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School of Mining Engineering



UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

Value creation and risk management in mining operations through an integrated reporting framework of geotechnical data, uncertainty, and materiality

Carrie Zermatten

A research thesis submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, Johannesburg, in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Engineering.

Johannesburg, 2024

Declaration

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“We are moving from a world of problems,
which demand speed, analysis, and elimination of uncertainty to solve,
To a world of dilemmas,
which demand patience, sense-making, and an engagement of uncertainty.”

Denise Caron

Abstract

The research considers a stance that every aspect of the mining operation is, at its root, dependant on the geomechanical / geotechnical integrity of the excavation. A mining operation would not be able to maintain production if the excavated workings in the rock mass cannot be kept 'open' - even if many other aspects of the mine are very favourable (e.g. metallurgical and/or mineral processing can produce excellent recoveries, commodity prices are high etc).

The research is compelled through several contributing factors, including the recognition that:

- There is no national inventory of mining geotechnical data (viz. a comprehensive or extensive database) readily available to offer insight into the factual account of data provision that has supported viable mining operations to date. Such aspects would include the type, quantity, quality, and spatial distribution of data (as well as changes therein over time) associated with respective "types" of mineralised ore bodies, mining method selection, hydrogeological regime, etc.
- The interpretation and application of scientific, engineering, and risk principles are often quite inconsistent within- and between- different mining operations.
- The content and clarity of rock-related reporting is often highly variable - especially beyond the assessment of project viability to the actual performance over time of rock engineering, geomechanical stability, and geotechnical design dimensions of a mining excavation.
- Practical realities in business (e.g. limited budget availability to particular cost centres, differing corporate priorities etc.) may limit the implementation of rock engineering decisions.

The research identifies and compiles various information from a wide range of specialised topics that are commonly studied individually in smaller settings (e.g. rock mechanics, aspects prescribed under law, risk, subjective belief, governance as well as reporting transparency for mining projects [distinguished from the requirements of reporting of mineral resources and/or mineral reserves]).

The topics are then related to each other, and their roles toward a holistic understanding of risk-related aspects of a mining operation are explored - with rock and geotechnical engineering as a central tenement of that consideration.

The research advances the discourse of value creation and risk management in mining engineering, through:

- The description of the complex interplay of components and organisations within the mining industry, as well as the potential for improving their coalescence.
- The identification of opportunities created from reporting rock-related information and the demonstration of technical competence. These opportunities could be applied toward the goals of risk management, value creation, sustainability, and growing investor confidence.
- The motivation that access to relevant geoscientific data is supported through the current regulatory framework;
- Various geoscientific data could be retrospectively shared by mining organisations; and
- The articulation of a proposition for voluntary disclosure.

Publications as part of this Research

The publications that have been prepared from this research include:

1) The reporting of geotechnical data, uncertainty, materiality for hard rock mining operations.

Additional publications that have been drafted and are being finalised, include:

1) Mandatory Codes of Practice in the South African Mining Industry.
2) An overview of legislated and regulated elements regarding ‘competency’ in mining operations.
3) An overview of the elements of section 54 and section 55 notices issued to South African mining operators.
4) What does it matter? An exploration of the language used in assessments wih regard to characteristics of risk-related elements.
5) Mining disasters and the resulting inquests undertaken to investigate and determine cause and responsibility.
6) An overview of the South African Mines Reportable Accidents Statistics System (SAMRASS).
7) ~~—~~
8) Mines Rescue Services of South Africa.
9) A comparison of mining rock-related, higher education learning programmes in South Africa, Australia, and Canada.
10) A comparison of the mining geotechnical elements required for reporting as part of the SAMREC Code, NI43-101 and JORC Codes.
11) An insight into various ‘risk reports’ generated by organisations across the globe, with interest in mining.

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- Mr Peter Terbrugge. Our spirited technical discourse motivated me to explore, challenge and expand my viewpoints – ultimately leading to the approach presented in this research. I hope that other practitioners will also be enticed to challenge their own viewpoints after reading the thesis.

Additionally, I wish to offer acknowledgement to -

The various publishers, universities, organisations, and individual authors who have allowed access to their publications and research findings:

- Thank you for allowing your repositories to be accessed and shared.
- The collective body of published material that could be sourced, proved instrumental toward this study.
- In turn, the study strives to offer continue this co-operative spirit by making the thesis publicly available. The purpose of the co-operative initiative is to advance the science, engineering, safety, and sustainability of hard-rock mining in South Africa and beyond.

The various university personnel, conference-speakers, laboratory technicians, and industry fellows:

- Thank you for your sharing your experiences and opinions with me.
- Your input has contributed a holistic reflection on the topics herein.
- I have endeavoured to formulate the output in such a way that it is accessible to a wide audience, and at the same time, that it is flexible enough to be tailored by bespoke groups.

The anonymous reviewers who carried out the external examination of the thesis:

- Your instructions for revisions to the thesis both inspired and challenged me.
- Incorporating your required changes improved the quality of the document and produced a more balanced output.
- I hope that (far from being a standalone contribution to industry's technical knowledgebase) the research assists in stimulating constructive conversation and innovative collaboration throughout the broader industry.

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List of Abbreviations and Terms

Abbreviation / Term	Meaning
2D	Two dimensional
3D	Three dimensional
ABET	Adult Basic Education and Training
batter angle	Synonymous with bench face angle
bench face angle	Synonymous with batter angle
borehole	often referred to as drillhole
c	Cohesion
CAD	Computer-aided design
CoC	Chain of custody (viz. refers to sample handling)
CoM	Chamber of Mines (now the Minerals Council of South Africa)
CoP	Code of practice
CSIRO	Commonwealth Scientific and Industrial Research Organisation
D	Disturbance factor
Decline	A generic term used to describe a shaft at an inclination below the horizontal and usually at the same angle as the dip of the reef
DInSAR	Differential Interferometric Synthetic Aperture Radar
Discretionary procurement	Procurement for which the purchaser is able to choose the supplier as opposed to non-discretionary expenditure where the purchaser has no choice of supplier, e.g. the purchase of electricity from Eskom which is currently the only company from which we can purchase electricity in South Africa
DME	Department of Minerals and Energy
DMR	Department: Mineral Resources
DMRE	Department: Mineral Resources and Energy
DTM	digital terrain model
EBITDA	Earnings before interest, taxation, depreciation and amortisation
EDI	equity, diversity, and inclusion
Employment equity	Achieving equity in the workplace by promoting equal opportunity and fair treatment in employment through the elimination of unfair discrimination and implementing affirmative action measures to redress the disadvantages in employment experienced by previously historically disadvantaged South Africans (HDSAs)
EOH	End of hole
ERM	Enterprise risk management
Fatality	Any death resulting from an unexpected and unplanned occurrence, including acts of violence on the premises of the Company

Abbreviation / Term	Meaning
FF	Fracture frequency
FF/m	Fracture frequency per metre
FIFR	Fatal injury frequency rate; the number of fatal injuries that have occurred in every 200 000 hours worked
FOG	Fall of ground
FoS	Factor of safety
GBIS	Geological Borehole Information System
GDP	Gross Domestic Product
GL	Geological Loss
GSI	Geological strength index
GTIS	Gross Tonnes In Situ
IAP	Interested and Affected Party
IDP	Integrated Development Plan
IGR	Independent Geological Review
In situ	The original natural state of the ore body before mining or processing of the ore takes place
Indicated mineral resource	An 'Indicated Mineral Resource' is that part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a reasonable level of confidence. It is based on information from exploration, sampling and testing of material gathered from locations such as outcrops, trenches, pits, workings and drill holes. The locations are too widely or inappropriately spaced to confirm geological or grade continuity, but are spaced closely enough for continuity to be assumed (SAMREC 2007)
Inferred mineral resource	An 'Inferred Mineral Resource' is that part of a Mineral Resource for which volume or tonnage, grade and mineral content can be estimated with only a low level of confidence. It is inferred from geological evidence and geologically or through analysis of grade continuity. It is based on information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes that may be limited in scope or of uncertain quality and reliability (SAMREC 2007)
InSAR	Interferometric Synthetic Aperture Radar
IOM	Inspector of Mines
IRA	Inter ramp angle
ISO	International Organisation for Standardisation
JCS	joint wall compressive strength
JRC	Joint roughness co-efficient

Abbreviation / Term	Meaning
KPI	Key performance indicator, a measure of factors that are crucial for the success of an organisation and specific to that organisation or sector
LHD	Load haul dump machine used in trackless mining
LoM	life of mine
LTI	Lost time injury: An occupational injury or illness that results in at least one day away from work on any rostered shift subsequent to the day on which the injury occurred. A fatality is also recorded as an LTI
LTIFR	Lost time injury frequency rate: The number of lost time injuries per 1 000 000 hours worked
MCOP	Mandatory Code of Practice
mi	Intact rock strength parameter
MII	Mining Integration and Intelligence
MOI	Memorandum of Incorporation
MRMR	Mining Rock Mass Rating
MSR	Movement and Surveying Radar
MTIS	Mineable Tonnes In Situ
MTS	Mines Technical Services: A set of IM systems that support the various mine production disciplines such as planning, survey, geology, ventilation, rock engineering and safety
NAV	Net asset value: Total assets less all liabilities, including deferred taxation, which equates to shareholders' equity. Net asset value as a percentage of market capitalisation is shareholders' equity expressed as a percentage of market capitalisation
No.	Number
Number of days without injury during the year	The number of calendar days on which no injury was reported or recorded at the BRPM Clinic. This can be for a specific area or the total mine, depending on the area being reported on in the reporting period
Number of employees counselled	The number of employees that received HIV counselling prior to deciding if they will accept the HIV test. HIV counselling is compulsory for all employees during initial and periodic medical surveillance examination
Number of employees currently on ART	The number of employees that have been identified as being HIV positive as indicated by the HIV test results and where the CD4 count is 350 or below
OEM	Original equipment manufacturer
OSA	Overall slope angle
PoF	Probability of failure
PPE	Personal protection equipment
QA/QC	Quality Assurance / Quality Control

Abbreviation / Term	Meaning
RMC	Rock Mass Classification
RMR	Rock Mass Rating
RPM	Rustenburg Platinum Mines
RQD	Rock quality designation index
RSA	The Republic of South Africa
Safety maturity levels	Basic, Reactive, Compliant, Proactive, Resilient
SAMRASS	South African Mines Reportable Accidents Statistics System
SDF	Spatial Development Framework
Section 54 stoppage	In terms of section 54 of the Mine Health and Safety Act 29 of 1996, if an inspector of mines believes that an occurrence, practice or condition at a mine endangers or may endanger the health or safety of people at the mine, the inspector may give an instruction necessary to protect the health or safety of people at the mine, including instructing that operations at the mine or a part of the mine be halted
Section 55 notice	In terms of section 54 of the Mine Health and Safety Act 29 of 1996, the Inspector is granted power to order compliance i.e. if an inspector has reason to believe that an employer has failed to comply with any provision of this Act, the inspector may instruct that employer in writing to take any steps that the inspector considers necessary or specifies toward comply with the provision/s of the Act.
SIB	Stay-in-business
SOP	Standardised Operating Procedure
SSR	Slope Stability Radar system
TARP	Trigger action response plan. Major accidents are usually preceded by indications of trouble (triggers). A TARP identifies these indicators and specifies appropriate actions to be taken when they occur
TCS	Triaxial compressive strength
TInSAR	Terrestrial Interferometric Synthetic Aperture Radar
TTC	Toe-to-crest
TTT	Toe-to-toe
UCS	Unconfined compressive strength
Workforce	Includes both enrolled employees and contract workers
ZAR	South African Rand
ZOI	Zone of Influence

1 INTRODUCTION

1.1 Overview of chapter 1

Chapter 1 introduces the different components of the research as well as sets out the structure of the thesis document.

The chapter contains:

1) An outline of the content of the various chapters (sub-section 1.1);
2) A note regarding language and mining terms used in the thesis (sub-section 1.2)
3) A description of the structure of the thesis (sub-section 1.3)
4) An introduction to the research (sub-section 1.4);
5) A description of the purpose of the study (sub-section 1.5);
6) Justification for- and impetus to- undertake the research (sub-section 1.6);
7) An explanation of the research objectives (sub-section 1.7);
8) A description of the research approach (sub-section 1.8);
9) A description of the methods used (sub-section 1.9);
10) A statement of the contribution to knowledge (sub-section 1.10); and
11) Concluding remarks for the chapter (sub-section 1.11).

Figure 1-1 shows an overview of the components presented chapter 1.

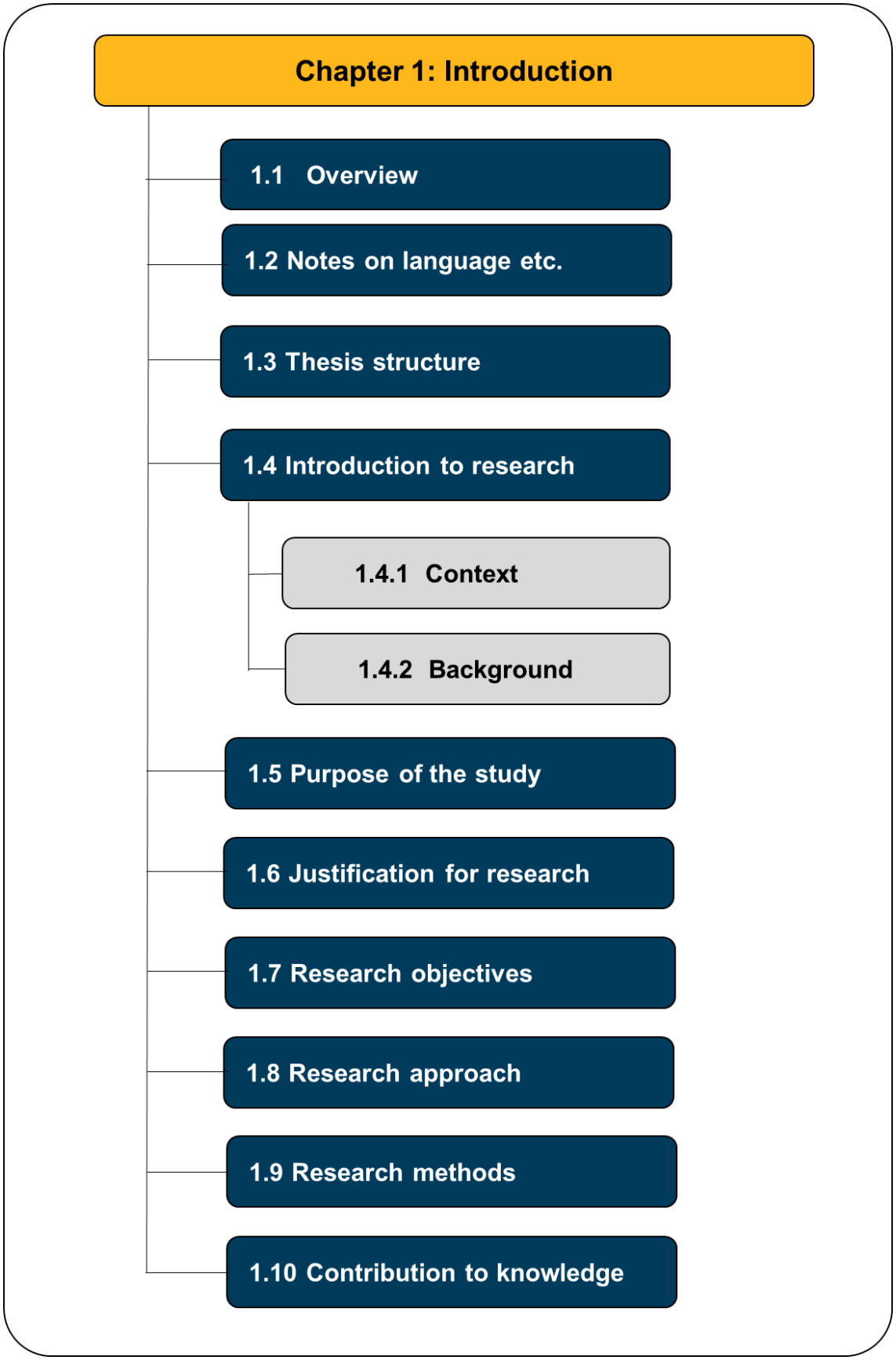


Figure 1-1: Overview of contents of chapter 1

1.2 Notes on Language and Meaning

1.2.1 Language

The thesis assumes and relies on an initial, existing exposure and/or insight into the related components of rock mechanics, geotechnical engineering, policy development, and codification [regarding aspects of voluntary versus mandatory disclosures, regarding legal obligations etc.] rather than specialised expertise in one discipline only.

However, the concepts and principles described herein under are first introduced in a 'reasonability accessible' language, and then build to more technically complex verbiage and concepts where relevant. The purpose of this is to:

1) Ensure the foundation and context are built systematically, and with due specificity; and
2) Allow recognition of information reported to non-technical audiences with that information used by technical experts.

Thereafter, the language explains and uses *specificity* and *nuance* to demonstrate the principles described. It is anticipated that the use of deliberate semantics - rather than the use of rhetoric - will be recognised and tolerated by the readers of the thesis.

1.2.2 Clarity on Broad 'Mining' Phrases

The nature, application, and collaboration of the fields of rock mechanics, geotechnical engineering, and engineering geology may be quite similar in many aspects. Throughout the document, the implied use of the phrase "engineering", relates to rock mechanics and geotechnical engineering (as opposed to mechanical engineering, electrical engineering, or to those parts of mining engineering such as mine scheduling and reconciliation).

Similarly, the implied use of the phrase "mining activity" hereinunder, is typically towards the rock-related elements that that form the mine workings (i.e. the actual 'excavation' that is the open pit, the boxcut, the portal, or the underground mine, etc.). Alternative contexts will be described as such within the relevant text.

It is re-iterated that the context of the discussion throughout the entire thesis document, is directed toward **mining excavations** in hard rock. Other mining elements are excluded from the explanations (e.g. tailings storage facilities (TSFs), waste rock dumps (WRDs) etc. However, to facilitate literary clarity and as not to overwhelm the prose with very long, repetitive sentences – the simplified phrase "mining operation" has been used throughout.

Lastly, the inference to ‘the mining industry’, is typically toward the entire aspect of mining (i.e. mining and engineering, production, processing, reporting, the business of, the regulators of, etc.). Alternative contexts will be descried as such within the relevant text.

1.3 Structure of the research thesis

The thesis consists of nine, main chapters – composed as follows:

Chapter 1 provides -

a) The introduction and description of the research and, *inter alia*:
    i) The context and background of the research;
    ii) The purpose of the study; and
    iii) The justification for undertaking the research.
b) The research objectives, approach and methodologies, as well as
c) A statement on the contribution to knowledge.

Chapter 2 identifies the ***data sources*** for the study, and chapter 3 identifies the ***data items*** used.

Thereafter, chapter 4 provides the literature review (presented in thematic groupings to align with the problem statement and expected contributions to knowledge outlined in chapter 1.10 below).

Chapter 5 presents the synthesis of the information, that leads to the findings of the research – that are subsequently presented in chapter 6.

The central content of the thesis closes with chapter 0. The chapter contains the summary conclusions of the research and identifies recommendations for potential, future research.

Chapter 8 provides a comprehensive list of references (citing the works used in the thesis), as well as an extensive list of bibliographic items used during the undertaking but not necessarily reproduced in the body of the thesis.

A large compilation of supplementary material is provided in chapter 9, i.e. the annexures to the main body of the thesis.

Each of the chapters in the thesis is organised in a similar fashion, i.e.:

- The chapter begins with a short overview containing a statement of the content addressed in the chapter, which is accompanied by a flowchart-type image.
- The main body of information is presented centrally and the key points are enumerated.
- The chapter ends with concise concluding remarks summarise the main elements and relate those to the contribution to the overall study.

An overview of the structure of the thesis document is shown in Figure 1-2, as an aid to navigating the document.

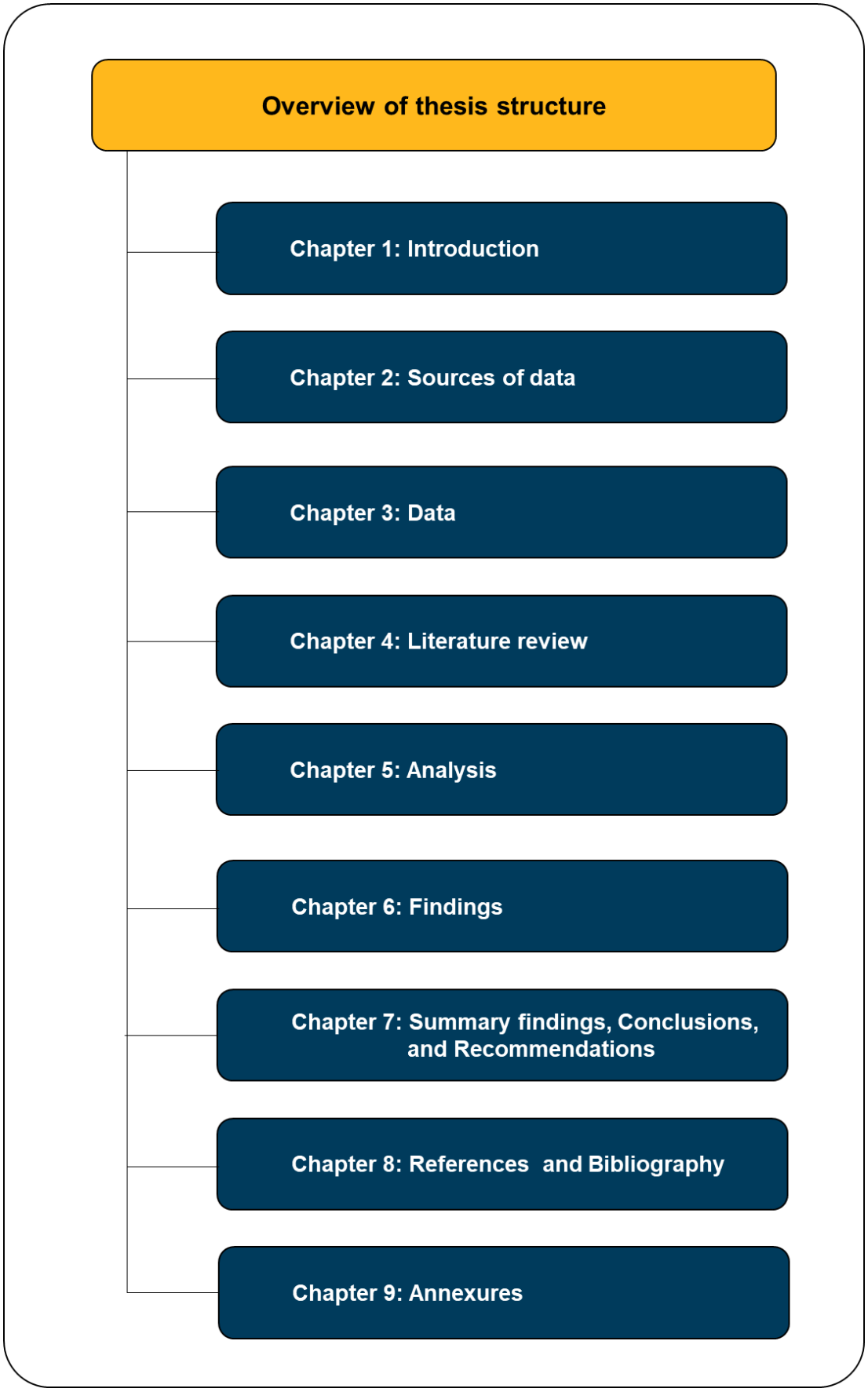


Figure 1-2: Overview of structure of thesis document

1.4 Introduction to the research

The research presented herein is relevant to hard rock mining, and spans across a variety of related disciplines - including mining rock mechanics, geotechnical engineering, risk management, analytical bias, cognitive bias, policy, technical reporting as well as voluntary disclosure.
The information about, as well as the implementation of each of these aspects varies between academic study, “common view”, and practical execution thereof in real world, day-to-day operational settings.

It is through the integration of these specialised disciplines, and very importantly – using the *specificity* and *nuance* within and between the disciplines – that the research facilitates value creation for mining companies, a contribution to the knowledge in the field of mining engineering, and impactful addition toward the transformation efforts aspired to by private and public South African organisations alike.

The data and knowledge used in the research has been drawn from a wide, international setting, and then is applied to the South African mining context in later chapters. It is intended that the contribution to knowledge will aid in narrowing the gap between pure academia and industry practice, for the benefit of all stakeholders and the attractiveness of mining investment in South Africa.

1.4.1 Research context

The research is composed of linked subject material, building

- ***From*** tangible elements such as:
    - The actual physical features and properties of the rock mass that is pursued by rock engineering, geomechanics and geotechnical engineering practitioners. These features and properties include
        - Identification and/or measurement of rock type;
        - The type, extent, and depth of weathering;
        - The type of orientation of discontinuity features;
        - Material strength on various axes and from various loading;
        - The nature and extent of blast-induced damage to the rock-mass;
        - Water volumes on surface (through stormwater recharge etc.) and underground (through the hydrogeological regime);
        - Heat sources and gradients [in underground workings]; and
        - The potential locations and magnitude of seismic events stemming from various initiators (e.g. mining induced).
    - Data collection (including quality and quantity of data), elements of database interpretation (including the concepts of characterisation,

classification, precision, accuracy, reliability, robustness, uncertainty, and variability);

- ***Through to*** philosophical arguments on hermeneutics, perception bias, and policy analysis.

  These are essential to the discourse because they are often applied in practice, but not articulated in any way – which is in contrast with typical reporting elements for Mineral Resources and Mineral Reserves, Financial and Operating Results, or Environmental and Social Governance. There is guidance on levels of 'data confidence' (Table 1-1) based on data interpretation, and levels of geotechnical effort (Table 1-2), where these concepts and tables are considered further in chapters 4 and 5.

Table 1-1: Suggested levels of geotechnical effort and target levels of data confidence by project stage (Read, 2009c)

Project level status	Conceptual	Pre-Feasibility	Feasibility	Design and Construction	Operations
Geology	>50%	50-70%	65-85%	80-90%	>90%
Structural	>20%	40-50%	45-70%	60-75%	>75%
Hydrogeological	>20%	30-50%	40-65%	60-75%	>75%
Rock mass	>30%	40-65%	60-75%	70-80%	>80%
Geotechnical	>30%	40-60%	50-75%	65-85%	>80%

Several pragmatic obstacles are encountered when deliberating the implementation of Table 1-1, for example:

- There is no existing, adopted, objective measure of data confidence in the various disciplines overseen by mining engineering; and
- If the characteristics of each of the components (e.g. geology, structural, hydrological etc.) are not entirely known in their own respective size, location, orientation, variability, representivity, interaction, total and/or final extent – then denominations are not likely to be known or discernible either. Stated simply, it proves difficult to assure the confidence of 20%, for example, if the 100% metric is not known.

