-	28	28	
Poisson's ratio		0,18 to 0,27		0,14 to 0,33	0,2	
Peak strength data			-			
Cohesion	MPa	6	-	3,79	2,2	
Phi	o	34	-	27	17	
Dilation	o	22	-	22	22	
Tensile strength	MPa	0,7	-	0,15	0,1	
Residual strength						
Cohesion	MPa	0,7	-	0,7	0,2	
Phi	o	35	-	27	17	
Dilation	o	5	-	50	5	
Tensile strengths	MPa	0	-	0	0	
RMR/RQD		62	30 to 85	52	50	
In situ strengths	MPa	23	-	12	6	

5 MONITORING

Knowledge from other shaft pillar extraction projects where Groundwork has been involved, site visits to the critical excavations in the Kloof Main Shaft complex and discussions with mine personnel have identified a number of excavations and areas within the excavation which should be regarded as highest priority for an instrumentation programme. It should be borne in mind that instrumentation is not necessarily required to monitor all high risk areas. Some areas are readily accessible and lend themselves better to visual monitoring than to point measurements using instrumentation. The focus of the instrumentation programme has been on sites that are not readily accessible, where movement may lead to immediate danger and instrumentation data would need to be obtained 'on demand'. The highest risk areas are summarised below. An example of specific risk areas in the 1SV shaft is given in Table 4.

- The concrete lining of the SV1 shaft barrel 24 and 25 levels and SV2 shaft between 25 and 26 levels which covers the reef plane, the WAF immediately above reef and some rock wedges which may be potentially unstable.
- The WAF behind the concrete lining immediately above the reef intersections on SV1 and SV2 shafts.
- Potentially unstable wedges behind the concrete lining between 24 and 25 level on SV1 shaft and between 25 and 26 level on SV2 shaft.
- The rock shoulders supporting the steelwork towers on 23 sub-bank for SV1 shaft and 24 sub-bank for SV2 shaft.

Table 4. An example of some of the specific risk areas (hotspots) in 1SV shaft.

REF	EXCAVATION	FEATURE	HOTSPOTS
2.1.1	23 - 26 level	Concrete lining	23 - 26 level
2.1.2	24 - 25 level	WAF	24 - 25 level
2.1.3	24 - 25 level	Shaft fault	24 - 25 level
2.1.4	Shaft barrel, WAF, 24L	Potential wedge	SB, top of WAF, 24L
2.1.5	SB, WAF, VCR	Potential wedge	SB, WAF, VCR
2.1.6	SB, WAF, shaft dyke	Potential wedge	SB, WAF, shaft dyke
2.1.7	SB, shaft dyke	Potential wedge	SB, shaft dyke
2.1.8	SB, shaft dyke, 25L	Potential wedge	SB, shaft dyke, 25L
2.1.9	SB, VCR, 25L	Potential wedge	SB, VCR, 25L
2.1.10	SB, Elsburg quartzites	Potential wedge	SB, Elsburg quartzites
2.1.11	23 level sub-bank	Bridge bearing foundations	23 level sub-bank
2.1.12	23 level sub-bank	Bridge steelwork	23 level sub-bank
2.1.13	22 - 23 level	Brattice wall	22 - 23 level
2.1.14	26 - 27 level	Brattice wall	26 - 27 level
2.1.15	23 - 26 level	Steelwork - lining	23 - 26 level
2.1.16	31 level	Cobble reef intersection	31 level

The proposed monitoring programme (Figure 10) consists of the following :

- Installation of sensors (instruments) to monitor critical parameters (e.g. rock movement).
- Installation of sensors (instruments) to monitor steady-state changes for design

verification purposes.

- Data back-up and communications systems from the instrumentation to surface computers.
- Monitoring and database management procedures for the instrumentation data.
- Management procedures in response to pre-defined instrumentation data values.
- Visual monitoring and recording of unexpected movements and damage.
- Procedures in the event of unexpected movements and damage being observed.