Limited advances regarding methods to quantify the improvement in data confidence exist i.e. the work carried out by Fillion and Hadjigeorgiou (2017) and Fillion (2018).
It is not clear on how fast or pervasive the uptake of the findings have been by industry at large, because no publications by other agencies or individuals demonstrating their

application of Fillion and Hadjigeorgiou's (2017) and Fillion's (2018) work could be found during the preparation of the thesis.

Additionally, it is relevant to stress that mining operations are *not compelled* by any mechanism (law, regulation, code or rule) to determine the best arrangement of data quantity and quality for their operation[1].

The subject matter develops further in that, specifically for the South African context:

- Law, regulations, codes and/or rules do not prescribe any minimum safety factor (FS) and/or probability of failure (PoF) at this point in time,
    - That must be adhered to for geotechnical designs at mining operations, or
    - That must be evidenced against the data required to
- Mining operations are not compelled to:
    - To report on the FS-PoF that they have engaged[1], or
    - Release a periodic statement by the competent person[1] that
        - The extent and use of the data is correct and appropriate,
        - The design planned is appropriate, and/or
        - The planned design is achieved and performing as anticipated.

[1] The reader is reminded that the context of the discussion *throughout the entire thesis document*, is directed toward mining **excavations in hard rock**. Other mining elements are excluded from the explanations (e.g. tailings storage facilities (TSFs), waste rock dumps (WRDs) etc. However, to facilitate literary clarity and as not to overwhelm the prose with very long, repetitive sentences – the simplified phrase "mining operation" has been used throughout.

Table 1-2: Suggested levels of geotechnical effort and target levels of data confidence by project stage (Read, 2009c)

Geotechnical level status	Project stage				
	Conceptual	Pre-feasibility	Feasibility	Design and Construction	Operations
	Level	Level 2	Level 3	Level 4	Level 5
Geological model	Regional literature; advanced exploration mapping and core logging; database established; initial country rock model	Mine scale outcrop mapping and core logging, enhancement of geological database; initial 3D geological model	Infill drilling and mapping, further enhancement of geological database and 3D model	Targeted drilling and mapping; refinement of geological database and 3D model	Ongoing pit mapping and drilling; further refinement of geological database and 3D model
Structural model (major features)	Aerial photos and initial ground proofing	Mine scale outcrop mapping: targeted oriented drilling; initial structural model	Trench mapping; infill-oriented drilling; 3D structural model	Refined interpretation of 3D structural model	Structural mapping on all pit benches; further refinement of 3D model
Structural model (fabric)	Regional outcrop mapping	Mine scale outcrop mapping; targeted oriented drilling; database established initial stereographic assessment of fabric data; initial structural domains established	Infill trench mapping and oriented drilling; enhancement of database; advanced stereographic assessment of fabric data; confirmation of structural domains	Refined interpretation of fabric data and structural domains	Structural mapping on all pit benches; further refinement of fabric data and structural domains
Hydrogeological model	Regional groundwater survey	Mine scale airlift, pumping and packer testing to establish initial hydrogeological parameters; initial hydrogeological database and model established	Targeted pumping and airlift testing; piezometer installation; enhancement of hydrogeological database and 3D model; initial assessment of depressurisation and dewatering requirements	Installation of piezometers and & dewatering wells; refinement of hydrogeological database, 3D models, depressurisation and dewatering requirements	Ongoing management of piezometer and dewatering well network; continued refinement of hydrogeological database and 3D model
Intact rock strength	Literature values supplemented by index tests on core from geological drilling	Index and laboratory testing on samples selected from targeted mine scale drilling; database established; initial assessment of lithological domains	Targeted drilling and detailed sampling and laboratory testing; enhancement of database; detailed assessment and establishment of geotechnical units for 3D geotechnical model	Infill drilling, sampling and laboratory testing; refinement of database and 3D geotechnical model	Ongoing maintenance of database and 3D geotechnical model
Strength of structural defects	Literature values supplemented by index tests on core from geological drilling	Laboratory direct shear tests of saw cut, and defect samples selected from targeted mine scale drill holes and outcrops; database established; assessment of defect strength within initial structural domains	Targeted sampling and laboratory testing; enhancement of database; detailed assessment and establishment of defect strengths within structural domains	Selected sampling and laboratory testing and refinement of database	Ongoing maintenance of database
Geotechnical characterisation	Pertinent regional information: geotechnical assessment of advanced exploration data	Assessment and compilation of initial mine scale geotechnical data; preparation of initial geotechnical database and 3D model	Ongoing assessment and compilation of all new mine scale geotechnical data; enhancement of geotechnical database and 3D model	Refinement of geotechnical database and 3D model	Ongoing maintenance of geotechnical database and 3D model

A prominent paradox put forward by the candidate in the thesis, is that:

- There are many different rock mechanics and geotechnical engineering case studies and interpretations available (in the form of publications, journal articles, conference proceedings etc.),
- However, despite the extensive body of publications showing outcomes of design interpretations and intentions etc. ***primary data is not typically disclosed,*** i.e.:
    - Through access to the *actual* databases to accompany the publication.
    - Such items would show
        - Some variation of the ***actual*** drill logs, structural measurements from within mine workings, rock strengths from laboratory testing programmes, etc.,
        - A statistical analysis of the data parameters (number of data points, minimum value, mean value, maximum value, standard deviation etc.).
        - The evolution of the databases over time.
- Similarly, routine records showing ***geomechanical operational performance***[2] of open pit mining slopes or underground workings in South Africa are not readily disclosed during routine operation.

Therefore, there is no national or international consensus, compendium or compilation available –

- Either formally or informally
- Stating the type of data for each discipline (hydrogeology, rock mass, etc.), or
- Stating the quantity of data needed for each of those disciplines,
- For each type of ore deposit occurring
- Each type of mining method used,
- Over the life of mine.

[2] Note to clarify and distinguish '**safety performance**' from '**geomechanical / geotechnical** performance':
It is recognised that safety performance is reported on an annual basis by the Department of Mineral Resource and Energy (DMRE), Mine Health and Safety Inspectorate (MHSI). The metric for reporting of safety performance is provided through the number of fatalities in mining each year. This is a very important metric.

The nuance relating **geomechanical / geotechnical performance** intends to specify that performance specifically to the rock, rock mass and excavation. Such performance would offer insight into targets intended and results achieved for elements such as slope angles (for surface mines), mining depths, rock and ground conditions, deformation and/or failure of mine excavation design (even if there are no injuries encountered).
The aim is to have objective, factual, evidenced records of the rock-related performance of all mines (not only large, deep, or listed operations), over their life.

Consequently, the concept of ‘confidence level’ transitions from ‘*inferred observations from an evidential basis’* to ‘*subjective individual opinion’*. This transition is contrary to the intention and the spirit of the Mineral Reporting frameworks currently in place (e.g. the South African Mineral Reporting Codes, the SAMCODES).

Related to closely to this, is the incongruity between confidence level of the data of each of the disciplines in their natural state (hydrogeology, rock mass etc.) – and the performance achieved by the mining operation as a role in ensuring that the ‘mined state’ meets the modelled criteria.
In simple terms, we understand the natural state of the rock mass, and we have a reasonably good understanding of the rock mass response to mining – *when the activities (e.g. blasting, dewatering, etc.) are carried out according to known performance achievements*. If the execution of the mining activities deviates from the parameters incorporated into computational models, then the assessment of confidence and *inter alia*, of the stability of the workings, is incorrect. The outcome may be unfavourable if the performance realised does not meet the parameters incorporated (various examples include: where dewatering rates are not achieved in the timelines specified; where excessive back break from blasting occurs that may, through various potential mechanisms, eventually result in deformation or instability of slope walls). Hence, stability performance of the mine working is also important toward assurance of geotechnical stability, over and above the confidence in data of the rock mass in its natural state during precursory studies.

The candidate does not intend to specify that the data collection for related parameters (hydrogeology, rock mass, etc.) must be wholly exhaustive, but rather that **the status and description of the existing data collection** must be included in reporting, as must the geotechnical performance (i.e. not production and grade, but geotechnical performance and stability of the workings).

A pragmatic motivation for the proposed, improved reporting framework includes the fact that the mine workings themselves (i.e. the open pit or underground workings formed by the removal of hard rock) – and their ongoing geotechnical stability – are the most fundamental aspect of being able to win ore for processing and sale. If an instability occurs, resulting in sufficient deformation to a pertinent component of the workings, then the operation may potentially be forced to stop, indefinitely. Contrary to popular opinion, the author asserts that the event does not *strictly* need to be a *global* geotechnical failure – because a relatively localised disruption to a vital location in the workings has the potential to affect the operation (e.g. a crucial switchback is buried in an open pit; or the access shaft becomes blocked). The following examples demonstrate the nuance in the variability of the practical elements that could arise due

the intricacy and combination of contributing factors, and which could theoretically reach extreme endings:

- There may be insufficient funding to be able to conduct any remediation and/or rehabilitation [e.g. operations with tighter economic margins].
- The extent of remediation and/or rehabilitation required may appear disproportionate (i.e. funding is available, but the work will cost more than what is expected to be earned from recovery of the available Mineral Resources Mineral Reserves thereafter, considering current metal price forecasts).
- The pressure of decreasing commodity prices against increasing inflationary costs may generate significant uncertainty or doubt, that carrying out the remediation and/or rehabilitation will create value in the longer term.
- The duration of the disruption to mining, development and/or production while remediation and/or rehabilitation is being carried out, may cause a mining operator to experience a disruption to revenue that may further lead to business implications (e.g. contractual failures, defaulting on loan repayments, etc.).
- Even if a substantial Mineral Reserve was declared during project assessment, but the geotechnical workings are persistently unstable during operations (where critical equipment, and/or infrastructure are consequently damaged through rock fall, rockbursts, etc.; working conditions are unsafe; injuries, and/or fatalities occur greater than the threshold tolerated), then it is highly unlikely that the operation will be able or allowed to continue (e.g. due to company policy and regulatory authorisations, respectively).

A key element of the theoretical examples is that they are not experienced uniformly by each and every mining operation, and the response is not uniform – but the current reporting norms do not provide us with any insight to the geotechnical performance or the failure of geotechnical performance.
It is *not* the case that just because the other components are reported (production, revenue, social), geotechnical performance should be reported too. Rather, it is because all of the other are *dependent* on the geotechnical performance of the operation.

Alternatively, because we do not have insight into the [amount and type] of geotechnical data that has been used historically to develop the mines currently operating, or how well they are able to operate based on the extent of geotechnical data that they do have, we are at a deficit in understanding how much data we are likely to need for a future operation (based on similar elements e.g. mining method, geological complexity etc.) and we are missing opportunities to identify new potential mining projects that may be viable. Coupled with that, is the fact that where a mining company listed on the Johannesburg Stock Exchange (JSE) owns more than one

mining operation in South Africa, they are not strictly obligated to preserve any one operation over the others – as is contextualised and explained in chapter 5.

One of the outcomes of this combination is that the general public, stakeholders, shareholders, regulatory authorities etc. have to rely on mining companies annual reporting – which largely reiterates policy intentions of striving for positive business outcomes. The approach, therefore:

- Does not support informed understanding (e.g. there is a blind assumption that that the worked ground conditions are stable and unproblematic at all times, throughout all [spatial] areas of the operations - until a global failure reported retrospectively, with some element of 'surprise').
- Does not aid in the formulation of appropriate root-cause research formulation, contrasts with the occurrence of fatalities in the South African mining industry (e.g. theoretically, a well-understood rock mass, with an appropriate ground control strategy and mature mining procedures should not result in the persistent fatality rates observed from fall of ground incidents. Given that the industry understands the mechanisms of rockbursts, and that mining personnel are trained toward the preservation of life –therefore, externally, it appears that there is an unidentified disconnect that is not being adequately addressed).
- Does not support regional insights for common aspects (e.g. groundwater levels, surface subsidence due to proximity of unrelated operations [i.e. different operators or mining rights holders]).

The research therefore investigates and describes the elements, opportunities, subtleties and potential pitfalls that exist in the mining rock mechanics and geotechnical reporting practices of hard rock mining. These are used to create a narrative toward more transparent and relevant reporting regarding mining operations in South Africa.

The research culminates in the proposition for voluntary disclosure and a reporting framework that relates geotechnical data, uncertainty, and materiality for the benefit of value creation and risk management.

1.4.2 Research background

The concept for the research was borne out of real-world observations, over a period of time, regarding various mining geotechnical studies undertaken for different mining companies.

It was observed that “various, but inconsistent approaches” were followed in aspects such as data collection, data handling, data processing, design criteria selection, the basis of decision-making, computational analysis, and interpretation.

The approaches observed were not necessarily incorrect – but they were inconsistent, and they appeared to surpass being “just variations” or “personal preferences” of a common element. Attempts to resolve the inconsistencies by considering them under a paradigm of ‘customisation’ did not produce satisfactory relief. Simultaneously, and with maturing experience from greater exposure to the mining industry as a whole, the topics of uncertainty and confidence moved to the fore, but the vocabulary to describe these concepts during reporting does not seem to have developed with the same rate when transposed from the pure science to application in engineering.

The driving force to undertake the research was found through the confusion and contrast of reading volumes upon volumes of the eventual reporting carried out by mining companies of their operations, that ultimately include very little (if any) insight into the detail or the performance of the actual mining works that yield the production tonnages and mineral ounces reported so intricately.

It was then conceptualised that the formulation of an improved reporting framework – using existing and known elements [rather than creating a new, standalone framework] – may facilitate increased reliability as well as an improved, transparent reporting of material elements relating to the mine workings of South African hard rock operations.

1.5 Purpose of the study

The purpose of the study is to advance the knowledge and discourse in the subject of mining engineering. To this end, the practical formulation of the research is carried out by identifying a 'problem' and describing it in the form of a 'problem statement'. After which, and by applying appropriate research methods to the problem statement, solutions are devised, and where appropriate, recommendations are made for future research.

The problem statement for the study comprises of five elements, and these are introduced in the list below. Each of the five elements then explained in greater detail in sub-sections 0 to 0. Thereafter, the justification, objectives, approach, and methods to achieve the purpose of the study are presented in the sub-sections 1.6 to 1.10.

The five elements of problem statement have been formulated in the specific South African context of fundamental rights, democracy, legalisation, regulation, and mining governance, and are introduced as:

1) There is currently no comprehensive hard rock mining, geotechnical database available to correlate the number and type of data points used to generate and maintain a mine design [open pit or underground workings].
2) A wide body of technical information exists giving various options toward carrying out the activities belonging to- and associated with- rock mechanics and geotechnical engineering but the selection, application, extent of implementation, or evolution of options are seldom reported outside of the mining company.
3) The interpretation and application of concepts such as uncertainty, hazard and risk assessment, as well as risk management are tremendously inconsistent within and between different mining operations and/or projects.
4) The content and clarity of reporting of mining geotechnical studies is sometimes highly variable.
5) There is no obligation for mining companies to make information available regarding the stability performance related to mining geotechnics through the normal life of the operation [i.e. the excavation itself - the open pit or underground workings]. The information regarding the mining operation is focussed toward financial, production, and social governance.

A detailed explanation for each of these is presented in sub-sections 0 to 0 below.

1.5.1 No comprehensive database readily available

There is currently no national inventory of mining geotechnical data (viz. a comprehensive or extensive database), for the range of mineralisation settings that occur in South Africa, showing the number and type of data used as the basis to achieve corresponding, hard rock, mining geotechnical designs.

Therefore, mining companies have to compose and undertake individual studies on an *as-needed* basis to determine parameters independently. This is not an optimal situation in many aspects, including but not limited to, finance, time, disruption, suitability and/or competency of available service providers or personnel.

The crux of the intended application of a comprehensive mining geotechnical database would include, *inter alia*:

- To facilitate like-with-like comparisons for each nuance relevant to an operation.
- To facilitate improvement in the granularity of understanding with regard to specific mining geotechnical data and it uses and limitations, beyond the current *status quo*.

This is juxtaposed with the hypothetical example where a copper mine ‘A’ bases their mine design and stability assessment models on copper mine ‘B’, despite that the regional structural fabric differ, the extent of groundwater may differ, the extent of weathering of the rock mass differs. However, for lack of a more suitable alternative, an ideology of “I’m a copper mine – you’re a copper mine – we are the same” is applied and inadvertently creates a ‘false equivalence’. A mining geotechnical design developed on data that does not correspond to the actual mine setting could potentially be inappropriate, and therefore unstable. The realisation of an instability event could potentially result in undesirable incidents such as economic loss, and/or harm to persons.

1.5.2 Wide body of diverse information toward common activities

Simultaneously, a wide body of information exists toward common activities e.g. the logging of drill core - and while there are often common elements amongst methods, there are also nuanced differences. It has been observed that the current trends in reporting are to exclude information used as the basis of assumptions.

Consequently, this may to contribute to the derivation of incorrect assumptions, the allocation of certainty or confidence that is not true to the situation, and may impede the assessment of the activity outcomes if the reporting does not reflect all of the necessary information (e.g. it is difficult to confirm that the application was suited to the context if the description of the components is incomplete).

1.5.3 Variable interpretation and application of concepts

The interpretation and application of concepts are tremendously inconsistent within and between different mining operations and/or projects.

Rock mechanics and geotechnical engineers are required to have a robust knowledge and skill over a wide number of topics. Whereas mining engineering disciplines are well-established, practical subjects that use quantified and tangible inputs, the topics of uncertainty and confidence have only moved to the fore in recent times. As such, formal education or learning has not always been possible for the new developments in related sciences. It is perceived that rock mechanics and geotechnical engineering practitioners have diligently attempted to adapt by incorporating the new and abstract concepts – through their own interpretation and understanding, which is not always aligned with those concepts in their true form. Furthermore, within an organisation, the nomenclature, understanding and application of concepts may differ tremendously when applied to the project, however, when the project is reported – the differences are not identified and are inadvertently likened with each other without any assessment their of similarity.

The difference in conceptual understanding also extends to practitioners' views on wider topics - such as the ownership of earth-science data, and the purpose, content and duty to report ***geotechnical elements***, required under mineral reporting codes (e.g. the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves, the SAMREC Code). Examples of known misconceptions held by practitioners in the field of mining engineering include:

- That *all* data originating from a mine is *unilaterally* owned by the mine, and
- That all mines are required to report under the SAMREC Code.

1.5.4 Reporting content and clarity is highly variable

Mining geotechnical undertakings vary in scope, intensity, purpose and longevity – therefore, the reporting of those undertakings should reflect sufficient clarity of the relevant elements to such an extent, that an unrelated practitioner could use the report and continue to engage on a project without needing to converse with the author of the report. It has been observed that mining geotechnical reporting often does not provide an infallible record of the undertaking, and the gaps in the record may potentially impede future development or require additional, unplanned investigations to bridge the gaps.

1.5.5 No obligation to routinely report specific technical information

The current reporting regime for companies in South Africa does not require mining companies that are not listed on a stock exchange to provide *any* information regarding their mining operations to the public. A limited extent of annual reporting (viz. financial) is carried out from the unlisted company to the Companies and Intellectual Property Commission (CIPC) of South Africa.
Mining companies that are listed on a stock exchange also report to the CIPC but are also required to provide information regarding Mineral Resource and Mineral Reserve estimations and classifications, as well as financial aspects of the company. In recent years, the incorporation of social governance has resulted in an additional line of reporting. Therefore, the information regarding the mining operation is focussed toward financial, production, and social governance.

It is acknowledged that mining operations do report *safety-related* information and statistics originating within their operation, to the Department of Mineral Resources and Energy (DMRE) Mine Health and Safety Inspectorate (MHSI). The information includes the numbers of injuries and fatalities encountered by the respective mining operation and is typically tolerated as a monthly interval of submission.
The DMRE MHSI then prepares to report these numbers on an *annual* basis.
In preparation of the annual reporting, the numbers of incidents are aggregated (by region and commodity – to match the organisational divisions of the inspectorate) and eventually reported as *overall performance* by mines for the year.
However, the candidate intends a subtle - but important - distinction for the context of the study. Therefore, the following points emphasize the distinction and relevance to the overall study:

- The performance reported by the mines is made to the *Inspectorate – not to the public*.
- The reporting into the DMR MHSI is [approximately] *monthly*, but the reporting cycle out of the DMR MHSI is *annually*. The DMR does not maintain the publication of *monthly* statistics.
- The annual reporting of the numbers by the DMR MHSI, is *aggregated* – it is *not per individual mining operation,*
- Typically, the individual operations are *not identified or identifiable* from the report[3].
- The statistics reported by the mines are more commonly linked to *behavioural incidents* (e.g. injuries occurred during a certain type of activity). The statistics *are not* linked to *particular rock descriptions or rock engineering conditions* [as

[3] There are limited circumstances where an operation is named in relation to a safety event during the DMRE MHSI reporting. One such circumstances is when reporting a mining disaster with multiple fatalities.

relevant - for rockburst, rockfalls etc.]. An example using a hypothetical situation is offered to facilitate comprehensive explanation:

- Hypothetically, a rockfall occurred underground and debris struck ten mine workers, resulting in moderate injuries and time needed for medical intervention. The event is noted and reported as such.
- However, the designed safety factor and/or probability of failure determined by the engineer for the particular area where the [hypothetical] incident occurred, concluded that no rockfalls would occur at all.
- Hence, the existing reporting framework gives us insight into the ***outcome*** of the rockfall [injuries], but not into the rock-related ***driving factors*** for the particular event[4].
    - What were the ground conditions experienced in reality? (with specific detail on the relevant elements, rock type, strength, blast damage, dewatering, orientation of relevant features (bedding planes, lithological contacts, structural discontinuities and orientation of excavation feature e.g. drive etc.).
    - How do these differ to the ground conditions modelled?
    - Are there more areas within the mine workings that have similar ground conditions in reality [as those that led to the rockfall]?
    - Do the additional areas also predict zero events of rockfall?

Hence, the reporting of the number of injuries and fatalities is distinctly different from the technical information regarding design expectation [zero failures] and excavation performance [failure occurred].

Limited instances have occurred historically where the relevant entirety of geotechnical information (as well as relevant commentary regarding the preparation of appropriate records / documentation) is presented. These have been following from, and during the subsequent reporting of a mining disaster and/or inquest investigation.

As such, it is asserted that there is no obligation to state the attributes (e.g. pit depth, slope angle in the case of open pits) or ***geomechanical*** performance (e.g. a growing zone of influence in the case underground) of mine works as the mining operation through its life, as it matures.

[4] The further emphasis is on the ***particularity of the individual event***, instead of assigning a ***vague and generic*** list of possible theoretical causes.

1.6 Justification for research

Every aspect of the mining operation is, *at its root,* dependant on the rock, geomechanical and geotechnical integrity of the excavation.

Mining would not be able to continue to take place if the excavated workings in the rock mass cannot be maintained and kept open - even if metallurgical and/or mineral processing can produce excellent recoveries.

Stability of the excavation is absolutely essential for mining operations to continue.

A slope failure in a surface mining operation or a collapse in an underground excavation could potentially terminate access - in part or in whole. The timing and/or the duration of the disruption to access may eventually lead to *force majeure* – and even if the operation is sold or divested, the cost to restore the workings would not be considered attractive by potential buyers.

The research is therefore justified because the outcomes contribute to a universal application of understanding and benchmarking in aspects of hard rock mining.
The potential for cost savings, planning optimisation, and refining the rock engineering geotechnical systems - or any combination of these – as a result, will be beneficial to users of the information.
Additionally, the reporting framework will facilitate an improved level of transparency that will support informed decision-making, record material facts regarding maturation of the mining operation, offer objective information to shareholders [of listed companies], facilitate improved regulatory oversight, contribute improved understanding of the environment for closure and post-closure, and may potentially offer some extent of protection (against claims, damage to reputation and remediation costs) in the event of illegal interference with the mining operation by persons not associated with the mining right.

The research is further justified by the recognition that assessments into 'the safety, design, risk, failure, and consequence' of geomechanical / geotechnical instability are typically premised on a generalised approach. It is quite uncommon to find that the risk-considerations [regarding geomechanical / geotechnical stability] are separated into respective layers ***and reported across all the layers <u>simultaneously</u>*** *e.g.:*

- Physical safety of personnel at the mining face;
- Physical safety of employees nearby [elsewhere on the compound, in near proximity];
- Physical safety of members of society, infrastructure and environment; and

- Preservation of the integrity of the excavation [i.e. keeping the excavation open] to ensure longevity of the operation and enable the full potential of the associated business case to be realised in the long-term.

The nuance, objectives and specificities of relevant codifications must properly understood and applied to give meaning to the reporting undertaken in the mining industry as a whole. For example:

- The main objectives of the Mine Health and Safety Act, 1996 relate to securing the *physical safety* of workers in the mine. The main objective is *not* to ensure that the mining excavation stays open to be able to meet obligations to shareholders from expected production.
- The annual reporting by the Department of Mineral Resources and Energy (DMRE) Mine Health and Safety Inspectorate (MHSI) shows the number of fatalities and related safety information. It does not guarantee the performance of the mining excavation
- The objectives of the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (the SAMREC Code) is to ensure that potential investors are not misled by statements (e.g. overestimations not supported by appropriate data and calculation methods). The SAMREC Code does not state the limits of acceptability, and it does not 'police the implementation' of ongoing geomechanical / geotechnical maintenance to ensure that the excavation is stable for the entire life of mine.

Consequently, there needs to be an appropriate mechanism to allow navigation of the truest technical elements (e.g. mechanical nature of the rock and its strength properties (stress, strain, compressive, tensile, shear, uniaxial, and triaxial), deformation potential, response to mining, seismicity, etc.) to the greatest extent possible for all potential stakeholders (current and future). The mechanism must not compromise the mining operation.

1.7 Research objectives

The research objectives are comprised of three, complimentary parts. The three parts, referred to as ‘work packages’ are described in sub-sections 1.7.1 to 1.7.3 below.

1.7.1 Work package 1

Regarding data for rock and geotechnical engineering, the objectives of the research are to:

a) Compile a list of the mining operations and their respective companies.
b) Confirm the types of ore bodies for the mining operations.
c) Compile the specifications of the mining excavations for each operation (e.g. open pit slope angles, ramp angles, batter angles, depth, etc. and underground development dimensions, orientations of the drives etc., type of support, relevant observations regarding occurrence and intensity of seismicity etc.), including safety factors (FoS) and/or probability of failure (PoF) tolerated in each design.
d) Compile a list of the rock-related incidents and/or accidents, as well as ground deformation indicators and events, grouped based on their ***root cause***.
e) Identify the type of data collected for hard rock mining operations, per level of study,
f) Identify the number of data collected for hard rock mining operations, per level of study.
g) Derive the statistical comparison of the data sets for each operation.
h) Compare the volume of data across the various operations.
i) Determine the typical data profiles used for the various operations based on the findings.
j) Correlate the data profile with the stability performance of the excavation.
k) Prepare and plot relevant graphs to show the relationships over time.
l) Identify what, if any, common traits are shared by the mining companies with similar profiles and/or performance.

1.7.2 Work package 2

Regarding risk assessment in rock and geotechnical engineering projects, the objectives of the research are to:

a) Identify the various methods of risk assessment available.
b) Identify the methods of risk assessment used in rock and geotechnical engineering projects of mining operations.
c) Identify the methods of risk mitigation, response, and management used in rock and geotechnical engineering projects of mining operations.
d) Compile an inventory matching the mining operation, company and risk-methodologies used, as well as their risk mitigation, response, and management.

e) Identify the types of competence and accreditation recognised by the regulatory environment.
f) Identify the regulatory requirements that connect risk assessment and risk management to mining rock engineering, geomechanics and geotechnical engineering aspects.
g) Identify which, if any, of the mining operations do not meet the minimum regulatory requirements for risk assessment and risk management.
h) Investigate the relationship between stability performance of the excavation over time, with the “non-compliance to regulatory requirements for risk assessment and risk management”.
i) Quantify and profile the financial performance over time of the “non-compliant companies”.
j) Investigate the relationship between financial performance over time with “non-compliance to regulatory requirements for risk assessment and risk management”.
k) Investigate what, if any, common traits are shared by the mining companies with similar risk -assessment, -mitigation, -response, and -management profiles.
l) Identify which specific technical qualifications and/or accreditations show evidenced superiority with regard to work undertaken toward risk -assessment, -mitigation, -response, and -management (grouped by qualification and/or accreditation).

1.7.3 Work package 3

Develop a framework for integrated reporting by:

a) Integrate the findings from work package 1 and 2.
b) Identify which (if any) comparable or adaptable reporting frameworks existing in related sectors of engineering, the built environment, the greater mineral extractive industry, and mining.
c) Composing the reporting framework by:
    i) Incorporating appropriate principles and elements from any existing comparable or adaptable reporting frameworks (in the step above), and
    ii) Developing appropriate new and novel content to complete the reporting framework.

1.8 Research approach

The thesis demonstrates the breadth, range, variation, and diversity of information that is relevant to rock engineering, geomechanics and geotechnical engineering in mining operations. The diversity of information is evident in the variety of aspects such as:

- Commodity;
- Region / country;
- Application of technical principles, conventions, and options;
- Technology use and technological advancement;
- Inter-dependency and co-dependency with other disciplines;
- Applications in and by the business enterprise; as well as
- The eventual reporting of relevant technical[5] aspects.

These aspects are then viewed in context of the current approach to reporting from mining operations – which relies very heavily on Mineral Resource-Mineral Reserve, production statistics and corporate-social responsibility – to the point that very limited *factual* data is readily available:

- *From* the specific data elements collected and used by rock engineering, geomechanics and geotechnical engineering disciplines; and
- *About* the [open pit or underground mine] excavation made from the data;
- Presented on a year-by-year basis, for the full life of the mining operation.

To demonstrate the variability and interconnectivity (and therefore vulnerability) of the interrelated elements, the literature review intentionally begins at a low impact introduction and increases momentum and complexity, toward the ultimate discourse.

Furthermore, the approach develops the recognition that:

- The inputs to the rock engineering, geomechanics, and geotechnical engineering function are almost innumerable.
- Interrelated elements may differ along every step of the way from conceptual design to mining production.
- The current approach to reporting of mining operations is disproportionate in terms of the type, format, extent, and frequency of “rock-related” aspects and performance, especially when compared to reporting that deals with Mineral Resources and Mineral Reserves.
- A more balanced and proportionate reporting approach is reasonable and beneficial.

The role of education, research, and technical skills are also be mentioned - and there relevance to the overall discourse is explained in chapters 5 and 6.

[5] viz. rock engineering, geomechanics and geotechnical engineering in mining operations

1.9 Research methods

The research made use of both qualitative and quantitative methods.

1.9.1 Qualitative research

The research used qualitative research tools, including close reading and classification to hermeneutic, narrative, and discourse analysis as well as aetiological investigation.

Qualitative processes included both deductive and inductive reasoning with an extensive content analysis over a vast volume of material. The investigative and systematic nature of the qualitative approach is *highly re-iterative* to facilitate the association and categorisation of data. The process then transitioned to the identification and interpretation of trends and/or patterns from the data.

As such, the qualitative components were readily drawn from case study research, record reviews, document study, observational process, and checklists. Additionally, the candidate has – during the course of their professional interest, development, and employment – conducted a number of interviews, and discussions, from which information and understanding was built.

1.9.2 Quantitative research

Various tools had been prepared for the intended qualitative analysis of extracted data.

The research intended to use normative statistical methods to describe, process and characterise different types of data (e.g. through descriptive statistical methods, counter and correlation). Subsequently, the quantitative approach was intended to describe and provide a summary the main characteristics of the data (e.g. mean, mode, median, range, standard deviation, central tendency, variability, and distribution). The process allows the identification of patterns as well as insight into the relationship of the data.

Although the research intended qualitative and quantitative approaches ***in nearly equal proportions*** - limitations that manifested during the research (regarding the very limited availability of continuous, quantitative data that could be made known to the public) had the effect of reducing the extent of the quantitative approach applied. However, this feature in itself is considered a relevant finding, explained in chapter 6, as it reflects the elements of the research context and problem statements in chapter 1.

1.10 Contribution to knowledge

The research has produced the following contributions to knowledge:

1) Demonstration that it was not possible to compile a national inventory of geotechnical information (viz. a comprehensive database) from hard rock mining operations in South Africa using publications in the public domain alone.
    a. The current circumstances are that the technical data is held privately by the various mining organisations.
    b. There is, however, scope within the application of the Geoscience Act 100 of 1993 to create an avenue for controlled, voluntary disclosure of pertinent rock engineering, geomechanics and geotechnical engineering data from mining operations.
    c. Mining organisations could potentially use the opportunity (of voluntary disclosure) to improve their perceived value, risk management, governance, technical credibility, and sustainability.

2) A proposition for the voluntary disclosure of relevant technical data and performance relating to geomechanical, geotechnical and rock engineering aspects, through an integrated reporting framework.
    a. The principles that the proposition is based on, align with various initiatives toward sustainability and governance emerging in contemporary mining industries.
    b. The initiative is intended to improve value creation and risk management in mining operations throughout the industry, at the tactical, operational, and strategic levels.
    c. Demonstration of the need for improved technical reporting, and conceptualisation of its subsequent contribution to value-creation (including technical longevity, governance, financial, national advancement and potential for improved investor confidence).

3) Identification and demonstration that the existing Mandatory Codes of Practice in South Africa for slope stability, rockfall and rockburst (in mines other than coal), do not demonstrate the required conformance to the relevant legislative framework.
    a. The implication, stemming from legal precedent, is that the codes are invalid, and mining organisations cannot legally be held to them.
    b. Subsequently, recommendations for improvements have been identified.

4) Identification and demonstration that selected (but not all) rock-related certificates of competency, as well as modules toward qualification, do not demonstrate the required conformance to the respective regulatory frameworks.
    a. The interpretation is that:
        i. Selected modules are not accredited
        ii. Specific competency certificates are not accredited
        iii. A number of practitioners, despite holding the particular certificate, therefore do not conform to the requirements for competency as laid out in the respective regulatory frameworks.
    b. Subsequently, recommendations for improvements have been identified.

5) Identification and demonstration that selected (but not all) Mines Rescue Services training and assessment, does not demonstrate entirety of the required conformance to the respective regulatory frameworks.
    a. The interpretation is that:
        i. The emergency response services required by law in South Africa, and
        ii. The services offered by volunteers does not entirely meet the training requirements for competency as laid out in the respective regulatory frameworks.
    b. Subsequently, opportunities for improvements have been identified.

6) A description of various practical shortcomings of the South African Mines Reportable Accidents Statistics System (SAMRASS) in its current form, when considered in the context of the contemporary mining industry. Subsequently, recommendations for improvements have been identified.

7) An extensive (albeit not wholly exhaustive) inventory of codified items that can be applied to various aspects of the rock engineering, geomechanics and geotechnical engineering life cycle in mining operations.

1.11 Concluding remarks for chapter 1

Chapter 1 explained the setup of the thesis document and then described various components regarding the initiation and elements of the research.

The elements included an outline of the context that compelled the candidate to carry out the study, the intentions of the research, the methods used to pursue the objectives, as well as the formulation of statement that expresses the contribution to knowledge realised through the completion of the study.

2 SOURCES OF DATA

2.1 Overview of chapter 2

Chapter 2 identifies the various sources of data used in the research.

Data and information were sought, collected, reviewed, and/or interrogated from a wide and diverse range of sources. It is therefore noted that selected background information about the various *originating bodies* (e.g. research institutions and relevant organisations) is also provided alongside the description of the sources of data, or the description of the data itself (as relevant).

The purpose of including information about the originating body is to enable comparison and understanding of organisational roles and responsibilities within the mining industry and sector. This in turn:

- Emphasises the complex composition of the mining industry, and
- Contrasts the diversity of elements which all have an important role in the rock engineering lifecycle of a mining operation. Examples of the elements include geotechnical design, design performance, technical skill and competency, mine safety, and reporting. These aspects are introduced in the literature review presented in chapter 4, then explored further in chapters 6 and 0.

Figure 2-1 provides an overview of the categories of sources, followed by the description of the respective data sources in sub-sections 2.2 to 2.11.

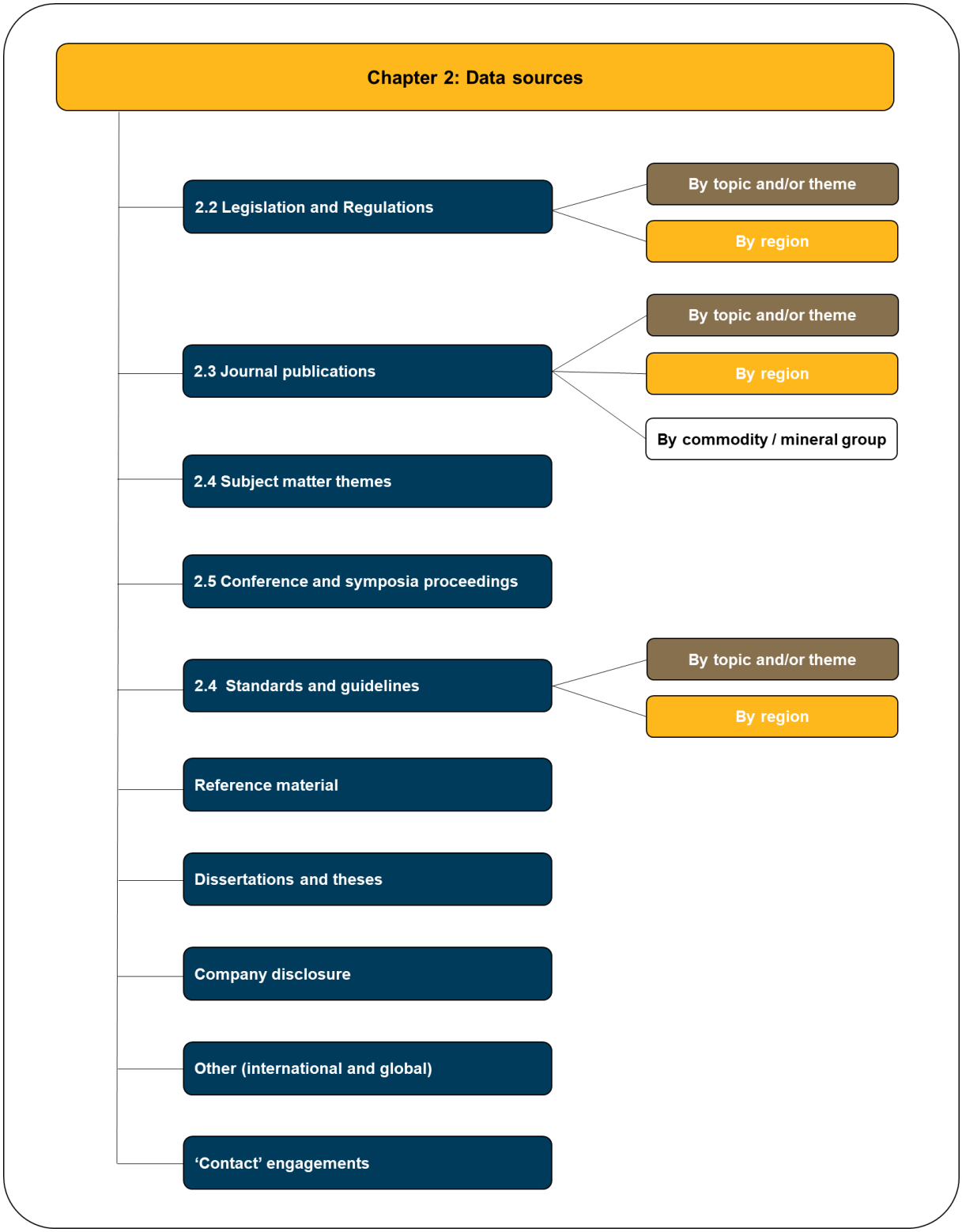


Figure 2-1: Overview of sources of literature and data presented in chapter 2

2.2 Legislation and regulations

Focus was given to South African legislation and regulations, given that the study is based at a South African University. Additionally, court rulings, Gazetted notices, Gazetted Mandatory Codes of Practice, etc. we also considered – and incorporated where relevant.

2.3 Journal publications

Journal publications (often also termed 'journal articles' or 'journal papers') were key sources of data. Journals were pursued by region, for example:

- Individual countries (e.g. South Africa (SA), Australia, Canada, the United States of America (USA) etc.);
- International (i.e. a singular body joining an array of diverse groups); and
- Global (i.e. separate regions throughout the globe).

The identification of regions was informed by reasons such as:

- The study is based at a South African University;
- An international institution has a far reach and benefits from participation of experts around the world;
- Global institutions are focussed on the development of the needs of their mining industry – which may be the same, similar, or different to the South African mining industry (and therefore inform us which solutions may be extrapolatable to South Africa); and
- South Africa, Australia, Canada, the USA are known to have developed mining industries.

Regions such as China, Russia, Kazakhstan, etc. were difficult to include due to challenges in securing texts printed in English.
Academic, scholarly, peer-reviewed, professional journals were prioritised (e.g. over journals that are not peer reviewed).

2.3.1 Special features in formal publication processes or products

Special features in academic and technical publications are outlined as follows:

- **Erratum / errata** are issued by a publisher for a production error (e.g. an error introduced during the publishing process).
- **Corrigendum / corrigenda** are a correction of a published text – to correct an author's error in their own work (i.e. the article / manuscript they submitted to the publisher). An example of a correction is shown in Kumar *et al.* (2018).
- A retraction is the removal [retraction] of an article *in its entirety*. This may be the result where the work has been found to be unreliable (which may be linked

to genuine mistakes during the research process or issues of misconduct etc.). It appears rare that a **retraction** occurs in mining- or rock- engineering related literature.

The purpose of specifically seeking out errata, corrigenda, retractions etc. for inclusion in the thesis include:

- To demonstrate the dynamic elements of the writing- and publishing- cycles.
    - Information reported to the scientific and engineering industries follows a strict process (e.g. plagiarism evaluations, journal peer-review etc.).
    - The strict process often differs from the flexibility and freedoms when sharing information within self-exclusive or incentivised communities (e.g. amongst colleagues, as presentations within professional societies, etc).
- To demonstrate the lifespan of information and knowledge (e.g. by its very nature, a 'retraction' of a published piece brings an end to the material, data, and/or hypothesis that had been initially put forward.
- To ensure clear demonstration of academic research proficiency and methodological rigor.

2.4 Subject matter themes and keywords

Subject-specific material was identified using thematic searches, keywords and combinations thereof via Boolean Operators (for electronic databases), whereas printed material was identified and source by reading the item 'manually'. The searches were applied to all the data sources describe in chapter 2.3 to 2.10. An example of the themes and keywords is shown in chapter 9, Table 9-1.

2.5 Proceedings

Conference and symposia proceedings were pursued by region (as for those regions and explanations given in sub-section 2.3 above), by topic (as for similar themes shown in 2.4) as well as by commodity / mineral group, for example:

- Base Metals, Chrome, Cobalt, Copper, Diamond, Gold, Iron, Lithium, Manganese, Nickel, Platinum Group Metals, Vanadium, Zinc, etc.

2.6 Standards and guidelines

Standards and guidelines were reviewed by theme, for example:

- Geotechnical investigation, Laboratory testing, Risk Management, Uncertainty of measurement, Quality Management, etc.
- Description of rocks, description of soils, geotechnical engineering processes, laboratory testing, occupational health and safety, quality management, risk assessment, risk management, reporting [technical projects], rock engineering processes, site characterisation, slope design, etc.

As well as were by region (as for those regions and explanations given in sub-section 2.3 above), and by topic (as for similar themes shown in 2.4).

2.7 Reference material

Reference material produced by reputable organisations were considered and covered many different forms, including almanacs, bibliographies, bulletins, case books and case studies, catalogues, handbooks, laboratory reports, manuals, monographs[6], reference guides, special publications, technical notes, technical specifications, textbooks, and yearbooks, etc.

2.8 Dissertations and theses

Dissertations and doctoral theses and post-doctoral publications from South African institutions were prioritised, given that the current research is based at a South African University. Additionally, dissertations and doctoral theses and post-doctoral publications from other [global] institutions we also considered – and incorporated where relevant.

It is noted that the perceived credibility (though university rankings / “league tables”) as assessed by various education and/or independent organisations did play some part in the selection of institutions for consideration. More established intuitions and those that perform ‘well’ in Science and Engineering were considered and included, whereas ‘lesser performing’ institutions were not included.
Information regarding the elements of assessment is given by agencies such as the Times Higher Education (2017).

[6] Monographs seem to have previously held more popularity than in recent trends; they are scholarly items of writing [that is essay or book length] on a specific, often limited subject.

2.9 Company disclosures

Full and/or historical company disclosures relating to geotechnical aspects were difficult to find – but were sought, nevertheless. These include disclosures to a Securities Exchange (where relevant), annual reports, other documents associated with the reporting suite [viz. mining company annual reporting], and [mining company] policy documents (e.g. 'Zero Harm' etc.).

The listings of the Johannesburg Stock Exchange (JSE), the Australian Securities Exchange (ASX), the Toronto Stock Exchange (TSX), and the New York Stock Exchange (NYSE) were incorporated into the research, because they have a greater number of mining-related companies listed compared to many of the other Securities Exchanges.

2.10 Other (international and global)

Other sources of data and information were drawn from:

- Government, Intergovernmental reports;
- Publications by parastatal organisations (e.g. the Council for Geoscience);
- Publications by higher education institution research groups;
- Publications by dedicated research bodies (e.g. CSIRO, SIMRAC);
- Publications by Recognised Overseas Professional Organisations (ROPOs);
- Publications by Voluntary Associations;
- Publications by private organisations made in the course of their work (e.g. technical reports, etc.);
- Periodicals and serial publications (e.g. catalogues, etc.);
- Publications by Original Equipment Manufacturers (OEMs);
- Trade publications and media items [that do not constitute advertisements] (e.g. mining-specific magazines, op-ed essays, topic-specific articles);
- Colloquia;
- Forums,
- Indabas;
- Media releases;
- Seminars;
- Summits; and
- Symposia.

2.11 ‘Contact' engagements

In this regard, the candidate also drew from their own professional experience gained during their professional exposure, involvement (intern) and employment. The candidate has led, participated in, and/or assisted in various research and commercial projects (across the spectrum projects for government, parastatal organs, and also for private companies).

2.12 Concluding remarks for chapter 2

Chapter 2 identified the nature of each of the data sources used toward the research, and then outlined the relevance of each source.

Information about the originating body (for information and data) was provided where appropriate and the information:

- Emphatically demonstrated the complex composition of the mining industry, and
- Introduced the juxtaposition of the diverse elements that make up the rock engineering lifecycle of a mining operation.

3 DATA FOR THE STUDY

3.1 Overview of chapter 3

The identification of data ***sources*** from chapter 2 are carried forward and chapter 3 now identifies the particular data ***items*** used in the research.

Figure 3-1 provides an overview of the data items, followed by the description of the items in sub-sections 3.2 to 3.10.

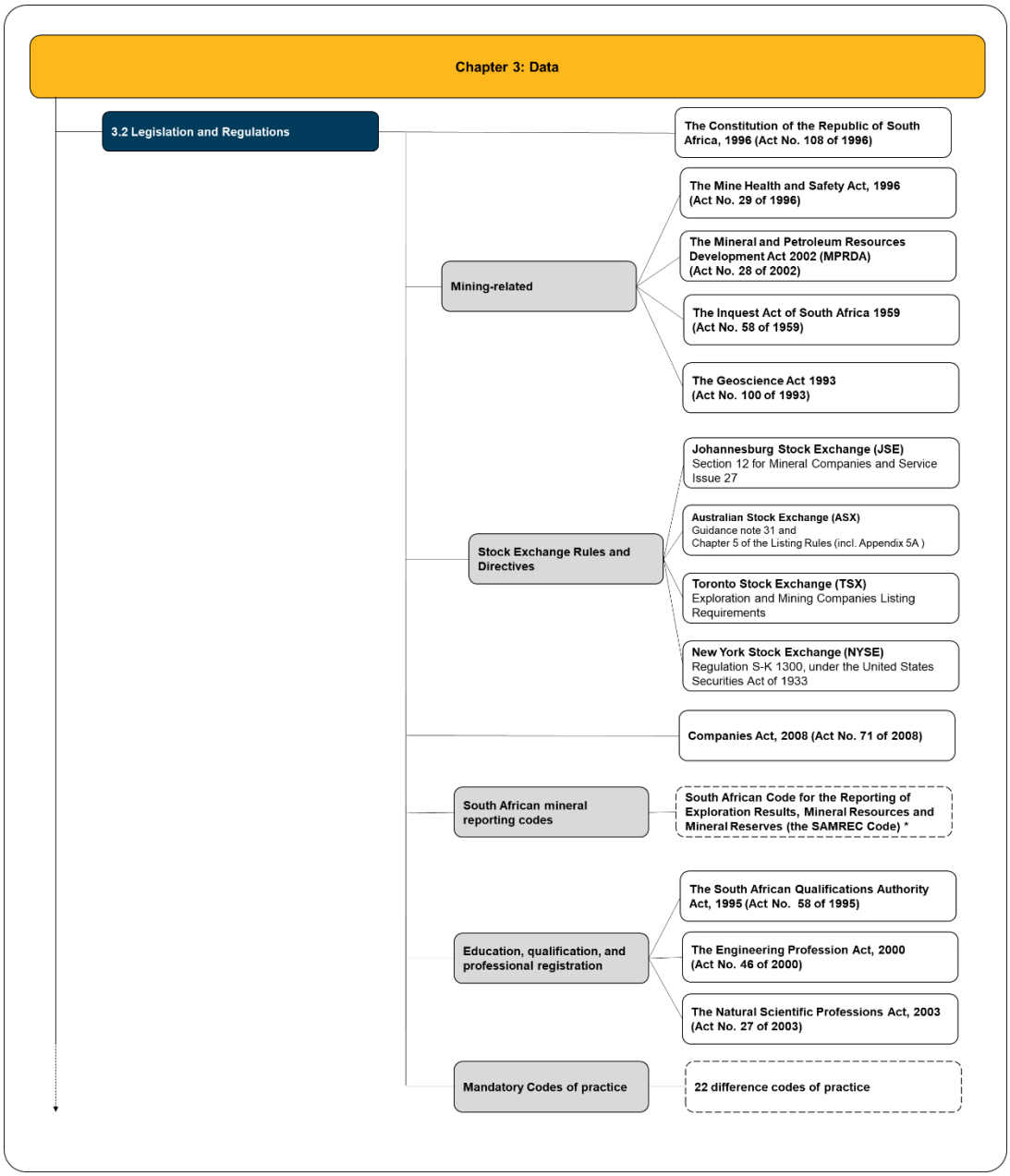


Figure 3-1: Overview of data items included in chapter 3 [7]

[7] There are several additional Reporting elements that apply to the South African Mineral Reporting Codes (SAMCODES) Standards Committee (SSC) (e.g. The South African Code for the Reporting of Mineral Asset Valuation, the SAMVAL Code), however, they are not essential to the context of the current research.

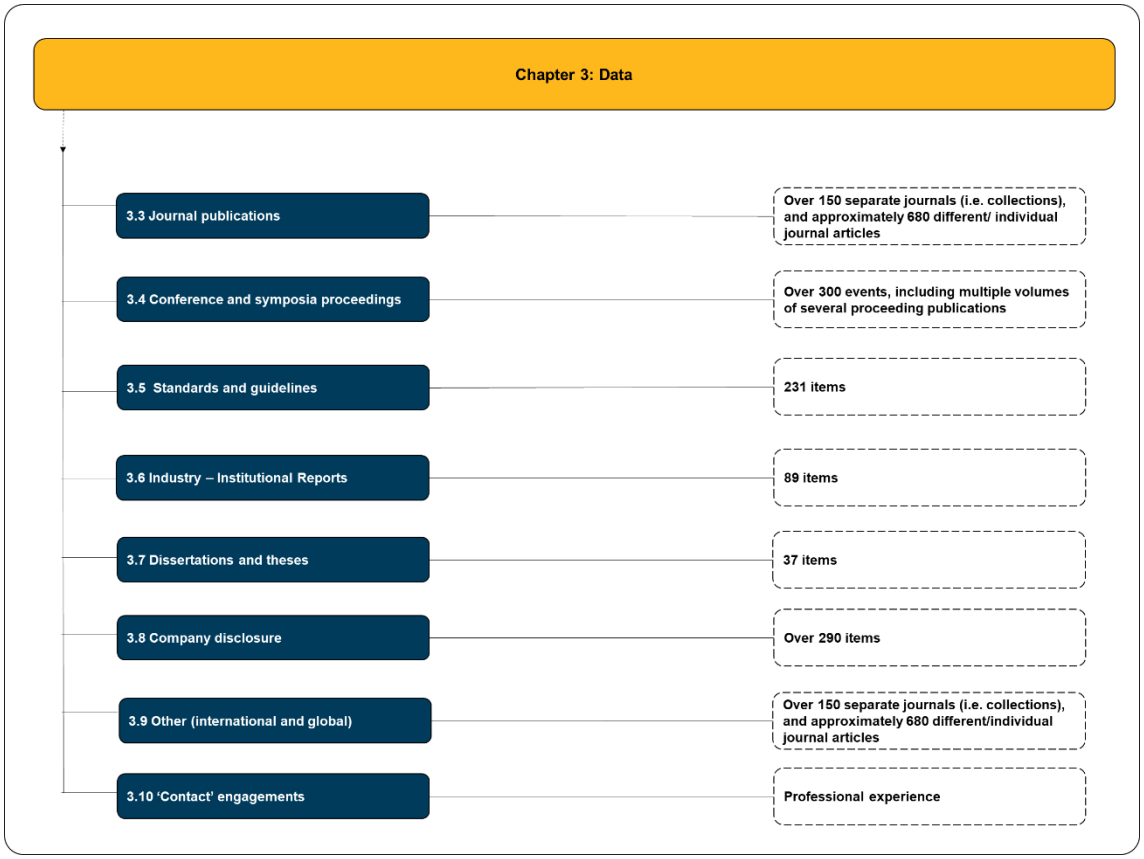


Figure 3-1 (continued): Overview of data items included in chapter 3

3.2 Relevant legislation and regulatory framework

In understanding of the expectations made of a mining, rock and/or geotechnical engineering practitioner, it is useful to have a broad insight into legislative and regulatory landscape. While a detailed account of Mining Legislation and related elements (mineral tenure, environmental management, social and labour development, water use, etc.) is out of the scope of the current research, the key legislative items are summarised below, as they will be challenged in the chapters that follow.