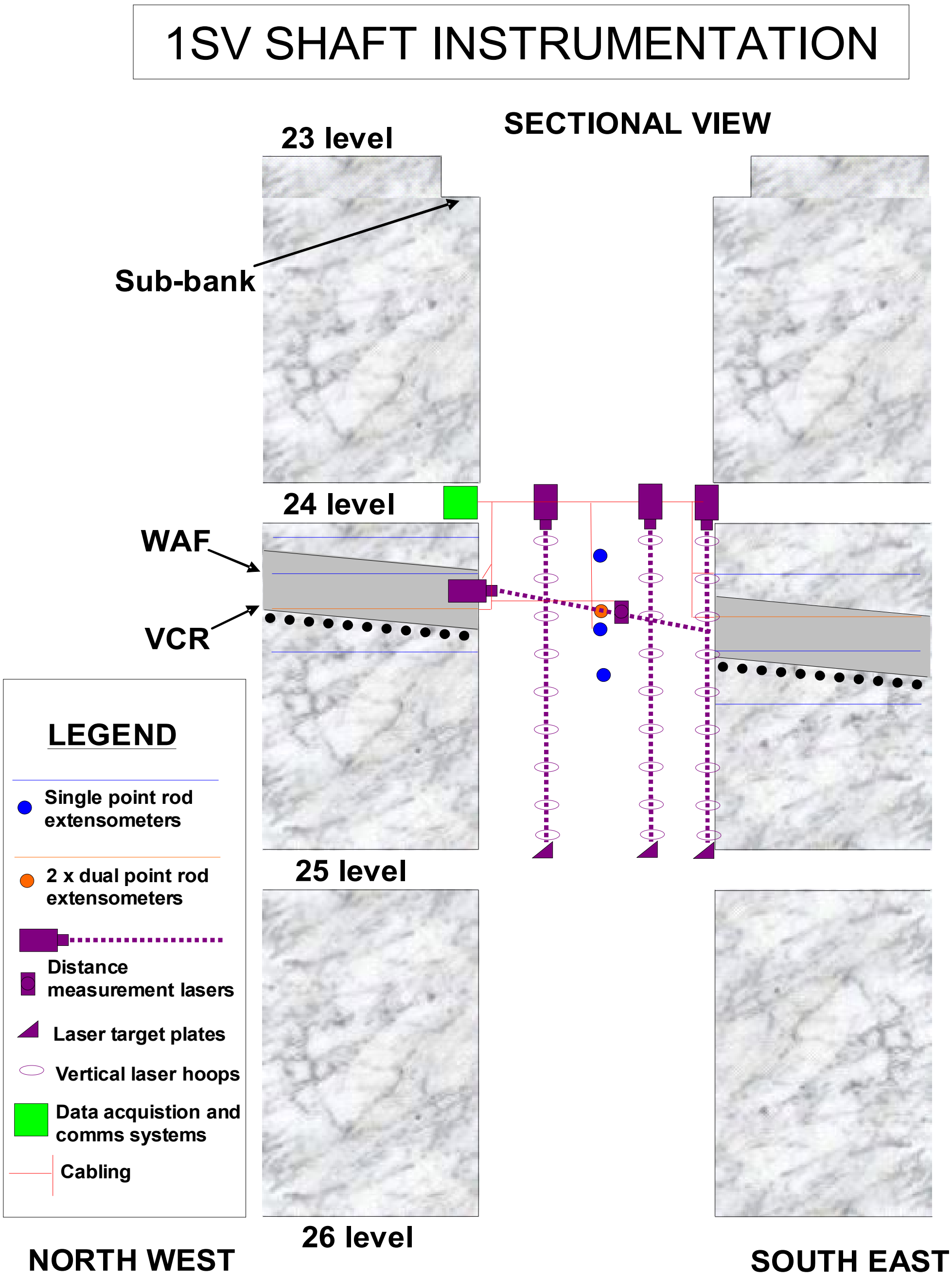


Figure 10. An example of the proposed instrumentation and locations for 1SV shaft.

6 SUMMARY

The extraction of the Main Shaft pillar at Kloof Gold Mine is expected to be one of the most challenging rock engineering projects in recent years. The scale, scope and complexity of the project are particularly unique. This extraction will affect four vertical shafts directly and indirectly affect a further three shafts. Most of these shafts intersect the notoriously unstable Western Area Formation which was responsible for the major collapse and de-commissioning of a shaft at Western Areas Gold Mine. In addition to these shafts, twenty-nine critical excavations are housed within the pillar and seventy-seven potentially unstable hotspots have been already identified within these excavations. The risks associated with this shaft pillar extraction are being managed through comprehensive investigations and a monitoring programme. The initial results from this programme are presented in this paper.

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