3.2.1 The Constitution of the Republic of South Africa

The Constitution of the Republic of South Africa, 1996 (Act No. 108 of 1996) has largely been celebrated as one of, if not the most, "*progressive constitution in the world*. *This means that it makes provision for, and fortifies, basic human rights which are often seen as privileges in other countries*" (South African Human Rights Commission, 2022).

3.2.2 Selected South African mining legislation

The most pertinent legislation, and their accompanying regulations, applicable to the context of the research, are:

- The Mine Health and Safety Act 1996 (Act No. 29 of 1996);
- The Mineral and Petroleum Resources Development Act 2002 (MPRDA) (Act No. 28 of 2002);
- The Inquest Act of South Africa 1959 (Act No. 58 of 1959); and
- The Geoscience Act 1993 (Act No. 100 of 1993)

with their respective amendments and regulations.

3.2.3 Mandatory codes of practice

Various guidelines for the preparation of mandatory codes of practice have been generated by the Department of Minerals and Energy (DMRE) and relate to both mine safety and mine health. Table 3-1 shows an overview of topics of mandatory code of practice for the department of minerals and energy in South Africa.

Table 3-1: Overview of topics of mandatory code of practice for the Department of Minerals and Energy in South Africa

	Topic of mandatory code of practice
1).	Combat rock fall and rock burst accidents in tabular metalliferous mines
2).	Combat rock fall and slope instability accidents in surface mines
3).	Combat rockfall and rockburst in metalliferous mines and mines other than coal
4).	Combat rockmass failure accidents in massive mining operations
5).	Combat roof fall accidents in underground coal mines
6).	Cyanide management
7).	Management of medical incapacity due to iii-health and injury
8).	Management of self-contained self-rescuers in mines
9).	Management of working in confined spaces at mines
10).	Minimum standards of fitness to perform work on a mine
11).	Mitigation and management of covid-19 outbreak
12).	Occupational health programme (occupational hygiene and medical surveillance) on personal exposure to airborne pollutants
13).	Occupational health programme (occupational hygiene and medical surveillance) on thermal stress
14).	Prevention of flammable gas and coal dust explosions in collieries
15).	Prevention of flammable gas explosions in mines other than coal mines
16).	Provision of personal protective equipment for women in the south african mining industry
17).	Right to refuse dangerous work and leave dangerous working places
18).	Risk-based emergency care on a mine
19).	Risk-based fatigue management at mines
20).	Safe use of conveyor belt installations for the transportation of mineral, material or personnel
21).	Trackless mobile machines
22).	Underground rail bound equipment

3.2.4 Companies

The Companies Act, 2008 (Act No. 71 of 2008) provides for the incorporation, registration, organisation and management of companies, as well as the capitalisation of profit companies in South Africa.

The purpose of including information regarding the setup of companies, is to demonstrate the contrast and support the arguments introduced in chapter 3.10.1.

3.2.5 Stock Exchange Rules and Directives

3.2.5.1 Johannesburg Stock Exchange Rules and Directives

For companies listed/intending to list on the Johannesburg Stock Exchange (JSE), the JSE Rules and Directives are relevant[8], including Section 12 for Mineral Companies and Service Issue 27.

3.2.5.2 Australian Stock Exchange Rules and Directives

For companies listed/intending to list on the Australian Stock Exchange (ASX), Guidance note 31 and Chapter 5 of the Listing Rules, as well as it's Appendix 5A are relevant, and they incorporate the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (the JORC Code).

3.2.5.3 Toronto Stock Exchange Rules and Directives

For companies listed/intending to list on the Toronto Stock Exchange (TSX), the Exploration and Mining Companies Listing Requirements are relevant.

3.2.5.4 New York Stock Exchange Rules and Directives

For companies listed/intending to list on the New York Stock Exchange (NYSE), Regulation S-K 1300, under the United States Securities Act of 1933, is relevant for the initial disclosure as well as for on-going disclosure requirements of mineral assets.

3.2.6 The South African mineral reporting codes

For companies that intend to declare a Mineral Resource, the South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (the SAMREC Code), drawn up by the SAMREC Committee (previously the SAMREC

[8] There are several additional aspects of legislation that apply to the JSE (e.g. the Financial Markets Act, 19 of 2012, and the Financial Intelligence Centre Act, 38 of 2001, as amended), however, they are not essential to the context of the current research.

Working Group) of the South African Mineral Reporting Codes (SAMCODES) Standards Committee (SSC), under the joint auspices of the Southern African Institute of Mining and Metallurgy (SAIMM) and the Geological Society of South Africa (GSSA)[9].

3.2.7 Education, qualification, and professional registration

3.2.7.1 The South African Qualifications Authority Act, 1995

The South African Qualifications Authority Act, 1995 (Act 58 of 1995) provides for the development and implementation of a National Qualifications Framework (NQF) and establishes the South African Qualifications Authority (SAQA) for that purpose.
Formal recognition of the achievement of the required number and range of credits (and any such other requirements) at specific levels of the NQF as may be determined by the relevant bodies that are registered by South African Qualifications Authority.

3.2.7.2 The Engineering Profession Act, 2000

The Engineering Profession Act, 2000 (Act No. 46 of 2000) provides for the registration of professionals and specified categories in the engineering profession through ECSA. Registration as a Professional Engineer (Pr Eng) or Professional Engineering Technician (Pr Eng Techni) is required to be able to sign-off [approve] engineering reports and/or provide expert opinion related thereto.

3.2.7.3 Natural Scientific Professions Act, 2003

The Natural Scientific Professions Act, 2003 (Act No. 27 of 2003) provides for the registration of professionals and specified fields of practice through SACNASP. Registration as a Professional Scientist (Pr Sci Nat) is required to be able to sign-off [approve] relevant reports and/or provide expert opinion related thereto. The variety of sciences has overlap with mining, because earth science, geological science, geospatial science, mathematical science, soil science, statistical science and measurement science fall in the scope of natural science professions.

3.3 Journal publications

Over one hundred and fifty-four different journals, and in the order of six hundred and eighty different journal articles were identified and used for the current research, these are shown in chapter 9, sub-section 9.1, Table 9-2.

[9] There are several additional Reporting elements that apply to the SSC (e.g. The South African Code for the Reporting of Mineral Asset Valuation, the SAMVAL Code), however, they are not essential to the context of the current research.

The particular journal papers used, are cited within the body of text of the thesis (as alongside to the information referred to, with author surnames and year of publication - as per citation norms and rules of academic referencing), as well as shown in the list of references to the thesis (i.e. chapter 8).
The purpose of including the relatively voluminous list is deliberate, and intends to demonstrate and emphasise the *extensive* body of knowledge that is available to industry practitioners (or potentially out of reach, in some cases), as discussed in chapter 1. The body of knowledge is diverse and differs in application, context, scope, and extent of development.

3.4 Proceedings

More than three hundred conferences and symposia were identified and for the current research, these are listed in in chapter 9, sub-section 9.1, Table 9-3.

3.5 Standards and Suggested Methods (SM)

Three main bodies were selected toward the purpose of identifying specific, relevant standards. The bodies are the International Organisation for Standardisation (ISO), the International Society for Rock Mechanics (ISRM) and ASTM International (formerly known as American Society for Testing and Materials, ASTM).
It was not necessary to include the South African Bureau of Standards (SABS) because the 'SABS' range of standards are a regional derivative of the ISO[10].

The complete lists of standards identified are considered too voluminous to be presented in this portion of the document, but are provided in chapter 9, sub-section 9.2. An overview of the data is provided below, for the sake of including sufficient contextualisation in the main body of the thesis.

The ISO has an extensive collection of standards for various topics. From the range:

- Sixty-four standards were identified and selected relating to geotechnics;
- Two for drilling;
- Five for soil;
- Twenty-nine relating to mining;
- Two for uncertainty (though it is noted that additional items are planned by the ISO);
- Three for risk;

[10] There is an instance where SABS certification may have been relevant, as reported by Czernawalow (2016). The matter dealt with shortcomings attributed to the SABS, by the Southern African Plastic Pipe Manufacturers Association (SAPPMA), who perceived that the conduct (as well as failures in conduct by the) SABS threated the sustainability and functionality of various infrastructure sectors, including mining and water supply. The matter has since been resolved.

- Four for statistics;
- Four for quality; and
- Fifteen relating to artificial intelligence and information technology.

The ISO material is listed in chapter 9, sub-section 9.2, Table 9-4 to Table 9-12.

From the ISRM, thirty-eight Suggested Methods (SM) and thirteen technical reports were identified. The ISRM material is listed in chapter 9, sub-section 9.2, Table 9-13 to Table 9-14.

From the ASTM range (focussing on rock and soil):

- Twenty-two Standard Test Methods;
- Fourteen special technical publications; and
- Twelve manuals were identified.

Additionally, four work items (that largely deal with rock core specimens) were identified.
The ASTM material is listed in chapter 9, sub-section 9.2, Table 9-15 to Table 9-19.

3.5.1 Laboratories

Laboratories, for the testing of rock and soil, also have avenue to assurance of their performance and quality.
The South African National Accreditation System (SANAS) is the national body mandated to issue accreditations (through the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act 19 of 2006) to testing facilities and/or laboratories. The SANAS register was used toward the identification of accredited rock testing facilities in South Africa.

3.5.2 Emphasis on the intention regarding inclusion of Standards etc.

The candidate provides a special note to emphasise the intention, clarification, and motivation for including Standards etc. in the research.

Standards and Suggested Methods provide a strong basis for consistent, transparent, regulation of various technical aspects – and these can be applied both nationally and/or internationally.
The benefits that may rise from using standardised approach and/or standards include:

- Identifying potential uncertainties or weaknesses *before* they are encountered,
- Identifying potential opportunities,
- Preventing problems from re-occurring or recurring,
- Improving performance in the technical aspect,

- Improving control over the business, and
- Facilitating *appropriate* comparisons and evaluations of different projects, given that they have elements of similarity in their implantation and execution.

It is ***definitely not*** the intention of the candidate to insist that all mining companies must become accredited with each and every organisation that oversees certification of standards, or with each and very standard.
Rather, the candidate motivates that the use of the frameworks developed by those organisations, is very advantages as they give a clear and fixed starting point to describe, compare and evaluate the activities of the mining company. The items are identified for the research to also be able to assess 'if' and 'where' they are included in the company disclosures.

3.6 Industry and Institutional Reports

A collection of research and reports from institutional bodies, including the Chamber of Mines (CoM), the Mine Health and Safety Council (MHSC), and the Mandela Mining Precinct (MMMP).

Given that the current thesis describes research related to rock mechanics and geotechnical engineering, the selection of institutional reports was made accordingly.

3.6.1 The Chamber of Mines (CoM)

The Chamber of Mines (CoM), as it was then known, was a voluntary employer's organisation that provided strategic support and advisory input into relevant mining matters. Mgojo (2018) mentions that the organisation has undergone several name changes to coincide with developments in South Africa, since the formalisation of the CoM in 1889. The CoM has since been renamed to the Minerals Council of South Africa.

3.6.1.1 Chamber of Mines' Research Organisation (COMRO)

The CoM had an associated body viz. the Chamber of Mines' Research Organisation (COMRO) and although COMRO was active for nearly thirty years - no index, description, list, or account of the research projects undertaken by the organisations during that time could be sourced through a detailed search. Although separate individual COMRO publications were referred to by other authors e.g. Jeppe (1946), Phillips *et al.* (1983) and Keilis-Borok *et al.* (1990) in Phillips (2019), few (if any) of these could be retrieved from institutional libraries.
Separately, several individual COMRO publications were found in print and those used in the current thesis are cited within the body of text of the thesis, alongside to the information referred to, as well as shown in the list of references to the thesis.

Subsequent to completing the university research described in this thesis, the candidate learned that the Southern African Institute of Mining and Metallurgy (2023), intends to release a book during 2024 showcasing 30 years of COMROs research. It is understood that the publication will be entitled "*COMRO's Legacy: Research and Development of Stoping Mining Machinery and Technologies*".

The SAIMM (2023) reflect that:

> *"…it would be impossible to discuss all [of the technologies developed by COMRO] in detail – some selectivity was inevitable, and [the compiler of the book has] homed in on those [technologies] that had (or in some instances should have had) the greatest impact on the development of improved methods for the mining of gold at great depths.*
>
> *As the book is an anthology, it is only as good as the technological, personal accounts, and related people stories provided by the contributors, and [the compiler of the book is] extremely grateful to those who participated. Many of them indicated that their time with COMRO was possibly the most rewarding and satisfying period of their professional careers.*
>
> *This book is the story of their achievements, peppered with personal anecdotes, and which hopefully will be of interest not only to those involved with COMRO's research programmes and those who benefitted, but also anyone planning on improving current mining operations or restarting this type of research in future.*
>
> *No biography – and certainly no anthology – can be complete, but [they] trust that the activities, events, and stories recounted here are representative of COMRO's programme of R and D to improve productivity and the health and safety of its workforce".*

3.6.1.2 The Mining Industry Occupational Safety and Health (MOSH)

The CoM also had association with the Mining Industry Occupational Safety and Health (MOSH) - and while no initiating mandate could be sourced, it appears that MOSH was a programme, rather than an organisational body – as MOSH documentation now appears bearing the logo for MOSH as well as the logo of the Minerals Council of South Africa. The theme of knowledge retention and information management systems, such as introduced here, is discussed in further detail in chapter 6.

3.6.1.3 The Minerals Council of South Africa (Minerals Council)

The Minerals Council of South Africa (Minerals Council) is the employer's organisation (i.e. a voluntary association) transformed from the Chamber of Mines. The Minerals Council appear to process data from other agencies (e.g. commodity profiles,

production statistics, fatality statistics, etc. It is not clear whether or not they originate new research, however, their online platform does make a fair amount of publications by other institutions, available to the general public.
The MHSC material is cited within the body of text of the thesis, alongside to the information referred to, as well as shown in the list of references to the thesis.

3.6.2 The Mine Health and Safety Council (MHSC)

The Mine Health and Safety Council (MHSC) is a national public entity (Schedule 3A) established in terms of the Mine Health and Safety Act, No 29 of 1996, as amended.

At least seventy-five research-related publications by the Mine Health and Safety Council (MHSC) could be identified. Of these, the three most prevalent themes are

1) Rockfall (thirteen research publications),
2) Rockbursts (nine research publications), and
3) Machinery and transport systems (twelve research publications) – as shown in Figure 3-2 and Figure 3-.

It is noted that during the year 2002, the MHSC produced almost double the amount of research publications than any year thereafter – the source of this anomaly is unclear (e.g. if it is superficial reason, such as the finalisation of project documentation for research that had been completed in previous years, or if the cause has more substance to it, such as budg*et* allocation and spending for that year).

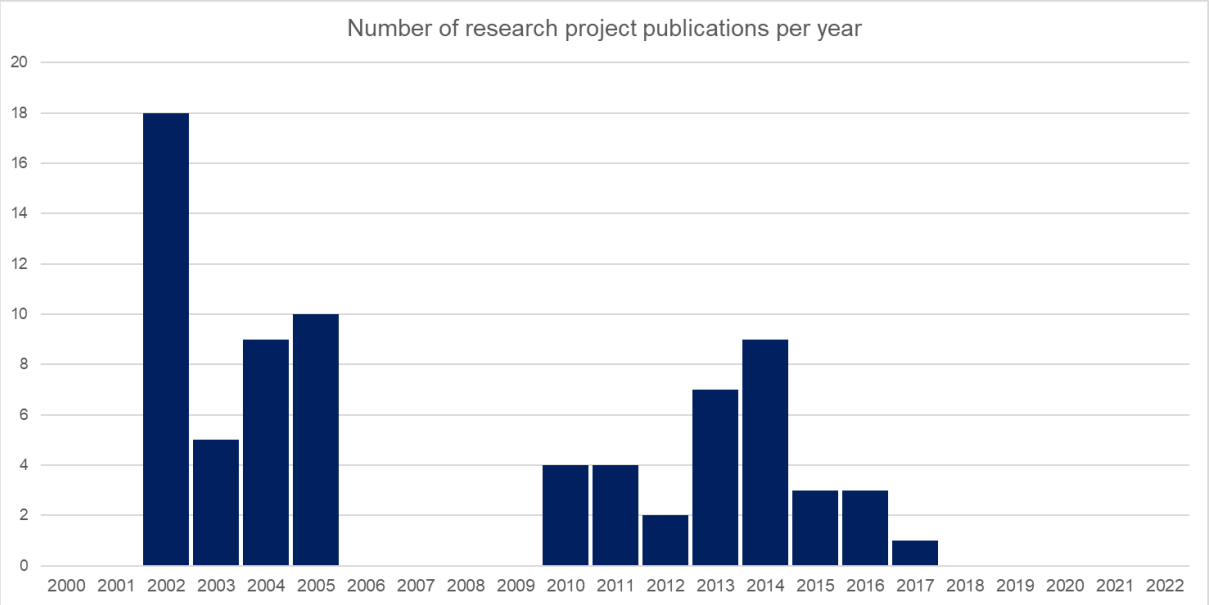


Figure 3-2: Number of MHSC research project publications per year

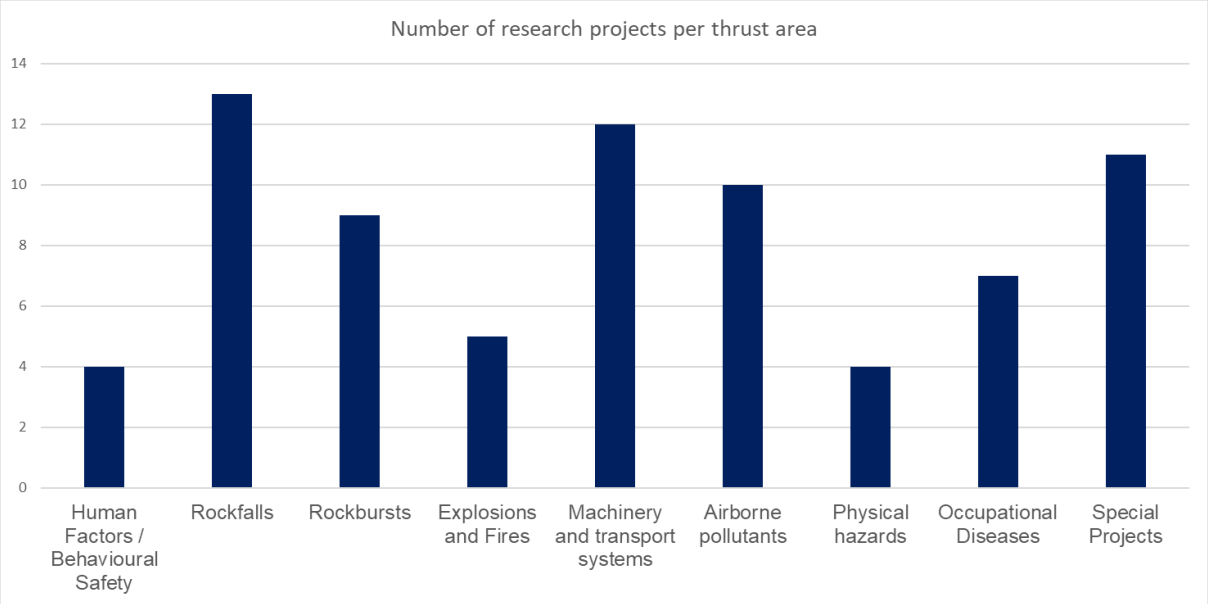


Figure 3-3: Number of MHSC research project publications per thrust area [11]

[11] The phrase '*thrust area'* appears to be synonymous with the concept of '*research theme'*.

3.6.3 The Mandela Mining Precinct (MMMP)

The Mandela Mining Precinct has a number of research programmes ongoing, Longevity of Current Mines (LoCM), Mechanised Mining Systems (MMS), Advanced Orebody Knowledge (AOK), Real-time Information Management Systems (RTIMS), Successful Application of Technologies Centred Around People (SATCAP).

The Mandela Mining Precinct has released various guidelines to date, namely:

1) Application of Electric Resistance Tomography (ERT) in South African Mining;
2) The Application of Ground Penetrating Radar (GPR) technology in South African Mining;
3) Mechanised equipment;
4) Shaft infrastructure and access development;
5) Inclusion of stakeholders in equipment design and development;
6) Pillar design;
7) Ventilation;
8) Energy utilisation;
9) Modernisation: Kolomela case study; and
10) Engagement of workers in OEM equipment development.

Various principles, paradigms and components from the guidelines have been extrapolated, as cited within the body of text of the thesis, alongside to the information referred to, as well as shown in the list of references to the thesis.

3.7 Dissertations and theses

The individual dissertations and theses used are cited within the body of text of the thesis, alongside to the information referred to, as well as shown in the list of references to the thesis.

3.8 Mining companies and their disclosures

The Department of Mineral Resources and Energy's (DMRE's) (2022) register of operating mines in South Africa was used to identify mining companies and mining operations. The information is extracted using an online tool featured on the DMRE's website, however, the tool produced differing numbers of results based on extracting the information one province at a time versus selecting the entire country all at once (Table 3-2). The candidate opted to evaluate the dataset with the larger number of entries, reasoning that even if the mine had stopped operating, their historical documentation may still be available. The dataset related to Table 3-2 was refined to remove quarries; various industrial minerals; processing, refinery and retreatment facilities; petroleum and energy related operations, as well as those operations at sea. Two hundred and ninety-three operations were then identified (Table 3-3).

As part of the diligence and detail applied to the research, the S and P Global MI© database was also evaluated to identify mining operations in South Africa. The dataset was refined, and identified four hundred and eighty-five operations. The platform allows further assessment, and it was identified that two hundred of the operations were considered active, the remaining two hundred and seventy-six are not active for various reasons shown in Table 3-5, and there was no information for nine of the operations.

Table 3-2: Differing numbers of results obtained using the DMRE online tool

Province	Number of operations, when examining one province at a time	Number of operations, when examining the entire country all at once
Eastern Cape	179	203
Free State	78	129
Gauteng	188	254
Kwa-Zulu Natal	140	145
Limpopo	148	254
Mpumalanga	235	288
Northern Cape	316	460
North-West	374	543
Western Cape	198	218
Sub-total	**1856**	**2494**

Table 3-3: Number of operations extracted from the DMRE (2022) register [12]

Metal, Mineral, Commodity	Number of operations
Chrome	83
Copper	1
Diamond	24
Gold	4
Iron ore	60
Manganese	52
PGM	61
Rare Earth Metals	1
Uranium	5
Zinc	2
Sub-total	**293**

[12] The dataset from the DMRE (2022) register was refined to remove quarries; various industrial minerals; processing, refinery and retreatment facilities; petroleum and energy related operations; as well as those operations at sea.

Table 3-4: Number of operations identified using S and P Global MI© [13]

Metal, Mineral, Commodity	Number of operations
Chromite	48
Copper	8
Diamonds	121
Gold	131
Iron Ore	22
Lead	2
Manganese	15
Nickel	6
Palladium	1
Platinum	99
Tin	5
Uranium	15
Vanadium	8
Zinc	4
Sub-total	**485**

Table 3-5: Activity status of operations identified using S and P Global MI©

Activity Status	Number of operations
Active	200
On Hold Awaiting Financing	3
On Hold Awaiting Higher Prices	2
Temporarily On Hold	13
Care And Maintenance	33
Rehabilitation	5
Inactive	220
Sub-total	**476**

Company disclosures were reviewed to identify any and all descriptions, explanations, information or events relating to the geotechnical design, performance, instability etc. Using S and P Global MI© user-defined search criteria [14,15]:

- Sixteen companies listed on the JSE were identified (listed in chapter 9, Table 9-21)
- Seven hundred and forty-nine companies listed on the ASX were identified (listed in chapter 9, Table 9-22),
- One hundred and seventy-seven companies listed on the TSX were identified (listed in chapter 9, Table 9-23), and

[13] The dataset from the DMRE (2022) register was refined to remove quarries; various industrial minerals; processing, refinery and retreatment facilities; petroleum and energy related operations; as well as those operations at sea.

[14] S&P Global MI© Search criteria: "Issuer Name"; "Instrument Item ID"; "MI KEY"; "Description"; "Industry Classification [|(Issuer)]"; "Industry Classification [|(Ultimate Parent)]"; "Equity Type"; "Ticker"; "Country of Incorporation Name [|(Issuer)]"; "Country of Incorporation Name [|(Ultimate Parent)]"; "Exchange".

[15] Industry classification and groupings by S&P Global MI© are: Diversified Metals and Mining, Copper, Gold, Precious Metals and Gemstones, Silver, Aluminium.

- Forty-six companies listed on the NYSE were identified (listed in chapter 9, Table 9-24).

It is noted that S and P Global MI's (2018) Global Industry Classification Standard (GICS) for 'Metals and Mining' is defined as "*Companies engaged in the diversified production or extraction of metals and minerals not classified elsewhere. Including, but not limited to, nonferrous metal mining (except bauxite) salt and borate mining, phosphate rock mining, and diversified mining operations. Excludes iron ore mining, classified in the Steel Sub-Industry, bauxite mining, classified in the Aluminium Sub-Industry, and coal mining, classified in either the Steel or Coal and Consumable Fuels Sub-Industries*". Hence, the numbers of companies include those that are not hard rock mines, but the structure of the tool does not facilitate further differentiation, therefore further refinement of the database was carried out manually.

The eventual list of hard rock mining operations in South Africa investigated during the research is shown in chapter 9, Table 9-25.

3.9 'Contact' engagements

3.9.1 Consulting projects

The candidate has drawn from their own experience gained during their professional exposure, involvement [intern] and employment over many years – having led, participated in, and/or assisted in various research and commercial projects. These projects include, but are not limited to:

- Various research and development projects for the Council for Geoscience;
- Various research projects and project inputs for the MHSC SIMRAC;
- Commercial projects for international and national mining companies carried out by SRK Consulting (South Africa) (Pty) Ltd (SRK South Africa), as well as by SRK South Africa for regional offices such SRK Consulting (Canada) Inc. (SRK Canada);
- Expert witness service carried out by SRK Consulting (South Africa); and
- Membership, mentoring, professional training and development carried out at the Institute of Risk Management South Africa.

It is noted that:

1) No identifying markers whatsoever are given in the thesis regarding expert witness service, however, the procedural findings and principles learnt are incorporated,
2) Only those projects that are not held under confidentially agreements are identified where it is explicitly appropriate to do so, and

3) The projects are cited within the body of text of the thesis, alongside to the information referred to, as well as shown in the list of references to the thesis.

3.10 Other

3.10.1 Mining sector market capitalisation and company ranking

S and P Global (previously Standard and Poor's) is a company that creates financial market indices using company data. The information is widely used toward investment benchmarks. Using S and P Global's Market Intelligence (MI) © platform[16], available market data for mining companies domiciled in South Africa was extracted and is shown in Figure 3-2, Figure 3-3, and Figure 3-4.

The purpose of including the financial overview of the companies is to support the arguments presented in later chapters, outlined as:

a) The resources [financial, skills, etc.] to various mining companies is rather variable;
b) Risk is contextual;
c) Each company's ability to tolerate uncertainty, risk, or unplanned disruption differs – and therefore reporting risk should be adapted to be able to incorporate the specific instances at hand;
d) Some companies are better positioned financially to address their geotechnical engineering needs, however, the same level of calm perception / benefit is extended to companies that cannot match the effort or expenditure – and therefore reporting should be adapted to be able to incorporate the specific instances at hand; and
e) Industry players are diverse in many respects – and therefore an improved framework to report rock and geotechnical engineering is needed to be able to provide relevant, transparent and material information.

The relative ranking of Global Mining Companies by market capitalisation was considered using Price Waterhouse Cooper's (PWC's) yearly publications of the assessment (including PWC, 2019, 2020, 2021, 2022). The list of top forty global mining companies (PWC, 2022a) is summarised in Table 3-6.

[16] S&P Global MI© Search criteria: "SNL Institution Key; Industry; Institution Name; Country / Region Name; Country/Region of Incorporation Name; Year Established; Ticker; Exchange; Market Capitalisation (RM); *In situ* Value: Reserves (RM); Net Operating Profit After Tax (R000); Net Operating Profit After Tax (R000); Net Operating Income (R000)" with Boolean & OR.

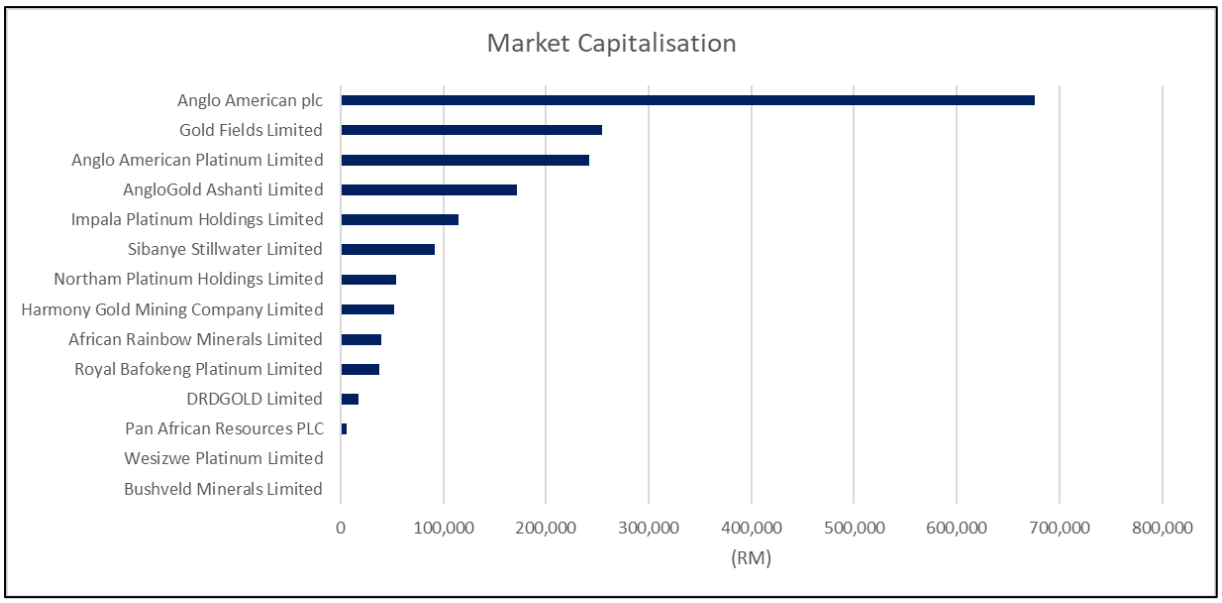


Figure 3-2: Approximate market capitalisation (in South African Rands) of various South African mining companies (S and P Global Market Intelligence ©, 2023 using user-defined criteria[16])

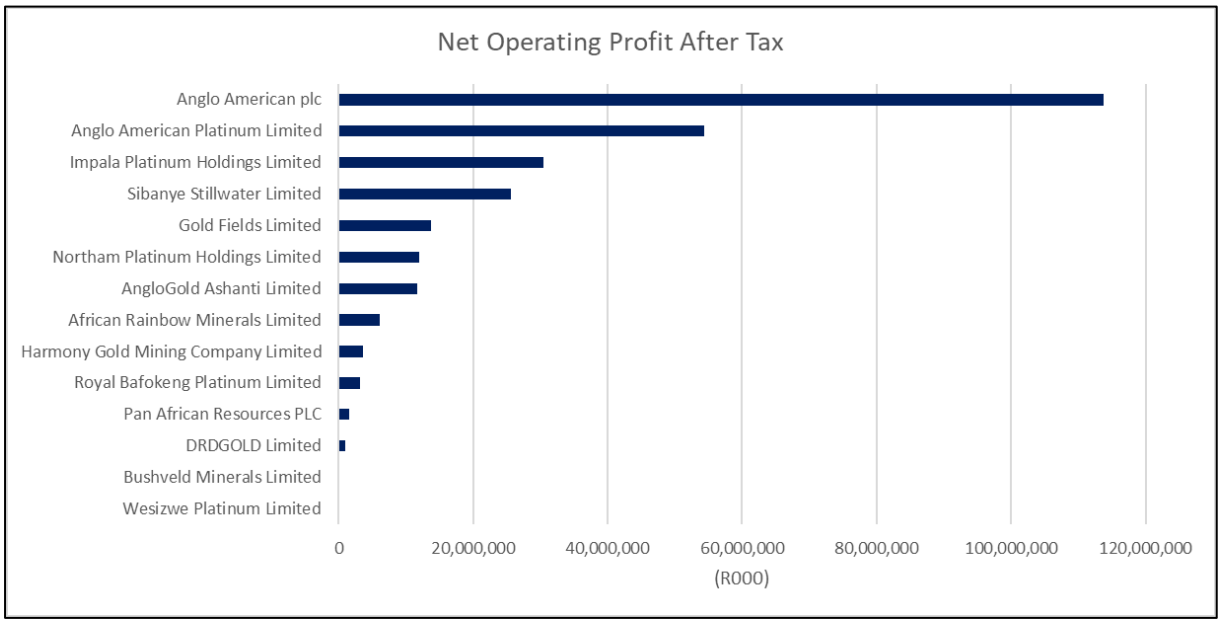


Figure 3-3: Approximate net operating profit after tax (in South African Rands) of various South African mining companies (S and P Global Market Intelligence ©, 2023 using user-defined criteria[16])

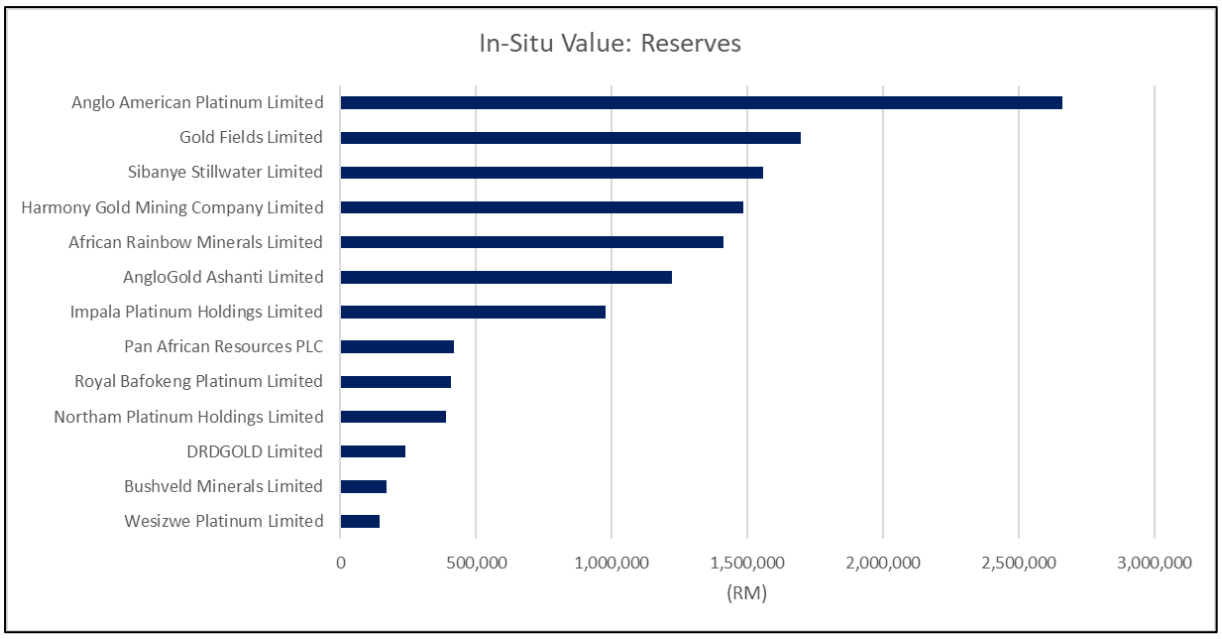


Figure 3-4: Approximate in situ values (in South African Rands) of mineral reserves of various South African mining companies (S and P Global Market Intelligence ©, 2023 using user-defined criteria[16])

Table 3-6: Relative ranking of top 50 global mining companies (Mining, 2023)

	Company	Country	HQ	Operations	Symbol	Market Cap ▾
1.	BHP Group	Australia	Melbourne	Diversified	ASX:BHP	156.33B
2.	Rio Tinto	Australia	Melbourne	Diversified	ASX:RIO	130.24B
3.	Glencore	Switzerland	Baar	Diversified	LON:GLEN	76.22B
4.	Vale	Brazil	Rio de Janeiro	Diversified	BOVESPA:VALE3	62.66B
5.	Southern Copper	Mexico	Mexico City	Copper	NYSE:SCCO	58.67B
6.	Freeport-McMoRan	US	Phoenix	Copper	NYSE:FCX	58.02B
7.	Fortescue Metals	Australia	Perth	Iron Ore	ASX:FMG	47.19B
8.	Zijin Mining	China	Xiamen	Diversified	SHSE:601899	45.30B
9.	Ma'aden	Saudi Arabia	Riyadh	Diversified	TADAWUL:1211	43.56B
10.	Anglo American	UK	London	Diversified	LON:AAL	40.15B
11.	Newmont	US	Denver	Precious Metals	NYSE:NEM	35.38B
12.	Barrick Gold	Canada	Toronto	Precious Metals	TSE:ABX	30.50B
13.	Nutrien	Canada	Saskatoon	Fertilizer	TSE:NTR	30.28B
14.	Franco-Nevada	Canada	Toronto	Royalty	TSE:FNV	28.03B
15.	Albemarle	US	Charlotte	Lithium	NYSE:ALB	27.88B
16.	Norilsk Nickel	Russia	Moscow	Diversified	MCX:GMKN	27.44B
17.	Agnico Eagle	Canada	Toronto	Precious Metals	TSE:AEM	25.95B
18.	SQM	Chile	Santiago	Lithium	NYSE:SQM	22.57B
19.	Shaanxi Coal	China	Xi'an	Coal	SHA:601225	21.89B
20.	Teck Resources	Canada	Vancouver	Diversified	TSE:TECK.B	21.42B
21.	Wheaton Precious Metals	Canada	Vancouver	Royalty	TSE:WPM	19.80B
22.	Antofagasta	UK	London	Copper	LON:ANTO	19.37B
23.	First Quantum Minerals	Canada	Vancouver	Copper	TSE:FM	17.89B
24.	Ganfeng Lithium	China	Jiangxi	Lithium	HKG:1772	17.67B
25.	Coal India	India	Kolkota	Coal	BOM:533278	17.29B
26.	Polyus	Russia	Moscow	Precious Metals	MCX:PLZL	17.16B
27.	Newcrest Mining	Australia	Melbourne	Precious Metals	ASX:NCM	16.83B
28.	Shandong Gold Mining	China	Jinan	Precious Metals	SHSE:600547	15.87B
29.	Gold Fields	South Africa	Johannesburg	Precious Metals	JSE:GFI	14.69B
30.	Tianqi Lithium	China	Chengdu	Lithium	SZSE:2466	13.99B
31.	Cameco	Canada	Saskatoon	Uranium	TSE:CCO	13.69B
32.	Anglo American Platinum	South Africa	Johannesburg	Precious Metals	JSE:AMS	13.66B
33.	CMOC Group	China	Luoyang City	Copper	HKG:3993	12.88B
34.	Vedanta	India	Panaji	Base Metals	BOM:500295	12.83B
35.	South32	Australia	Perth	Base Metals	ASX:S32	12.29B
36.	Yanzhou Coal	China	Zoucheng	Coal	SHSE:600188	12.19B
37.	China Northern Rare Ear...	China	Baotou	Rare Earth	SHSE:600111	12.03B
38.	Mosaic	US	Plymouth	Fertilizer	NYSE:MOS	11.88B
39.	Ivanhoe Mines	Canada	Vancouver	Copper	TSE:IVN	11.67B
40.	Northern Star Resources	Australia	Perth	Precious Metals	ASX:NST	10.66B
41.	Huayou Cobalt	China	Tongxiang	Cobalt	SHA:603799	10.51B
42.	Pilbara Minerals	Australia	Perth	Lithium	ASX:PLS	10.39B
43.	AngloGold Ashanti	UK	London	Precious Metals	NYSE:AU	9.74B
44.	Sumitomo Metal Mining	Japan	Tokyo	Base Metals	TYO:5713	9.53B
45.	Mineral Resources	Australia	Perth	Lithium	ASX:MIN	9.33B
46.	Amman Mineral	Indonesia	Jakarta	Copper	IDX:AMMAN	9.00B
47.	Boliden	Sweden	Stockholm	Diversified	STO:BOL	8.74B
48.	Cleveland-Cliffs	US	Cleveland	Iron Ore	NYSE:CLF	8.66B
49.	Kazatomprom	Kazakhstan	Nur-Sultan	Uranium	LON:KAP	8.55B
50.	Jiangxi Copper	China	Guixi City	Copper	SHSE:600362	8.43B

Source: MINING.COM, Miningintelligence, Morningstar, GoogleFinance, stock exchange data, company reports
Share data from primary-listed exchange at July 17 2023 close of trading converted to US$ at cross-rates July 18 2023.
Percentage change based on US$ market cap difference, not share price change in local currency.

3.11 Concluding remarks for chapter 3

Chapter 3 affirms that a very extensive (although not exhaustive)search was undertaken to identify and collect a very extensive body of information, spanning various disciplines, decades and organisations.

The information is relevant to the industry as a whole and to individual mining operations in which practitioners in rock engineering, geomechanics, geotechnical engineering, and/or engineering geology carry out their functions.

The search deliberately included a broad spectrum of sources ranging from formal, peer-reviewed, authoritative, academic publications, to mining interviews by executive members as well as presentations by original equipment manufacturers (OEM). The purpose of incorporating the broad spectrum is to be able to demonstrate:

a) The actual experiences in the field, realised by operators (contrasted against the idealised expectations occasionally put forward by marketing and advertising initiatives); as well as
b) The norms – and the deviations from the norm – realised by operators.

The candidate emphasises that it is ***definitely not*** their intention to insist that all mining companies must become accredited with each and every organisation that oversees certification of standards, or with each and very standard.

Rather, the candidate motivates that the use of the frameworks developed by those organisations, is very advantages as they give a clear and fixed starting point to describe, compare and evaluate the activities of the mining company.

4 LITERATURE REVIEW

4.1 Overview of chapter 4

Chapter 4 contains an extensive literature review. As introduced in chapter 1, sub-section 1.8, the literature review intentionally begins at a low impact introduction and increases momentum and complexity, toward the ultimate discourse. The purpose of the approach is to demonstrate the variability and interconnectivity (and therefore vulnerability) of the interrelated elements.

The literature review has been formulated to draw from a broad base of information at first, then progressing to a more refined and detailed deliberation. The information:

- Has been drawn from a wide, international setting;
- Is presented in thematic groupings; and
- Learned from the literature review is applied to the mining context in later chapters (i.e. chapters 5, 6, and 0).

The literature review also demonstrates that:

- There is a plethora of information available on technical subjects and topical elements, and
- There are many elements of agreement, but still some elements of disagreement between practitioners in the mining industry.

Either of these demonstrations by themselves, is a motivating factor for an improved reporting framework within the South African mining industry.

The literature review provides insight into the following themes:

1) Knowledge progression in rock mechanics and geotechnical engineering
   a) The historical basis, current state and likely future trends and/or developments in progression in rock engineering, geomechanics, and geotechnical engineering, and
   b) The full range of activities from site investigations and field studies, descriptions and attributes of rocks, drilling, blasting, technology, computational developments, monitoring, mechanisation, as well as the integration of fields of knowledge and processes.
2) Evolution of the mining excavation (to steeper slopes in the open pit, deeper depths underground as well as the transition from open pit mining to underground mining.
3) The range of *subjective* elements that may potentially be involved in and/or influence rock mechanics, geotechnical engineering, data selection, data accuracy, uncertainty, model construction, decision-making and the difficulty in evaluating a mining operation based on all of these inter-related elements.

4) An overview of concepts that may contribute to existing and growing complexities of interpreting needs, performance and optimisation related to rock mechanics / geotechnical design and stability, decision-making and business priorities, i.e. the potential value of the geotechnical designs based on rock mechanics may extend - far beyond the simplification of likelihood and consequence of a vaguely described incident – to incorporate concepts such as susceptibility, fragility reliability, and robustness.
5) The Regulatory Environment of Mining in South Africa (as relevant to the context of the research).
6) Risk as a 'pure' science, given that it is, a speciality subject on its own.
7) When, where, and how reporting of rock mass and geotechnical data, information, and/or performance arises for mining operations that are situated in South Africa.
8) Technical qualifications, skills, research and professional competency.
9) Existing principles, tools, and approaches available in the greater mineral extractive industries that are amenable for the purposes of the proposed technical[17] reporting initiative.

It is noted, and emphasised, that the literature review and narrative developed herein is ***not*** a ***pure, linear*** one. The various elements considered in the review are described sequentially, as required by academic guidelines and facilitated in the University thesis template. In reality, however, the concepts may occur selectively, simultaneously, partially, iteratively, or even phenomenally.

Therefore, a general contextualisation of the various literature components - in relation to each other (when grouped thematically), and in terms of the research objectives and methods - is visualised simplistically in Figure 4-1.

It is intended that Figure 4-1 serve as an aid to facilitate comfortable readability and comprehension regarding the presentation and general flow of the literature review.

[17] rock engineering, geomechanics and geotechnical engineering in mining operations

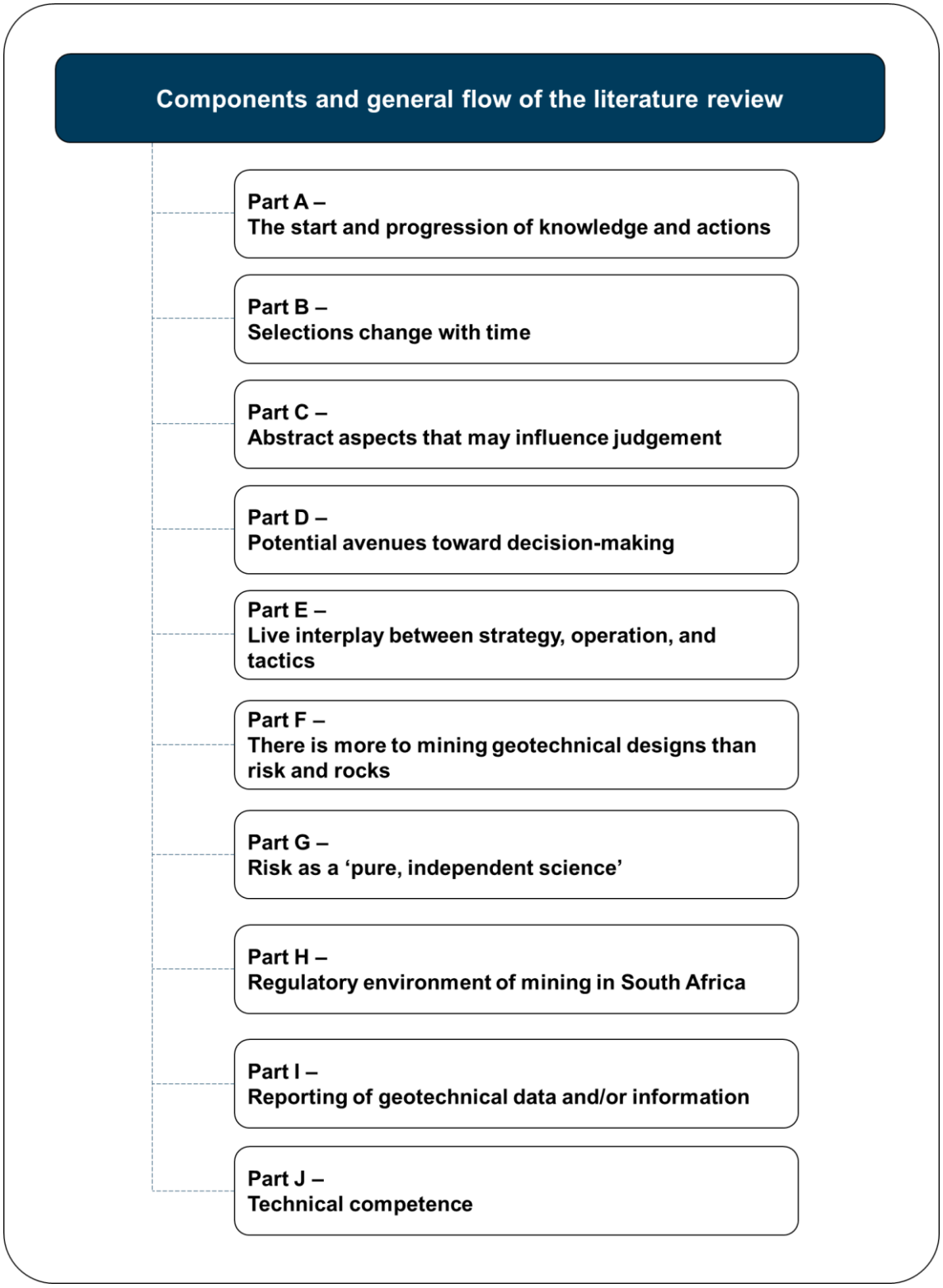


Figure 4-1: Simplified visualisation of the various components of the literature review and their general flow in chapter 4

4.1.1 Practical considerations toward a manageable document

Practical considerations have been applied to maintain a manageable document size. The eventual collections amassed (consisting of journal articles, case studies, conference papers, etc.) that were sourced and reviewed by the candidate numbered in the hundreds, and the information eventually came to form a near-continuous spectrum of sorts. The information revealed a stepwise progression through the years and decades, demonstrating how several aspects transitioned from one development to the next.

Although reading and reviewing each item proved valuable in recognising detail and expanding insight, understanding and horizons – it became impractical to include the entirety of information in the literature review and in the thesis.

Therefore, a number of the selected items (though still quite voluminous) are included in the annexures (chapter 9), and others are provided in annotation for further consideration.

4.2 Part A – The start and progression of knowledge and actions

The various components for Part A of the literature review and their general flow are outlined in Figure 4-1. The content is then presented in detail in sub-sections 0 to 4.2.3.

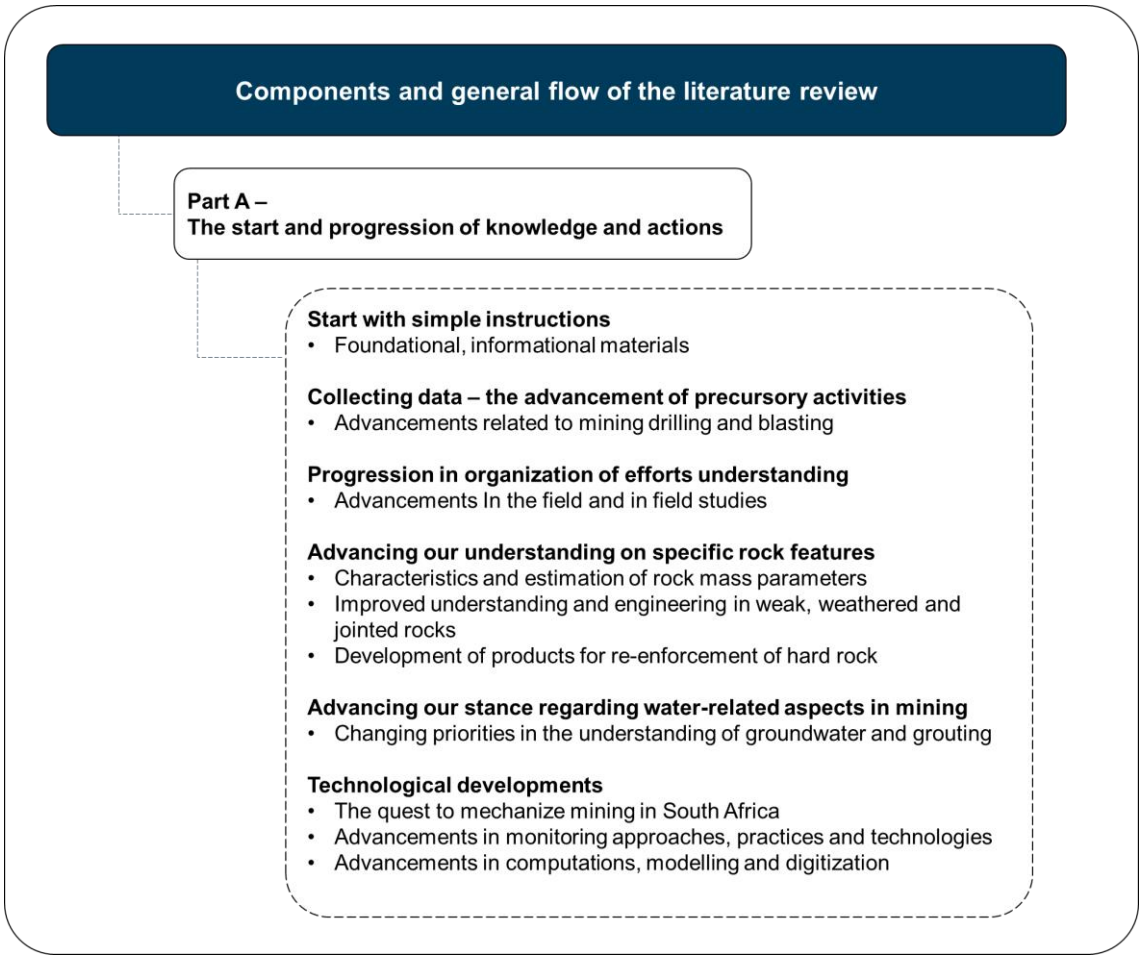


Figure 4-2: Simplified visualisation of the various components for Part A of the literature review and their general flow

4.2.1 Start with simple instructions

4.2.1.1 Foundational, informational materials

The use and application of ‘Guidelines’ (also referred to ‘handbooks’ or ‘textbooks’) are often considered to be universal introductory texts because they typically provide:

- An introduction to the technical topics and subject matter being described;
- Formal definitions of words, phrases, processes, etc.;
- Explanation and description of the theoretical components of the subject matter;
- Examples demonstrating the practical and/or ‘real world’ application of theoretical components;
- A guided walk-through, from start to finish, of the subject matter being described;
- Historical case studies; and
- Recommendations for further reading and topic-specific references.

Various guidelines have been developed over the years that give an extensive overview of thematic elements in mining geotechnical engineering.

a) Guidelines for elements of fieldwork include:
    i) Guidelines for soil and rock logging in South Africa (Brink and Bruin, 1990).

b) Guidelines for field work include:
    i) Site investigation handbook for engineers (Clayton *et al*., 1982 and 1995).
    ii) Geotechnical and Geophysical Site Characterisation (Huang and Mayne, 2008).
    iii) Field Guide for Geoscientists and Technicians (The Australasian Institute of Mining and Metallurgy (AusIMM), 2009).
    iv) Field Geologists' Manual (The Australasian Institute of Mining and Metallurgy (AusIMM), 2010).
    v) Site investigation - Code of Practice (The Geotechnical Division of The South African Institution of Civil Engineering (SAICE), 2010).
    vi) Handbook for Field Geologists (Hayes, 2018).

c) Guidelines for open pit slope stability, including:
    i) A guideline series developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), includes:
        - Guidelines for Open Pit Slope Design (CSIRO, 2009).
        - Guidelines for Evaluating Water in Pit Slope Stability (CSIRO, 2013).

- Guidelines for Open Pit Slope Design in Weak Rocks (CSIRO, 2017).
- Guidelines for Slope Performance Monitoring (CSIRO, 2020).

ii) Rock slope engineering (Wyllie and Mah, 2004).

d) Guidelines for underground mining and engineering include:
   i) Rock Slope Engineering (Hoek and Bray, 1974).
   ii) Underground Excavations in Rock (Hoek and Brown, 1980b).
   iii) Geotechnical Site Investigations for Underground Projects (United States National Committee on Tunnelling Technology, 1984 and 1984a).
   iv) Rock Engineering Practice for Tabular Hard Rock Mines (Jager and Ryder, 1999).
   v) Rock mechanics for underground mining (Brady and Brown 1993 and 2004).
   vi) Canadian Rockburst Support Handbook (Kaiser *et al*., 1996).
   vii) Mining and its Impact on the Environment (Bell and Donnelly, 2006) [the text presents a number of principles and case studies relating to subsidence associated with different mining methods and ore deposit types].
   viii) Mining Methods in Underground Mining (Atlas Copco, 2007).
   ix) Hard Rock Miner's Handbook (Stantec Consulting Ltd., 2008).
   x) Rock engineering (Palmström and Stille, 2015).

4.2.2 Collecting data – the advancement of precursory activities

4.2.2.1 Advancements related to mining drilling and blasting

Overview

There have been advancements in many aspects of drilling and blasting practice over the last four decades – from initial assessments of open pit drilling and blasting by Bauer (1971), to improvements in raise and shaft drilling pursued by Robbins (1974), improvements in stope drilling and blasting White *et al.* (1975) for deep gold mines, to the “spotlight” on the status of drilling and blasting in surface mines (Brown, 1986) and in underground mines (Kersten, 1986), using an empirical method of assessing rock mass blastability (Lilly, 1986) and the mathematical model of rock breakage put forward by Kleine (1988).

Insights of the effect of blasting on the rockmass

The effect of blasting on the rockmass, toward the objective of designing effective preconditioning blasts in deep-level gold mines, has been studied by Toper (2003)

The development of operation specific practices of drilling and blasting are a concerted effort in observing, identifying and application of lessons learnt, such as those described by Crosson *et al.* (1976) for the operations owed by the Palabora Mining Company Limited and Mukoya Adebayo (2019) for optimum drill performance at Rossing Uranium Mine, Namibia.

Roux *et al.* (2006) includes the role and implementation of limit blast techniques with pre-splits and trims, and good housekeeping in the slope management programme developed for Navachab Gold Mine, Namibia - where economics initially dictated an aggressive slope angles in the design of the open pit which has a steeply dipping footwall geology.

Lessons from the Field

Practical, field-based elements such as a newly developed plaster stemming method were described by Cevizci, (2012) and optimisation of fragmentation using a ‘plan-do-check-act’ course of action is described by Amiel (2008).

Furthermore, Oates and Spiteria (2021) provide an insightful literature review of stemming and best practice in blasting (to follow the amendments to regulations in South African on explosives) – even objectively navigating the findings from the literature review of where some motivation for not using stemming for presplit, trim, shot hole, and reactive ground blasting, exists in some instances. The authors conclude from the literature review that benefits from stemming significantly influences the control of flyrock, air-blast, and toxic fume generation.

The blastability index continued to be refined such as in the design of blasts for open pit (Lillly, 1992) and in more recent years, incorporation of rock mass classification and the Blastability Index for improved wall control, reported by Segaetsho and Zvarivadza (2019). In a more complex setting, Andrieux and Hadjigeorgiou (2008) set out a Destressability Index Methodology as part of probability assessment of the of success of a large-scale confined destress blast in an underground mine pillar.

Through a simulated rockburst experiment, Hildyard, and Milev (2001) developed a numerical model for seismic wave propagation from the blast, and forward analysis.

Cunningham *et al.* (2002) describe the results of a field trial using threshold blasting in narrow reef mining underground (i.e. using small amounts of high explosive to break and fragment hard rock without needing to evacuate mining personnel from the area), where rigid control on drilling, charging and timing allow the method to be assimilated with reasonable ease, and if the correct procedures are followed stringently, the after-blast fumes, dust and fly rock can be contained so as to maintain safe working environment. Cunningham *et al.* (2002) outlined potential refinements for future consideration, including revision to identify the optimum explosive energy and blast hole geometry to be able to fire multiple sets of shot holes in a continuous manner.

Predictive modelling

The theme of 'predictive modelling' has made progress on a number of fronts, including the development of a fuzzy model for predicting the penetration rate of tricone rotary blasthole drilling in open pit mines (Kricak, *et al*., 2015), the development of a predictive model of fragmentation using both drilling and blasting data (Silva, *et al*., 2017) and the development of a blast-induced vibration prediction model using an artificial neural network (Das, *et al*., 2019). In recent years, the prediction of back break in blasting using random decision trees has been explored by Kumar *et al.* (2021).

Costs and value

The work by Kumar *et al.* (2021) has valuable practical application for slope stability in hard rock open pits. Where back break occurs, typically as a result of the combination of characteristics in the rock condition, blast geometry, explosive and initiation systems, it may also cause rockfall during the next drilling activity - due to the cracks present in the *in situ* rock mass at the perimeter. The creation of an improper free face from a previous blast, and the presence of loose strata in the face often lead to increased overall cost of production. The study by Kumar *et al* (2021) concluded that the random forest system has sufficient flexibility to provide a suitable measure to minimise uncertainties encountered during the blasting operations and the application of the findings facilitated a reduction in back break at the operation, increased blasting

efficiency, reduced costs, and time savings for face preparation. Kumar *et al* (2021) do recognise that cost constraints and availability issues may potentially prevent mining operations to opt for electronic detonators, however, an alternative is available through the use of low-density emulsion explosive at the localised portions where the problem of back break occurs (and that the use of low-density emulsion may potentially aid in reducing blasting cost through the reduction of the consumption of explosives).

Another method for improving financial returns has been developed by Ortiz and Magri (2012), using geostatistical simulation and an optimised advance drilling grid, where Ortiz and Magri (2014) then developed an approach to design an advanced reverse circulation drilling grid for short-term planning in open pit mines, based on three case studies. Afonseca and Silva (2022) provide a novel, integrated analysis to define optimal drill-hole spacing.

Drilling costs and the evaluation thereof have been considered by Tarr *et al.* (2000) and Kinver (1990) considers the potential financial and cost benefits of mechanised drilling.

Wayland and du Chenne (1999) systematically describes value added blasting projects completed at two gold mines, having already identified the need for improved blasting. The principles and method were customised (e.g. supervisor interviews, confirming actual implantation vs company standard etc.). It was found that improved work practices and behaviours allowed a reduction in stoping width and external waste at the first site, and significant financial benefits were realised at the second site. Part of the success is attributed to establishment of a training course, with follow-up training (i.e. more than one cycle of learning).

Technology

The incorporation of improved technologies has also been realised, such as those descried by Ferreira (2003) for the application of a small twin boom mechanised drill rig for improvements in longhole blast hole drilling, applied to dropraising and longhole stoping.

Review of performance: past and present

Objective review of performance is an essential tool in the pursuit of good practice, and safe mining.

Performance can also be evaluated in very narrow functions to give insight to the greater geomechanical system – for example fault drilling and stope drilling.

Brodsky *et al.* (2009) provide a well-rounded discussion of the past practices, present achievements, and future potential for rapid response fault drilling. In terms of stopes, the review by Wills and Buysens (2002) describes the various successes and failures from the rollout of stope drilling systems in South African Mines.

Differing perceptions

Published and academic literature confirms a framework of well-structed consideration and studies regarding drilling and blasting – however, that does not strictly mean that all potential users of the information will be able to access or consume the information as intended.

The candidate specifically refers to an instance where Mining Technology (2013) state that "*the approach taken towards understanding explosions in the mining industry may best be described as* ***'trial and error'****, but a new team of scientists is setting out to change this [using advanced computational modelling systems]" [bold text added by the candidate for emphasis].*

The differing perceptions identified provide awareness of the practical uncertainty, variability, and sources of risk that may exist in the mining industry.

4.2.3 Progression in organization of efforts understanding

4.2.3.1 Advancements in the field and in field studies

Overview

Practical, field-based methods for geotechnical and geophysical site characterisation are presented in the international conference on the topic, hosted every few years by the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) as well as the International Symposium on Field Measurements in Geomechanics (FMGM) (outlined in chapter 9, Table 9-3). The FMGM 1999 alone included nearly one hundred papers devoted to the topic of field measurements in geomechanics, and the FMGM 2007 over one hundred papers – there have been eleven such dedicated events between 1982 and 2022.

Similarly, in the application of engineering principles, the Portuguese Geotechnical Society (1994) and Canadian Geotechnical Society (1999) published their proceedings [each over six volumes], totalling nearly five thousand pages and four thousand pages respectively - of case studies, lessons learnt and advances in the discipline.

Large strides forward have been made in tools and techniques for the collection of data from the field (e.g. discontinuity data of rock) and many of the advancements are transforming field studies from labour-intensive, in-person activities, to remote, automated, and/or mechanised efforts.

Many advancements used to collect field data are based on related principles, e.g.

1) Remote applications (such as being stationed independently without a human operator making physical contact with the unit, either on the ground or in the air. Airborne apparatus are not usually named consistently and can include any form, combination or variation of ‘drone’, ‘drone-based;, unmanned aerial vehicle (UAV), unmanned aircraft (UA), remotely piloted aircraft (RPA), Micro Air Vehicle (MAV) small Unmanned Aircraft System (sUAS) etc.). The apparatus may have a custom, aftermarket or separate payload attached, to affix a second equipment piece for the purpose of data collection.
2) Imaging techniques (i.e. photogrammetric collection and consolidation).

Image analysis

As part of the more primary options in the transition from activities carried in-person to remote, automated, and/or mechanised efforts, image analysis was previously considered relatively promising, and then very quickly expanded into more robust photogrammetric methods.

Digital image processing of underground rock exposures has been used to construct a discontinuity trace map (Lemy *et al*., 2002) and Grenon *et al.* (2004a) have developed a method of fracture system modelling based on input data from traditional mapping (i.e. in-person, observational notetaking) and image analysis.

Scanning of hard rock core

As expressed by Damaschke *et al.* (2023), drill core is considered a vital resource for subsurface characterisation and understanding – but it is expensive to collect. Therefore, the geoscience community at-large is becoming increasingly reliant on data from historic core (i.e. collected as part of programmes carried out many years before) to address today's challenges. A similar principle of limitation is expressed in Lemy *et al.* (2001), stating that it is often the circumstance at pre-feasibility stage and early stages of mining operations, that rock mechanics information is only available core logging (until the excavation allows further access for observations, scanline mapping etc.). Lemy *et al.* (2001) completed Image Analysis of Drill Core using a fixed-mounted camera on a tripod.

The Sustainable Minerals Institute (2023) has initiated a project using hyperspectral drill core scanning for geotechnical characterisation, following from other successful applications of hyperspectral drill core scanning shown by Mandende *et al.* (2023)

Hard rock core, '*res ipsa*[18]'

Given the inherent values of the information that can be learned from intact hard rock core, many authors have motivated and explained for the best methods and use of using hard rock core for rock mechanics, geotechnical undertakings, ground management and the study of related features or events. These include a contribution to the mechanism of core discing (Stacey, 1982), explanation and example for the optimal usage of exploration core for geotechnical purposes (Dempers, 1991), a new method of diametrical core deformation analysis for *in situ* stress measurements (Funato and Ito, 2017), the prediction of variability in joint frequency (Peacock, 2006), proposed theoretical components of core-based methods for measurement of *in situ* stress of hard rock core (Yamamoto, 2009) as well as the findings from core and

[18] *res ipsa* - the thing itself

borehole logging, with the collection of stress measurements of borehole, being 817 m long and drilled from a depth of 2.9 km, at Moab Khotsong, South Africa, reported by Ziegler *et al.* (2018).

Radar

The applications of radar have grown and ranges in use from surface, sub-surface to underground. In part, the adaptability of radar is facilitated by the advantage that radar often uses a shorter repeat time and greater spatial resolution than airborne and satellite systems can provide (McHugh *et al*., 2006).

Advances in radar applications are shown in Goldstein *et al.* (1998) where phase noise can be substantially reduced through the development of a 'new', adaptive filtering algorithm that results in improved accuracy of measurements, in their radar interferogram research for geophysical applications and in Elmouttie *et al.* (2020a) where the estimation of true deformation vector from slope radar was shown.

The growing use of radar is also shown in applications of ground-based interferometric radar systems, for example, that have been designed to monitor displacement of unstable slopes in the mining case studies in Reeves *et al.* (2001) and McHugh *et al.* (2006), in-mine feature mapping (Vogt *et al*., 2005), and the monitoring of unstable slopes reported by Pieraccini *et al.* (2006).
Severin *et al.* (2014) developed a pseudo- three-dimensional, pit slope displacement map using data from ground-based radar and Silwamba *et al.* (2016) recount the use of radar as part of the slope management strategy surrounding the footwall failure during 2014 at Nchanga open pit mine, Zambia.

A comparative case study of spatial trend using fine-scale ground-penetrating radar data by Dagasan *et al.* (2018) concluded that although the results obtained when using different, common kriging algorithms where slightly different, they all produced satisfactory results.
Ground penetrating radar has been successfully used for rock mass characterisation by White and Doorgapershad (1996), and to quantify the changes in the fracture pattern associated with a simulated rockburst in the experiment by Grodner (2001).

It is also not uncommon for technology to be advanced in specific mineralisation settings e.g. in Bushveld Complex platinum mines of South Africa, borehole radar has been used to detect disruptions in mineralised rock horizons (du Pisani *et al*., 2009) and three-dimensional ground penetrating radar has been used in strategies relating to falls of ground (Kgarume *et al*., 2019).

Photogrammetry

Following from the collection of digital images, the practice of photogrammetry followed quickly – using one, two, or more digital cameras mounted onto a tripod, vehicle or craft of sorts (outlined in chapter 0 above), or held by hand, to be able to collect a large number of digital images, relatively quickly.

Photogrammetry is itself, a field of specialisation – and combines the functions of image analyses and remote sensing (e.g. Schenk, 2005; Seker and Duran, 2020).

Schenk (2005) clarifies that the principle difference between photogrammetry[19] and remote sensing lies in the application of the technique viz.

- Photogrammetry is used to produce maps and identify the positions of points in three-dimensional space, whereas
- Remote sensing analyses and interprets various images for deriving understanding about the earth's surface,
- Thereby forming a relationship with Geographic Information Systems (GIS), illustrated in Figure 4-3.

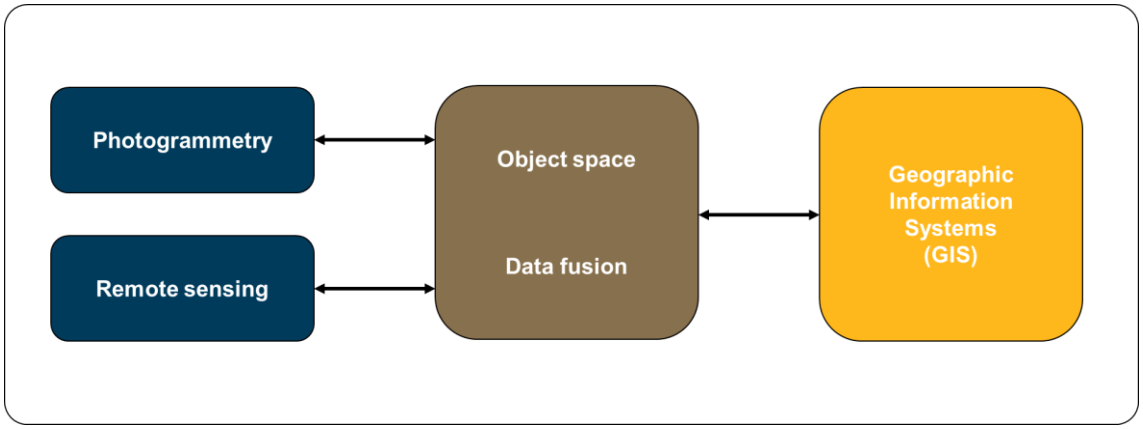


Figure 4-3: Relationship of photogrammetry, remote sensing and GIS (redrawn from Schenk, 2005)

Sub-division with photogrammetry is possible, for example:

1) Aerial photogrammetry (collected using airborne craft), and
2) Terrestrial photogrammetry (collected using one or more 'land-based' cameras).

Other approaches for sub-division are also possible, for example, dependent on the camera lens setting i.e.

1) Far range photogrammetry, and
2) Close range photogrammetry.

[19] Photogrammetry is applicable to a wide variety of scientific disciplines e.g. planetary industrial, historical / architectural, and biostereometrics of the human body. The explanations and examples included in the thesis only relate to aspects that are applicable to mining.

In terrestrial photogrammetry, which may also be combined with tripods and theodolites, two types of cameras are commonly used: metric cameras and non-metric cameras (Seker and Duran, 2020).

1) **Metric cameras** are considered to be highly specialised - designed and calibrated specifically for photogrammetric measurement, using a known and stable interior orientation, very low lens distortion, and usually a fixed-focus camera (and therefore used for limited range of distance). The camera also contain fiducial marks mounted on the frame of the camera to with which to recover the interior orientation / image coordinate system. Metric cameras allow for precise measurements.
2) **Non-metric cameras** are less specialised, and may even lend themselves to amateurs – as they do not have the same internal consistency as metric cameras. Their internal geometry is not stable and is generally unknown therefore producing imagery that is less accurately orientated etc.

Kölbl (1976) provides arguments and examples on the use of metric and non-metric cameras by comparing and recommending lens angles, object distance, camera calibration and error tolerance.

If an object is photographed from two different positions simultaneously (either with a single camera from two positions or using a stereometric camera) with a known base or projection centre, the overlapping area of two photographs (i.e. a “stereopair”) can be used to visualise a three-dimensional image

There is also some variation in the positioning of cameras e.g. aerial, metric cameras mounted onto aircraft mostly look ‘straight downwards’ (Seker and Duran, 2020) from a vertical position, whereas terrestrial cameras often view objects on a horizontal plane. Literature on the differences was less distinct in more recent years, and therefore only described in summary herein.

Photogrammetry – pure and true

Literature regarding photogrammetry is dichotomous – on the one hand, aspects relating to photogrammetry are described in detail for their pure and true science under the jurisdiction of GIS, and on the other hand, the use of 'photogrammetry' in the broad sense appears in mining-related literature, with far less description of the elements of photogrammetry and more description of the convenience.

The literature for photogrammetry – pure and true – covers very technically specialised aspects such as lens assembly, focal planes, drive mechanism, image motion, camera calibration, photographic processes (including exposure, sensitivity, colours, filters, and film), resolution of cameras and images, sensitometry, signal transmission, frame transfers, spectral response, angular coverage, scale, relief displacement, transformations, corrections for radial distortion, corrections for refraction, correction for the earth's curvature, orientation as well as orientation of stereopairs, analytical plotters and auxiliary devices used, where Schenk (2005) provides a well-written explanation on each of these aspects.

Additional resources include Mikhail *et al.* (2001) introduction to modern photogrammetry, McGlone's (2004) manual of photogrammetry, and Hellwich's. (2017) review of photogrammetric methods in the 'Encyclopaedia of GIS'. Conference themes are also highly specialised e.g. symposium on 'close-range' photogrammetry, and Computer Vision and Pattern Recognition (CVPR).

Journal publications range in scope e.g. direct, linear transformation from comparator coordinates into object space coordinates (Abdel-Aziz and Karara, 1971), considerations of the geometry of multiple images (Faugeras *et al*., 2001) and multiple view geometry Hartley and Zisserman (2003), as well as perspectives on distortions (e.g. Swaminathan *et al*., 2003).

Additionally, the identification, role and application of benchmarking in photogrammetry and remote sensing 'communities' is an ongoing exercise (Bakuła *et al*., 2019).

Figure 4-4 shows an overview of systems within photogrammetry, toward providing insight on how the specialised aspects fit together. Photogrammetry, as reported in mining-related exercises, does not typically show any such detail, as discussed hereunder.

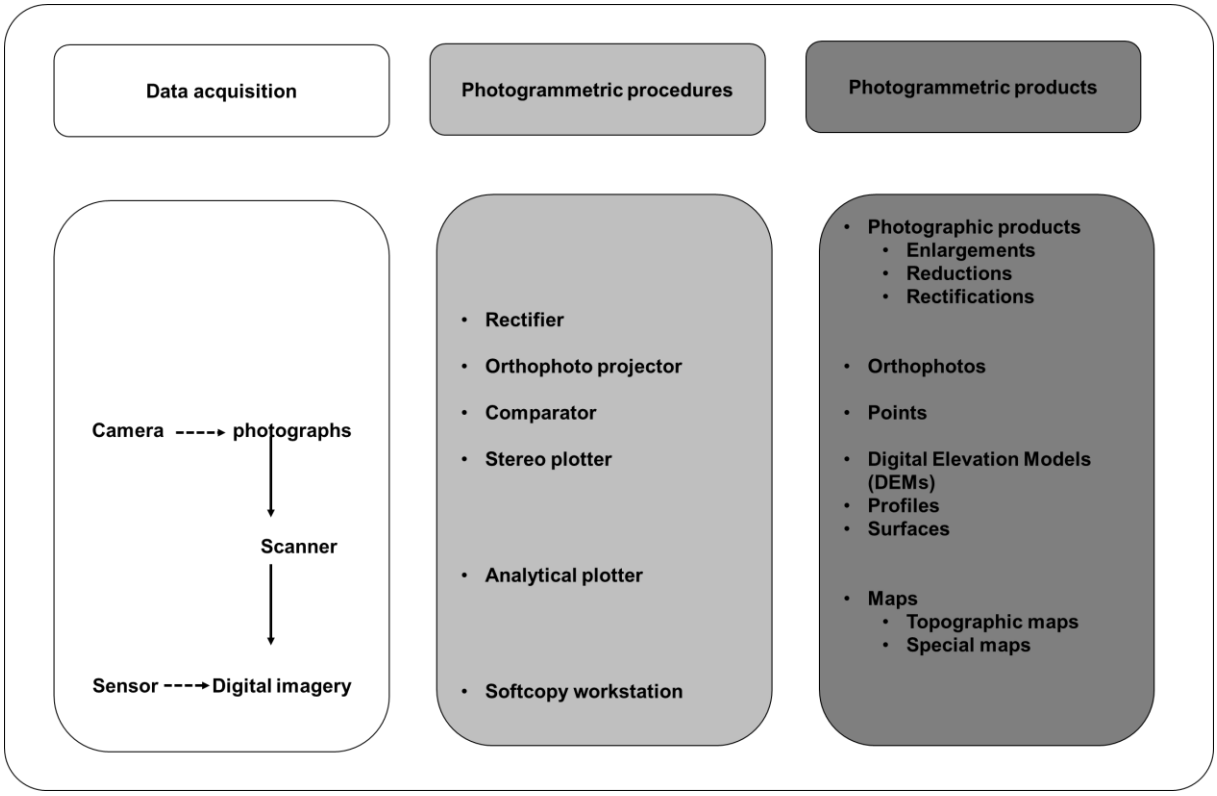


Figure 4-4: Overview of systems within photogrammetry (after Schenk, 2005)

Photogrammetry – mining-related

The candidate amassed a collection of nearly two hundred technical papers on the topic of 'photogrammetry in mining' during the research – and the content is very similar across the full collection, viz. photogrammetry:

a) Can be used for surface mining operations as well as underground operations,
b) Allows access to difficult locations in the mine,
c) Has a great potential to improve data collection,
d) Can be used to recognise and measure structural features,
e) Provides measurements (e.g. joint roughness co-efficient) that can be incorporated into three-dimensional modelling,
f) Can be integrated into open pit, slope monitoring programmes,
g) Is, to various extents, cost-effective.

For the reason that the content is very similar across the full collection, the review of the individual papers is not expanded in detail hereinunder, however, aspects listed above can be found in examples such as Gaich *et al.* (2007), Allemand *et al.* (2016), Jones *et al.* (2019a), Jones *et al.* (2019b), Vallejos (2019), Jones *et al.* (2020), Woolmer *et al.* (2021) and Baylis *et al.* (2020b).

In advancing the practical aspects of photogrammetry in mining-related applications:

a) Sturzenegger (2010) carried out a study, having recognised that terrestrial remote sensing techniques (i.e. digital photogrammetry and laser scanning) are increasingly being used by geologists and geological engineers and that their use needs to be properly evaluated. Sturzenegger (2010) also recognised that guidelines to optimise the use of the techniques are needed – as for the standardisation in place for conventional mapping techniques – for appropriate discontinuity characterisation.
b) Lato *et al.* (2014) provide instruction on correcting for over-calculation due to rockmass convergence when using photogrammetry and LiDar data to map shotcrete thickness.
c) CSIRO and ACG (2000), provide a more systematic framework and description for the development of the field programme for photogrammetry, including mention of practical limitations and shortcomings of some aspects of commercial software used to process photogrammetric images.

In contrast to the improvement explained above, the candidate observes several deficiencies of photogrammetry reporting identified during the literature review. These deficiencies include:

1) The terms 'photogrammetric mapping', 'photogrammetric modelling, as well as the phrase "'photogrammetry-based" do not appear to be formally defined and do not appear to be used consistently across authors of mining-related publications in the last decade or so.

   The most common manifestation of this example appears as statements by an author that a "*three-dimensional jointed rock mass model has been created using photogrammetry*" [most commonly referring to an open pit] when in reality the publication only describes:

   a) That two-dimensional trace lines of ***large*** discontinuities,
   b) On a limited portion of a wall
   c) Were estimated from photographs that were overlapped on-screen to form a 'view of the wall',,
   d) Using software or even freeware [20] [that is typically not identified or named in the write-up – instead the generic phrase commonly found reads "Software was used….."].

[20] Freeware is software available free of charge, and it is often not accompanied by any warranty or technical support.

The use of broad-phrasing:

a) Creates an impression of extensive detail and procedure – which is not a true representation of the work described in the respective publications[21], and
b) The suitability of 'simply' assigning extent [of discontinuity characteristics] from overlapped, two- dimensional images to a three-dimensional model is also questionable.

   In contrast, the importance of determining persistence of discontinuities for three-dimensional modelling is described in Bester (2019) and Bester *et al.* (2021).

2) Mining-related, photogrammetry publications typically do not include description of associated technical aspects, including but not limited to:
   a) Statement of procedural norms such as calibration of equipment,
   b) Factual recollection of the field survey elements (e.g. the use of target markers, statement of the nature of the survey viz. estimated of professional] etc.),
   c) The resolution of the images collected,
   d) The number of images used toward the construction of the 'coalesced' image [differentiated from the number of images actually collected, because computational limitations or software limitations may impede the data and image processing], and
   e) The algorithms used during automated merging of images.

   Therefore, independent verification cannot be carried out to assess the representativity of the data collected, the integrity retained during merging of images etc. Additionally, advancements in the algorithms used for image processing cannot be readily identified, if the foundational information is not provided.

3) Also, in terms of ambiguity of language, it was observed that mining-related, photogrammetry publications often:
   a) Do not clearly state the distinction between the fact that the resulting 'coalesced' image was only used as *one of many inputs* to understanding a larger, problem which was later analysed quantitatively - as opposed to implying that the 'coalesced image'

[21] The authors of the 'deficient' publications are not singled out by name in the thesis, as the objective is not to embarrass the individuals or their efforts. The candidate acknowledges that the context of the work or the desired emphasis of elements within the work by such authors may preclude the incorporation of a comprehensive, factual statement of all the elements in the process. The identification of the deficiency results as an output from undertaking the literature review.

provided absolute information that could not be determined through any other means.

b) Use vague language when identifying the specific aspect of uncertainty that prompted the photogrammetric exercise. The examples to this statement are observed in several case studies that mention in their abstract and introductory text that the photogrammetric exercise was to 'study the rock mass' – however, examination of the text suggests that often kinematic failures were occurring on a plane that did not appear in the data or model used by the mining operation – prompting the need to gain more reliable insight, as opposed to 'general study for interest'.

c) Do not clearly articulate if the once-off collection and coalescence of images that 'appeared to match conditions reasonably well at that time' performed similarly well as mining progressed with time and the validation held true. Rather, the exercises are presented as figurative windows of progress instead of a joined continuation.

In many instances the semantics, syntax and pragmatics were so varied that it was not able to compose a like-for-like comparison, due to the variable use of linguistic tools[22] used by authors in their publications.

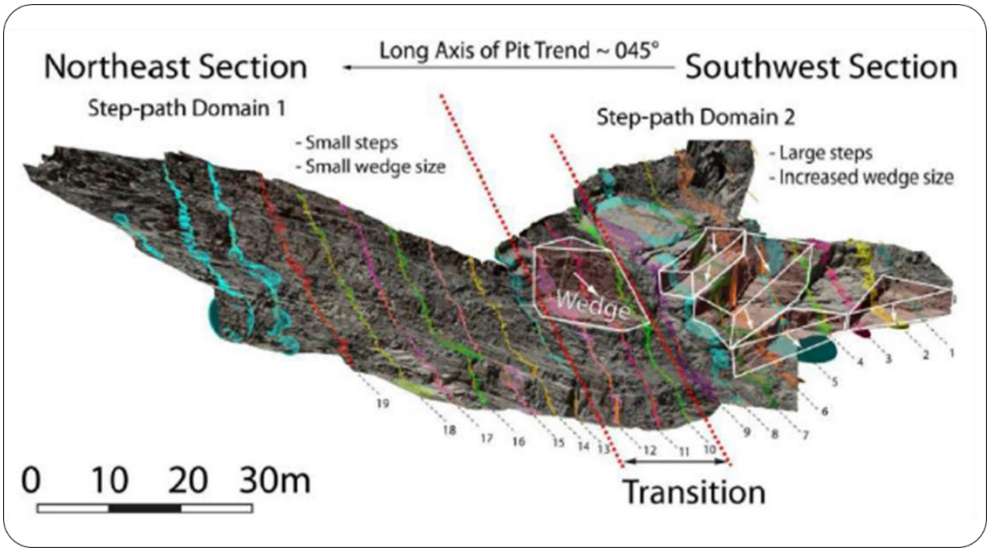


Figure 4-5: Photogrammetry model of east wall (f=100mm; distance=50m) showing a step path characterisation approach for evaluating existing slope geometry at Jwaneng mine, Botswana (Lupogo et al. 2014)

[22] Based on Andersen (1973); Briscoe (2000); Cann (2001); Batali (2002); Kirby *et al*. (2002); Blevins (2004); Bickerton (2007); Kalish *et al*. (2007); Baldi (2012); and Binder *et al*. (2013).

Amateur versus professional photogrammetric equipment

The accurate and precise measurement of metrics in general, rely on the use of appropriate equipment and tools – which is also true of photogrammetry, i.e. the mount or craft, and the camera are fundamental to the exercise.

During the course of their enrolment, the candidate participated in several conferences, one of which is particularly pertinent to the argument at hand – viz. '*Africa Drone Conference, 2019'*, held in Johannesburg, South Africa.

While it may appear uncharacteristic of a research thesis to recount such a unique experience – it is included with good reason: to point out the reality of differing opinions and equipment held by operators of 'drones' used in photogrammetry exercises carried out for mining projects in South Africa.

The event largely showcased equipment and examples of use for mining projects and civil engineering initiatives, rather than refinements in the pure science.

When the moderators opened the floor to discussion, several topics arose where operators identified their different opinions and practices, including:

a) The range of experience and legal compliance. Some operators were not in possession of licensing or registration from the South African Civil Aviation Authority (SACAA) even though they carried out photogrammetry exercises for companies and/or mining operations. In part, the reasoning posited included that their photogrammetry exercise was commissioned by and for a particular mining operation, and the commissioning provided tacit approval and acknowledgement. Other operators did not offer justification for operating without the required licensing and registration.
b) The use of survey markers. Some operators relied on survey markers within the *immediate vicinity* of the area being photographed for the photogrammetry exercise (e.g. within the open pit to the limits of the crest), within a moderate vicinity of the open pit (e.g. somewhere within the boundaries of the mine license area), or not at all. In the latter example, the photographs were said to be 'visually reconciled' with the digital vector file (e.g. dxf file[23]) of the open pit.
c) Georeferencing (e.g. the. transformation of the co-ordinate system to place digital images/photographs in spatial reference to the geographic co-ordinates of the ground system). Some operators stated their effort toward refined georeferencing, but lamented challenges in the undertaking that sometimes yielded only moderate results. A portion of the operators felt that in magnitude, tens of centimetres was considered to be 'close enough' and

[23] It is noted that the dxf file / model of the open pit did not always coincide with the timing of the photogrammetry exercise – in some instances, older / historic dxfs were used.

that georeferencing specific features to an ‘approximate’ level was sufficient. There did not appear to be any qualifying statement (e.g. if the feature was to be studied by an additional method, then approximation would suffice).

d) Image processing. Some operators described that to be able to process the images using freeware, they would take fewer photographs in the field, reduce the number of images imported to computer by randomly selecting areas that appeared to be visually inert, and/or selecting every n^{th} image and deleting it from the database. There is no description of this task in the reporting cycle, and no stated consistency regarding the extent of deleted images.

The conversation eventually moved to the topic of *quality* of equipment.
In this regard, one particular operator described their array of equipment [‘drones’]. The operator had high-end, specialised, ***commercial-grade*** units with:

- The resolution of the digital cameras was of the highest range available at the time [in the region of 80 megapixels],
- The global positioning system (GPS) unit used multiple bands of satellites [with connection to at least 12 different satellites], and
- The battery life for flights was in the order of an hour or more.
- For the purpose of demonstrating the contrast, the candidate includes mention that the cost per ‘drone’ was in excess of R1 million at the time (viz. 2019).

Conversely, the equipment used by the vast majority of the operators were all ***retail-grade*** units, typically with:

- Camera resolutions as low as 7 megapixels,
- GPS connections to often only 3 satellites, though some cases 4, and
- Battery life in the range of twenty to twenty-five minutes (depending on atmospheric conditions such as wind), and costs in the region of R17,000 to R39,000 at the time (viz. 2019).

The reaction from the majority of the audience was almost comical, in their collective ‘booing and jeering’ of the professional operator during their description of their equipment.
The professional operator maintained his composure and navigated the situation with well-crafted interpersonal skills and humour. However, he did raise several well-phrased debates regarding the quality of equipment in providing reliable data, including photo resolution, camera-lens distortion, calculating intersection angles correctly, accurate spatial orientation, and eventually the amount of overlap between

photos [24], linking the arguments to specific points in the conversation that had taken up until then.

It is specifically *this* level of divergence and discourse that has *not* made its way into scientific or journal publication – but which underpins the reality of the practice at the time.
Entrepreneurial spirit, with retail-grade equipment, conducting free-form photogrammetry exercises for mining operations, following little or no technical protocol (i.e. not in reference to safety procedures such as wearing a hard-hat and reflective vest, but in reference to equipment calibration, data handling, data processing, and integrity of reporting), with results that are treated with the highest order of confidence despite the lack of internal consistency, may be satisfying short-term, tactical goals, but potentially overlooking longer-term strategic benefits that could be achieved.

As the conversation and conference drew to a close, the general consensus from the group was that *'their respective Clients (being mining operations etc.) were satisfied with the way the work was carried out, so from an operators stance, a collective 'agree to disagree' sentiment took hold without further need or expression of resolution'*.

The tone and setting of the forum created excellent opportunities for debate and demonstration, as well as sharing and showcasing a broad range of elements for the benefit of interested parties from a wide range of backgrounds and professions.
The very practical demonstration of divergence and discourse is not conventionally available in journal publications, but did allow an appreciation to the spectrum of practitioners - from entrepreneurial spirit to professional operators – interacting with mining operations in South Africa.

[24] Although not part of the conference, the paper by Dai *et al.* (2014) offers clear descriptions of sources of error in photogrammetry, and their impacts on modelling and surveying.

LiDaR and other technology

Highwall mapping has been carried out using unmanned aircraft system technology (Katuruza, 2019), and Woolmer *et al.* (2021) have described the initiation of using drone-based LiDAR technology at Olympic Dam Mine, Australia.
Gallant *et al.* (2016) have undertaking automated, rapid mapping of joint orientations with mobile LiDAR, and structural recognition and rock mass characterisation in underground mines has been carried out by Vallejos(2019), using an unmanned aerial vehicle (UAV) and LiDAR mapping. Baylis *et al.* (2020b) have furthered the application and used mobile drone LiDAR for structural data collection, followed by a structural [kinematic] analysis.

Where the tools and techniques move to automation, computer programs for automated mapping of geometrical and kinematical properties of hard rock slopes are described by Günther (2003) and laser scanning technology has been used to quantify rock fracture orientation (Lemy and Hadjigeorgiou, 2004d).

A preliminary investigation of the use of mobile mapping technology for underground mining was carried out by Raval *et al.* (2019), and in later years, Lemy *et al.* (2004c) completed a case study using digital face mapping in an underground hard rock mine. Since then, robotic mapping of underground mine passageways has been shown by Artan *et al.* (2011), and three-dimensional mobile mapping and surface reconstruction of an underground mine has been described by Zlot (2013). Convergence detection in underground tunnel environments, using mobile-LiDaR appears to also be successful (Lynch *et al*., 2017)

The case study described by Zlot and Bosse (2012) and carried out at Northparkes Mine, Australia, provides an example of ingenuity and creative problem-solving. To understand how several large pieces of equipment could be moved through the decline, the miner operators required a locally accurate, three-dimensional surface model. Whereas existing techniques (comprising scanners mounted on tripods) rely on accurate surveyed, sensor positions and are considered to be relatively expensive, time consuming, and inefficient. Therefore, a mobile mapping solution was able to map the space more efficiently and completely - using a three-dimensional, Simultaneous Localisation and Mapping (SLAM) solution developed at CSIRO. The system incorporates two-dimensional lidar and industrial-grade micro-electro-mechanical system (MEMS) inertial measurement unit (IMU) that had been customised for the project, to overcome the constraint of existing, commercial, mobile mapping systems reliance on global positioning system (GPS) signal and high-calibre inertial systems.

The use of LiDar also aids related mining disciplines, as show by Watson *et al.* (2018), using a moving LiDar to collect three-dimensional data for use in estimating underground mine ventilation friction factors.

4.2.4 Advancing our understanding on specific rock-related aspects

4.2.4.1 Characteristics and estimation of rock mass parameters

The identification, description and characterisation of rock mass properties may be considered the very ‘heart’ of the fields of rock mechanics and geotechnical rock engineering – because the nature of the rock mass needs to be known in order to be able to apply engineering principles and estimate likely responses, as well as reason how these may change over time.

Overview

The construction of a conceptual or digital model to assess design criteria, optimise design elements, and/or identify support requirements for geotechnical mine engineering may potentially be a complex undertaking. The value of the model output can be considered to be dependent on a large number of precursory inputs – almost all of which are out of the hands of the practitioner building and running the model. In parallel, the role of good data and the role of sound judgement play a vital part in the evaluation of stability of a geotechnical mine design in hard rock. The candidate recapitulates the concept, using the SAIMM presidential keynote address by Stacey (2003).

Stacey (2003) establishes that, rock engineering as practised discipline, has existed for nearly half a century and a number of sophisticated methods of analysis have been developed during that time. However, in reality, some rock masses may be so complex that a realistic analysis cannot be achieved – regardless of the sophistication of the method.

At the same time, rock mass classification methods, for the purpose of quantifying the rock mass, have been developed and have formulated, in various form, a range of ‘expected’, ‘typical’, or ‘historical’ values. Such values and indices are nowadays applied as a normal course of process – which may not always be appropriate. Demonstrating the highly variable characteristics of a rock mass, and therefore the uncertainty in the behavioural parameters, Stacey (2003) presents real projects as examples to demonstrate the practical realisations of the concepts.

Mikeš (2010) re-iterates the apparent stance that the empirical method seems to have been accepted as being appropriate without question - in their address to the European Geosciences Union (EGU). Framing the address through “theoretical geology”, Mikeš (2010) uses “sequence stratigraphy" is an example of the dogma and

explains that it can be easily argued if the assumptions used to build a method are incorrect, then the subsequent interpretations derived out of the method are also incorrect, yet the method continues to survive, despite criticism. Mikeš (2010) then postulates that inherently four-dimensional systems such as geology (i.e. three spatial dimensions and one temporal dimension) are not likely to be correctly described using methods with an inferior [less than] dimensions of consideration.

An associated theme, of the apparent duality of empirical observations and technical analysis, continues in Elmo *et al.* (2020d).

Progression of discourse regarding analysis based on empirical tools

The matter of rock mass characterisation and classification is well established in literature.

An overview of the development and application of a variety of classification systems and schemes, built from publications by Palmström (1995), Stewart and Forsyth (1995), Edelbro (2004), and Fereidooni *et al.* (2015) is shown in chapter 9, sub-section 9.4. The table is not wholly exhaustive, as it looks to identify those classification systems more prevalent in literature.

Nearly each of the classification systems developed to date, has been subject to both praise and debate. Examples and their explanations are shown in chapter 9, sub-section 9.4.1. The decision to present the material in the annexure is based on the prerogative to keep the document to a reasonably manageable size (in terms of volume). The examples include:

- Rock Quality Designation (RQD);
- Q-system;
- Water and Stress in Rock Mass Characterisation;
- Hoek-Brown Failure Criterion;
- The Geological Strength Index (GSI) ;
- The Geological Strength Index (GSI) from Rock Mass Rating (RMR) ;
- Stability Graphs;
- Correlations;
- Characterisation and Classification;
- Scale Effects in Rock Masses; and
- General Relationships.

4.2.4.2 New ideas – though still only directed toward preliminary rock engineering studies

Recently, Ozturk *et al.* (2014) proposed a new method in rock engineering for estimating the mechanical and physical properties of rock materials (particularly compressive strength of rock, σc) from microscopic investigations i.e. using the quantification of rock texture. The study used a texture coefficient (TC), determined through statistical assessment of thin section images, to quantify rock texture (and used twelve different images from a single thin section to increase the reliability of texture analysis). The dataset subsequently prepared, was used to investigate correlations between TC and σc. Statistical correlations from the dataset were computed after classifying of the rock samples based on grain features and their lithology.

The study results allowed equations to be derived for use in predicting the approximate value of compressive strength from the texture coefficient, and Ozturk *et al.* (2014) suggest that the method is appropriate in preliminary studies in rock engineering projects.

4.2.4.3 Data and databases – their development, recognition and importance

The recognition of the value of databases has grown over the years. Little (2006) provides an account on the benefit of geotechnical databases to slope design in open pit mining with an excellent presentation of information in a step-by-step narration. Similarly, Elmouttie *et al.* (2016b)discuss the benefits of undertaking robust structural mapping for the slope design and management.

The compilation of databases has also become more prevalent, and there are several databases that are known and/or accessible to rock mechanics and geotechnical engineering practitioners. These include:

a) The (Canadian) seismicity and rockburst database (Brown *et al*., 2017a).
b) An online database of mine planning and peripheral software used in the South African mining industry (Katakwa *et al*., 2013).
c) An ore pass data base of Quebec's underground metal mines (Lessard *et al*., 2006).
d) An updated *in situ* stress database for Southern Africa (Wesseloo and Stacey. 2006).

4.2.5 Improved understanding and engineering in weak, weathered and jointed rocks

4.2.5.1 Weak rocks and weathered material

The Description and Classification of Weathered Rocks for Engineering Purposes was initially reported by Norbury, *et al.* (1995) when soon thereafter, Aydin *et al.* (1999) undertook to provide a critical review of efforts made to improve the description and classification of weathering grades, as well as practical issues and methods for characterisation of igneous and metamorphic saprolites.

'Saprolite' is considered by Aydin *et al.* (1999) to refer to '*that part of the weathering profile where the soil largely preserves its original rock fabric and volume'*. Their study found that a lack of comprehensive characterisation studies (including mineralogical, microfabric, geochemical, and engineering geological studies) within well-defined geological frameworks are underlying reasons for

- The failure to define, characterise, and model saprolites as complex engineering geological units.
- Devise specific site investigation methodologies to explore these complexities.

The analysis considered comparative studies of weathered profiles developed for igneous and metamorphic rocks (viz. of Moye, 1955; Sowers, 1963; Deere and Patton, 1971), as well as profiles with sharp transitions (Ruxton and Berry, 1957) and gradual transitions (Newbury, 1970).

Various efforts had been made over the years toward classification (for each specific rock type as well as for all rock types) and field methods for characterizing weak rock are shown in Santi (2006).

More recently, Martin and Stacey (2013) explored the topic further, stating that the strength of hard rocks is traditionally determined using rock mass classifications and the Hoek−Brown failure criterion where there is, however, sufficient evidence that those approaches do not correctly capture the strength characteristics and the failure processes evident in weak rocks. Martin and Stacey (2013) describe several aspects and processes to be considered when determining a the strength and failure envelopes as inputs intended for slope designs of open pit mines in weak rocks.

The International Society for Rock Mechanics (ISRM) 2014 symposium focussed on the topic of "Rock Engineering in Difficult Ground Conditions", producing approximately fifty-nine technical papers on the subject.

The, CSIRO have released the Guideline for Open Pit Slope Design in Weak Rocks (2018) where guidance is given on a variety of topics – from collecting field data in weak rocks, to use in models, the role of water in weak rocks and slope design, cemented sediments and specific discussion on weak sedimentary mudrock; coal,

chalk and limestone; residual soil; leached rocks; as well as hydrothermally altered rocks.

4.2.5.2 Jointed rock masses

The Technical University of Vienna (1990) have considered a variety of topics describing and affecting the mechanics of jointed and faulted rock – these include geology, faulting, fracture mechanics, testing, hydraulics, mining, and thermodynamics.

Toward more main-stream applications, the text hereunder considers discrete fracture networks and synthetic rock mass modelling.

Discrete Fracture Networks (DFN)

A 'discrete fracture network' (DFN) refers to a computational model used to model geomechanical evolution and/or hydromechanical behaviour of natural fracture networks in hard rock. Pertinent geometrical properties[25] of each individual fracture are represented with topological relationships between individual fractures and fracture sets in the DFN.

Steimle (2002) in Kiner *et al.* (2004), on the topic of the state of the practice [circa 2001] of characterisation of fractured rock, identified that there was a lack of technology/information transfer from researchers to practitioners.

Advances in the modelling of DFNs are described by Dershowitz *et al.* (2004) with handy reference to particular rocktypes. Later, Somr *et al.* (2016) also review the progress of DFN and present their findings showing the importance of statistical analysis to stochastic modelling. Stacey *et al.* (2015) chronical experience on developing and using a simple DFN approach over a period of 30 years.

DFN modelling – at the mine scale – has been used toward rapid upscaling in geomechanical simulations of large open pits by Rogers *et al.* (2009), has been used with discrete element modelling Esmaeili *et al.* (2015a) to address ground control issues in an underground mining operation, to design drift reinforcement by Hadjigeorgiou *et al.* (2017a). Practical findings on the influence of fabric mapping bias applied to DFN's have been made and the further impact on estimation of failure discussed by Mathis *et al.* (2018).

[25] These include the size, shape, aperture and position of each fracture

Synthetic Rock Mass (SRM) Modelling

Synthetic rock mass (SRM) modelling, is a reasonably new approach for simulating the mechanical behaviour of a jointed rock mass, and is considered “a step forward” in the characterisation of jointed rock masses Mas Ivars *et al.* (2007).
Computationally, a bonded particle model for rock to represent intact material and the smooth-joint contact model (SJM) to represent the *in situ* joint network (Mas Ivars *et al*., 2011a and 2011b) - where the macroscopic behavior of an SRM sample depends on the creation of new fractures through intact material as well as the opening of existing joints. Reyes-Montes *et al.* (2007) are also able to show validation of a SRM using excavation-induced seismicity.

Valuable insights are identified in Sui *et al.* (2021) using SRM in block caving pertaining to the propagation of rock disruption and caving. Use a case study of the Hemushan Iron Mine, China, the authors used a SRM to simulate the caving process and monitor caving characteristics. It was found that the crack zone was significant for rock mass with inclined joints after undercutting and the crack zone existed not only around the undercut area but also further away in the model. Further findings include that:

- The stress concentration areas dispersed in the model except for the top of the undercut area;
- The caving line was not a standard arch;
- The caving line was biased towards the direction of the undercut, at its highest point; and
- The number of cracks decreased, the degree of stress concentration became weaker, and the height of the caving line decreased when considering the same undercut width using a decrease of joint length in the joint system.

The findings are valuable not only in the direction toward optimisation of block caving, but also to gaining insight into potential deformation not expected or demonstrated using alternative modelling techniques.

Recommendations of the importance of geotechnical mapping to source structural information are put forward by Bester *et al.* (2021). The study used SRM to characterise the rock mass for slope stability analysis using a case study at Sishen Mine, South Africa. Incorporating, a sensitivity analysis to understand the relationship of bedding persistence with rock mass strength, results indicated that bedding plane sizes that are less than the sample dimensions, produce higher strengths. This is due to the influence of rock bridges. When using SRM modelling in slope stability analyses, joint persistence is a critical factor in the related rock mass strength analyses and Bester *et al.* (2021) conclude that the definitive resolution of SRMs is wholly reliant on

data provided by high quality, bench-scale structural mapping. The importance of geotechnical mapping is re-iterated, as it is currently the only way to accurately determine joint persistence.

4.2.5.3 Development of products for reinforcement of hard rock

Rock mechanics and geotechnical engineering also require understanding of the rock mass as it is altered by mining activity and the engineering mechanisms to contain vulnerable, loose, deformed, stressed or failed rock. By way of example, the use of shotcrete linings is explored and reviewed hereunder.

Other products have also undergone advancement and refinement – such as, tensioned rock bolts and cables, dowels, mesh and steel sets. However, it is not necessary for the current scope of the research to detail each of these or describe their subsequent deterioration (e.g. corrosion) – the demonstration of the principle of variation, evolution and application is shown through the description of shotcrete.

Examples and their explanations are shown in chapter 9, sub-section 9.4.2. The decision to present the material in the annexure is based on the prerogative to keep the document to a reasonably manageable size (in terms of volume).

4.2.6 Changing priorities in the understanding of groundwater and grouting

Cover drilling and grouting (i.e. drilling and grouting ahead of excavation as part of controls to managing the influx of groundwater by intersecting water-bearing fissures, and in some instances also to manage the influx of gasses) is said to vary only in the intensity of application of the treatment in South African mines, where cover drilling and grouting is in turn dependent on *in situ* rock mass conditions such as permeability and quality of the rock mass etc. in these mines (Heinz, 1997). When reflecting on the holistic evolution of the practice, Heinz (1997) perceives that grouting engineering has "*entered a new era…[with] a new dynamism [that] has evolved driven by new techniques, new materials, new research…. and other factors [that are part of and pertinent to the advancement are] environmental issues and computerisation…".*

The descriptions by Heinz (1997) considers "*the increasing scarcity of good formations" and the "necessity of using available but less suitable sites [that] will also require improved soil and rock investigation techniques*" – stating unambiguously that "*the characterisation and categorisation of individual sites with respect to grouting engineering still leaves much to be desired, hence, for grouting projects – the standard site investigation requirements should be extended by grouting tests in order to optimise solutions for the given conditions and available materials and techniques".*

A case study by Nel (1997) reveals that cover drilling and limited cementation did not prove very successful during the sinking of a 10.75 metre diameter shaft, 2500 metres deep, through water bearing strata where large quantities of water were intersected. Nel (1997) puts the practical challenges into perspective by incorporating a description of the impacts on air intake and upcast ventilation, the hoisting of rock, as well as service hoisting of men and material. The conclusions and recommendations put forward by Nel (1997) are very apt – cautioning mines and persons to resist the temptation of becoming impacting due to the time and cost of carrying out cover drill and cementation procedures properly, because rushing the work or taking shortcuts (e.g. plugging the fissures rather than sealing them) results in:

- Higher costs (viz. pumping),
- Bad environmental conditions,
- Potentially disastrous consequences of an expensive rescue operations, and
- Potentially even being compelled to abandon a mining project.

Nel *et al.* (2000) share practical experience and reveal that although cover drilling and pre-injection ahead of the advancing shaft face is standard practice in many South African mines, the method is sometimes perceived to be very expensive and time consuming and the results achieved are sometimes not always regarded with equal satisfaction.

The importance of cover drilling and cementation as part of standardised operating procedure is emphasised through the understanding that controlling ground water during shaft sinking may be complicated - especially if shotcrete is required (either as a temporary support close to the advancing face or following as permanent support) because wet face conditions impede the production of a high-quality concrete or shotcrete lining that would be conserved suitable as a permanent lining. Furthermore, even within the conceptualisation and implementation of the cover round design, there is potential for varied levels of success, for example, when considering a cover round design where all the holes intersect a point approximately 6 metres outside the excavation (e.g. the shaft), Nel *et al.* (2000) highlight that any distance close than 4.5 metres to the excavation line may become subjected to blast damage, resulting in leakage from fissures, even if they were previously sealed. Additionally, when considering the design length, there is also some vulnerability in that the longer the round, the larger the potential for deflections and inaccuracies resulting from the deflections. Where it is recommended all holes should be grouted and sealed on completion of the cover round - irrespective of whether or not water was intersected – there is insufficient reporting to confirm that the recommendation is followed on an industry-wide scale.

Again, very practical knowledge is available from Nel (2000) regarding site-specific requirements, costs and cost-relationships related to cover drilling and grouting where the use of a micro-fine cement as a grouting material for the sealing of water fissures in sinking shafts down to 3500 m below surface is demonstrated, and the potential application and advantages that can be gained from stable and low viscosity micro-cement grout are detailed by Nel (2000).
Compelling factors, such as that modern sinking methods have a limited provision for handling water in excess certain flow rates and viscosity, and therefore related excess is likely to seriously impede the viability or the progress of the project - and the capital costs. The revelations by Nel (2000) then also relate that no single factor influences total cost of shaft sinking as much as time – while the cost of materials using Ordinary Portland cement (OPC) in a grouting operation may amount to around 5% of the total, the time-related cost would be more than 60% of the total costs.

Kuś and Polozov (2000) continue the discussion and provide practical chronicles for the requirements and design of sealing grout curtains, as well as the selection of materials for their preparation, using both open-cast and underground mines as case studies – but even then, the matter of water in mining continues to grow in knowledge on how to incorporate with related disciplines, e.g. the 12th Annual International Mine Water Association Conference, under the theme of '*An Interdisciplinary Response to Mine Water Challenges*' - published over one hundred and sixty technical papers.

4.2.7 Technological developments

4.2.7.1 The quest to mechanise mining in South Africa

An account is given of the first introduction of fully mechanised mining methods to two mining operations by Mullller *et al.* (1959) and mention of the introduction of mechanised methods in certain sections of other mines is made (for trackless mechanised coal mining and although not in the hard rock context, does demonstrate that lessons learnt are available for the dynamics of transition).

Thereafter, emphasis on the mechanisation of gold and platinum mining operations moves to the fore.

Rhodes (2015) provides an extensive literature review of the transformation to mechanisation over a period of 25 years in South African Gold and Platinum Mines, focusing on tabular ore bodies, whereas other authors provide unique insights to more specific accounts of mechanisation, including Ilson (1975) on the mechanisation of haulage drilling in the gold mines of the Anglo American Corporation, Geldenhuys (1985) with a discussion on the mechanisation of mining operations with general view to benefits and advantages, Kendall (2000) regarding mechanisation in *stoping* of narrow tabular orebodies, Laflamme *et al.* (2002) on the generalities and variety of mine mechanisation and automation, and Willis *et al.* (2004) provide a framework for the introduction of mechanised mining [with reference to platinum operations]. Kendell and Gericke (2000) simplify the explanation of their drivers toward mechanisation, stating that many factors have influenced the cultural make up of deep level mines, but it is widely recognised that deep South African mines are run at ‘high cost’ due to the labour-intensive nature of deep level mining operations.

A key element linked to the increasing mechanisation of mining operations is the role of people – which is articulated holistically in both Voght *et al.* (2016) and Gumede (2018).

One particular experience of mechanisation in South African mines that stands out is reported in Madubela (2022). The piece offers a uniquely honest perspective on the challenges of mechanisation. The insights are extremely valuable because they are not layered behind ambiguous language and have not morphed, as so many other publications on mechanisation have - into marketing /advertorial material, rather than objective and holistic comparison of performance across all relevant features.

Interview components included by Madubela (2022) identified that:

- A relatively large expense (R75 m circa 2022) was made on a mechanised drill rig would that not see it surpass output of traditional mining methods in the near future
- Gold Fields’ South Deep mine is the only fully mechanised gold mine in South Africa - but is yet to live up to the benefits of full mechanisation.

- The country's other lesser-known mechanised gold mine is also not a top performer, having recorded a 7% decrease in revenue in 2021 for the mining company that owns the operation.
- Gold Fields made significant efforts to understand and navigate the situation to achieve the best outcomes possible , recognising the mine's importance and conforming with the company's principles.

Madubela (2022) cites Gold Fields' spokesperson Sven Lunsche reflecting that "*although South Deep… was mechanised – there was… a skills deficit: many of [the] miners lacked the skills set to operate the equipment and machinery…. And that's why we brought in engineers from Australia to try to upskill the miners in South Africa. But, mechanised mining requires years and decades of experienced operators which we simply didn't have in this country at the time*."

In addition to the matter of skills, another reason attributed the mine's underperformance was "*insufficient capacity to adequately maintain the sophisticated equipment needed to run the mine, most of [which is] imported*."

The confirmation is reported that the mechanisation has (albeit only in the last few years) seen a return on that investment and that the mining personnel are become more proficient at managing and running a mechanised mine.

The interview begins to draw to a close with the recognition that the mine ran at a loss for several years and only began to see some profits from 2019 when it generated R151-million in net cash. In 2020, net cash from operations was R558-million (which then jumped 157% in 2021 as South Deep generated net cash of R1.4-billion).

Toward the closing comments, Madubela (2022) cites Mining analyst Peter Major that "*South Deep was a conundrum and had caused more consternation and trial and error than any other gold mine in the country" and attributing the underperformance of South Deep to myriad reasons that included leadership, mismanagement and the type of mine – i.e. "… South Deep ….tried mining it in a pseudo trackless way and they did all that development and bought all those machines but it wasn't working…Then they fired management and brought in new management, then they brought in Australians [who have years of expertise in mechanisation]. They've had a lot of different managers and each manager wanted to try a different way. It has gone through a lot of hands. It was a new and different ore body and it did look like mechanisation would work but there was a lot of trial and error to figure it out*."

The interview and insights are released through periodical publication – rather than academic discourse, which does suggest the potential for more honest and more practical description of the matters under discussion.

4.2.7.2 Advancements in monitoring approaches, practices and technologies

The imperative for safe working conditions in a mining operation, in addition to economic considerations, have contributed toward the advancement in monitoring technology and practices.

Whereas initial slope failure prediction methods in open pit mines, for example, use acceleration, velocity, and strain criteria in their evaluation, Newcomen and Dick (2016) provide a motivation and justification for the implementation of slope monitoring in open pit mines on the rationale of an update to the strain-based approach to pit wall failure prediction. Newcomen and Dick (2016) elaborate on the need and ability to differentiate between non-critical pit wall movements as a result of rebound or relaxation of the excavated slopes. An account of forty-eight different slope failures - with surface monitoring data - are presented and subsequently assessed using the strain-based failure prediction approach, taking into account the rock mass quality and the potential failure mechanism.
The results indicate that the strain-based approach can be used to provide general guidance regarding strain thresholds for pit walls - for a variety of failure modes – and in diverse geological environments. The advantages and potential drawbacks of the strain-based and other slope failure prediction methods are also discussed.

A natural progression of implementation priorities appears to lie in the optimisation, and automation of the monitoring system.
Mphathiwa and Cawood (2014) put forward the design principles for optimising a slope stability monitoring system that is already established, while Gairns (2005) and Duffy *et al.* (2001) show:

- The semi-automation of a monitoring system (developed using reflectorless total station) to conduct structural deformation monitoring; and
- The integration of the monitoring program for Diamond Valley Lake, United States, respectively.

In contrast, Lutes *et al.* (2002) describe the advancement of monitoring using Robotic Total Station.
For the purpose of geohazard assessment conducted in real-time, in deep underground mines, the automation and results of a monitoring investigation is discussed in McGaughey *et al.* (2017).

A fully automated monitoring system has also been described for the use in emergency preparedness by Bond *et al.* (2007).

Complementary but practical accounts of case studies in field monitoring in geomechanics are presented in the international conference on the topic, hosted every few years by the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) (outlined in chapter 9, Table 9-3).

The Western Australian School of Mines (1993) has also published a range of advancements in geotechnical instrumentation and monitoring in open pit and underground mining.

4.2.7.3 Advancements in computations, modelling and digitisation

The research framework does not require the identification of each milestone regarding the advancements in modelling using in rock mechanics and geotechnical engineering, nor to contrast the advantages and disadvantages of the various methodologies – the research objectives rely on the demonstration that variable approaches do indeed exist, and that they may selectively identified and applied differently by practitioners. The summary that follows demonstrates the aforementioned variability.

Performance in the field

The aspect of surface subsidence provides a useful figurative example to highlight the contrast between expectations and performance.

Ropski and Lama (1972) investigated the caving, fracturing and bending in roof strata in their study of subsidence in the near vicinity of a longwall face. Ropski and Lama (1972) stated that "*the behaviour of any rock bed under given conditions of extraction is very difficult to predict… and as such the height of the [caving] zone cannot be determined from laboratory… investigations*" which serves as a reminder of the changing nature of knowledge and science in the rock mechanics and geotechnical engineering. The changing nature of knowledge and science may be a compelling reason to record [document] understanding and beliefs at the current time, even if they change with time.

Rankilor (1971) successfully constructed a photo elastic model simulating mining subsidence phenomena that was sensitive enough to be actuated by gravity alone, in order to simulating mining extraction and the effect of subsidence of varying panel-to-pillar ratios. The model was used for an initial assessment that displays a realistic subsidence- development curve, which also compared favourable with field observations. An interesting finding was that the formation of an inverted wedge over the mine workings could be shown, instead of the classical arch "so frequently postulated in mining papers, according to Rankilor (1971).

During their investigation of the angle of fracture in mine subsidence, Singh *et al*. (1976) contrast horizontal and vertical angles for different rock types – but were also diligent to include a concise literature review of the norms of measurement of the extend for various countries as being:

a) Vertically above the working perimeters
b) Normally above the working perimeter, or
c) In-between the vertical and normal planes.

The norms contrasted are relevant as they may potentially offer insight into the expectations of non-technical, and/or non-specialist stakeholders i.e. what extent of subsidence do the general public expect (or will tolerate) as the mine reaches nearer its life, closure, and post-closure – especially because the general public are not privy to the computations and models for 'unfavourable [but expected] outcomes' such as surface subsidence.

Statistical analyses

In terms of statistical analysis of geotechnical data, a variety of techniques have been developed as far back as Hald (1952) and as recently updated as trends in Bayesian theorem grew in popularity (e.g. Ross, 2007).

Uzielli (2008) and Ford (2019) provide a more modern and direct insight – and it emerges that one of the constraints to carrying out statistical analysis, is the *limited amount of and/or highly variable geotechnical data available* from individual studies.

Through a literature review focusing on open pit mines, Ford (2019) found that several limitations in practical stability analysis were apparent that prevent the formulation of a Factor of Safety versus Probability of Failure relationship for slopes in hard rock, when relying on the application of statistical methods.

Ford (2019) explains that rock mechanics and geotechnical engineering practitioners are free to choose any defendable value for each relevant rock material parameter during their assessment – as well as define the probabilistic behaviour of each relevant material parameter – which may create inconsistent Factors of Safety.

Probabilistic descriptions are considered to be poorly justified in many instances, and rely on matching Probability Density Functions from literature, or are based on simple assumptions (such as a normal distribution).

Given that the choice of Probability Density Functions determines the calculated Probability of Failure, if it is incorrectly specified then it may result in unrealistic Probability of Failure. Furthermore, when scale considerations are included, the Factor of Safety versus Probability of Failure problem becomes even less well understood, with very few studies even considering the probabilistic behaviour of rock at scale, in any meaningful detail, according to Ford (2019).

Given the inconsistencies in both deterministic and probabilistic rock material parameter selection, Ford (2019) concludes that it is highly unlikely that a viable relationship between Factor of Safety and Probability of Failure can be obtained using current industry practices, l*et al*one considering scale effects, and to achieve such relationship will require further research to explore deterministic material parameter selection criteria, probabilistic material parameter selection criteria, and an appreciation of probabilistic and deterministic descriptions of material parameters at increased scales.

Uzielli (2008) asserts that recognising the existence of variability in geotechnical data used for characterisation and design purposes is an important step towards consistent modelling, processing and assessment of the associated quantitative uncertainties. Uzielli (2008) offers a range of examples on statistical theory (usually employed jointly and iteratively with probability theory) to underpin the numerous methods and procedures toward practical application.

Read and Ogden (2006) eloquently reflect the challenges and solutions applied in open pit mines, remarking that

> *'over the years the slope design process in large open pit mines has been hampered by critical gaps in our knowledge and understanding of the relationships between the strength and deformability of rock masses and the likely mechanisms of failure. As practitioners we have not yet mastered particular complications associated with rock masses that are neither homogenous nor isotropic in low stress regimes that encourage large deformations. We usually manoeuvre around these difficulties by smearing the whole system with 'average' rock mass strength properties, calibrating its likely performance using existing slope movement data, and then performing parametric studies to isolate what we judge to be the more unlikely events. Although this is accepted practice, it has some distinct disadvantages.*
>
> *Notably, by approximating the behaviour of the whole system in the design phase we may have inadvertently masked a critical variation in the geotechnical model and potentially either underestimated or overestimated the geotechnical risk to the operation. Additionally, current procedures do not overcome the fundamental issue of accounting for anisotropy and large deformations. Last but not least, by calibrating against a known event we may also be inadvertently increasing production costs and, in fact, be limiting our chances of reliably predicting a future failure event.*

Collectively, these anomalies have generated a need to step outside the box and reassess the fundamentals of rock mass strength and slope failure mechanisms…"

The limits of limit equilibrium analysis

Krahn (2003) addresses the 'limits of limit equilibrium analysis' by considering that various types of limit equilibrium analysis are routinely used in geotechnical engineering practice – and have been for some time now. Advances in software have made it possible to gain more refined understanding of the inner workings of the methods. However, a closer examination of those details reveals that the method of slices has significant limitations – where a fundamental shortcoming is that limit equilibrium analyses do not consider strain and displacement compatibility. The shortcoming can be addressed by employing a finite element computed stress, inside a conventional limit equilibrium framework, where the total shear resistance and the total mobilised shear stress on a slip surface can then be computed, and subsequently used toward determining the Factor of Safety.

The discussion exemplifies the role of computational advancements and availability of software in current practice.

Transforming from two-dimensional to three-dimensional analysis

Continuing from the principles of limitation described in chapter 4, sub-sections 0 above, Steffen (1978) also demonstrated such limitations using case studies of the Saddle Pit and North Castle Pit at Ngwenya Iron Mine, the Kingdom of Eswatini (formerly Swaziland). Steffen (1978) demonstrated the principle that some failure modes cannot be sufficiently determined using traditional two-dimensional models, and that the construction and evaluation of a three-dimensional model was an important part of the assessment of design stability.

Numerical modelling

Numerical modelling, including Finite Element (FEM) and Discrete Element (DEM) modelling methods have been developed and rigorously debated – including computational components (such as discretisation) and parametric relationships respectively. Examples and their explanations are shown in chapter 9, sub-section 9.4.5. The decision to present the material in the annexure is based on the prerogative to keep the document to a reasonably manageable size (in terms of volume).

Numerical modelling has also been paired with other analytical tools to refine the application of the assessment - such as the evaluation of a hybrid coupled finite element-discrete element method (FEM/DEM) caried out by Elmo (2006) using a combination of discontinuity mapping and fracture mechanics modelling, in order to

determine rock mass strength, and the calibration of the numerical model described in Jones *et al.* (2016), using laser mapping from underground workings.

Progress in the number and specialisation of algorithms

Nhleko (2022) recounts that various algorithms have been developed to solve the value optimisation problem for near surface deposits and while researchers regard that the development of algorithms for open pit mine geometry has reached it peak, challenges in underground geometry optimisation remain largely unresolved. Given that a limited range of algorithms exist toward the optimisation of underground geometry, a dual interchange algorithm (DIA) was created by Nhleko (2022) by combining the strengths of two existing generic algorithms, was developed to offer a more versatile algorithm in handling variable stope boundaries in an effort toward.

Advances through integration of existing modelling methods

New and improved criteria for the evaluation of deep-level, tabular, mine layout design have been formulated by (MHSC SIMRAC, 2006), by integrating seismicity data and numerical modelling. The report provides an excellent systematic articulation of the basic formulation of rockmass stability assessment criteria, current practical strategies for integration of seismicity with numerical modelling, and future static and dynamic approaches to numerical modelling of mine seismicity, together with possible optimisation procedures for performing integration exercises.

Probabilistic, statistical, and machine learning

As for chapter 4, sub-section 4.2.7.3 above, the research framework does not require a detailed review of this aspect, the summary that follows demonstrates the variability required to assess the central hypothesises of the research: Cunningham (1983); Barton *et al.* (1990); Butcher (2000); Roy (2003); Helton *et al.* (2004); Asadi *et al.* (2005); Wiles (2005); Wiles (2006); Ebrahimabadi *et al.* (2011); Murphy (2012); Kricak *et al.* (2015); Silva *et al.* (2017); Wang (2018); Das *et al.* (2019); Guan (2020); Mutinda *et al.* (2021); Coetzee (2022); Porathur *et al.* (2022); Szendrei (2022); Hoek *et al.* (1980b); Goktan (2005a); Esterhuisen (2014a); Elmo *et al.* (2020d) and Lepenioti *et al.* (2020).

The volume by Soofastaei, (2021) provides a comprehensive and accessible review of data analytics applied to the mining industry, where each sub-branch of analytics is detailed.

Digital twin

A ‘digital twin’ is not a computational method of modelling, but rather a computational representation of digitised models.

It is understood that the concept of a “digital twin" derives, in part, from the National Aeronautics and Space Administration’s (NASA’s) use of the phrase ‘twin’ during the Apollo program, where two or more identical versions of space vehicles were constructed, which enabled specialists stationed on earth to use a vehicle to ‘mirror’ the conditions of vehicle in space, during the mission (Soofastaei, 2021). It is reported (Soofastaei, 2021) that NASA then introduced the term ‘digital twin’ to describe models that presented three essential characteristics:

1) A robust simulation environment,
2) High fidelity, and
3) A real-time connection with the physical version.

Elmo *et al.* (2020a) challenges the question of whether or not “*there really is such a thing as a rock mass digital twin*” and evaluate if machines may be capable of “learning” rock mechanics, by presenting their critical discussion on the potential use of machine learning algorithms based on empirical methods, as well as the use of qualitative to semi-quantitative scales of measurements that are inappropriate for a full statistical analysis.

Transfer of digital geotechnical data

Giles (1994) proposed and later, the Association of Geotechnical and Geoenvironmental Specialists (AGS) (1999) put forward standardised approaches for the digital / electronic transfer of geotechnical and geoenvironmental data – including guidance on file formats, units, rules of group hierarchy within the data and guidance on change control.

Zheng *et al.* (2013) released the ISRM Suggested Method for Reporting Rock Laboratory Test Data in Electronic Format – that includes the data structure to be followed.

4.3 Part B – Selections change with time

4.3.1 Getting steeper, going deeper, transitioning from open pit to underground

The various components for Part B of the literature review and their general flow are outlined in Figure 4-6. The content is then presented in detail in the sub-section below.

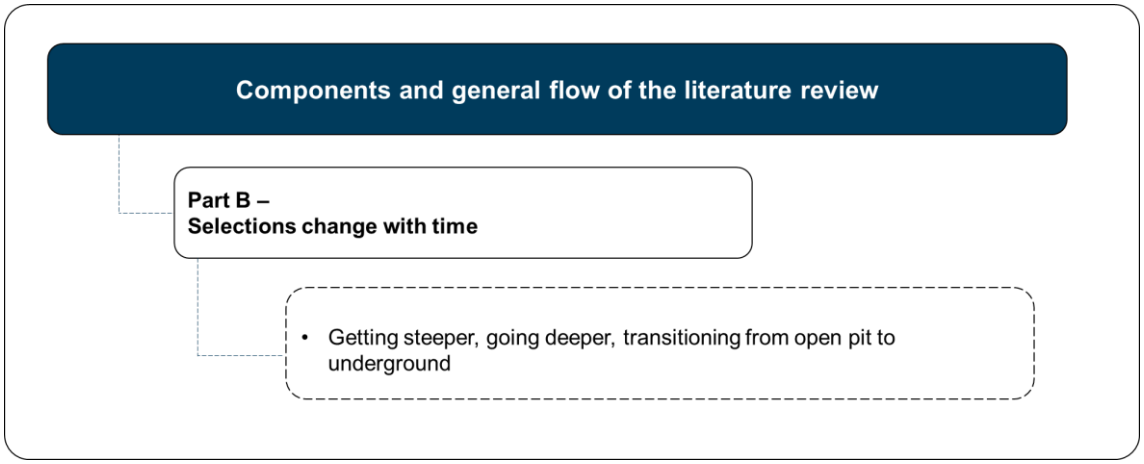


Figure 4-6: Simplified visualisation of the various components for Part B of the literature review and their general flow

It is not only the preliminary geotechnical mine design that requires assessment of viability, but also potential changes through the life e.g. steeper slope angles targeted in open pit mines, underground workings progressing deeper and deeper, or the potential for transition from open pit to underground.

In sequence of the options postulated in the paragraph above:

a) An investigation into a practical approach of design and implementation of steeper slope angles (at a kimberlite open pit diamond operation) is reported by Madowe (2016).
b) Thin *et al.* (2006) evaluate the future potential for mining even deeper still, at the Perseverance Mine, Australia; and Brown (2012c) explains the progress and various challenges encountered in areas of deep mining.
c) Several mining operations have transitioned from open pit to underground – hence, the identification of potential, methods of evaluation, design requirements are discussed in Flores (2005); Brummer *et al.* (2006); Carter *et al.* (2008); Bakhtavar *et al.* (2012); Chung *et al.* (2016); Hamman *et al.* (2020); PricewaterhouseCoopers Inc. (2022); Hoek *et al.* (1980b); Goktan (2005a); Esterhuisen (2014a); and Elmo *et al.* (2020d) and Olavarría, (2006).

4.4 Part C – Abstract aspects that may influence judgement

The various components for Part C of the literature review and their general flow are outlined in Figure 4-7. The content is then presented in detail in sub-sections 4.4.1 to 4.4.3.2.

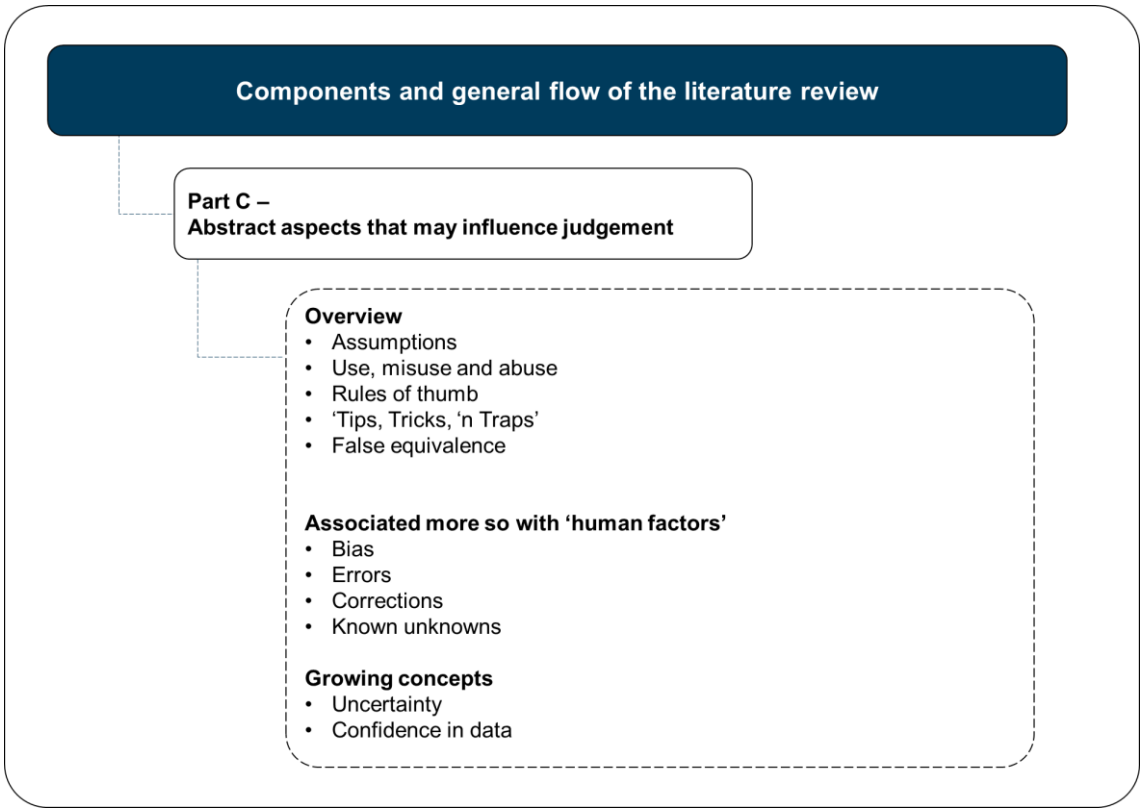


Figure 4-7: Simplified visualisation of the various components for Part C of the literature review and their general flow

4.4.1 Overview

The professions of rock mechanics and geotechnical mining engineering are largely based in factual, objective, tangible paradigms.

It would be (and is) very challenging to persuade many of the rock mechanics and geotechnical mining engineering practitioners currently active in industry, to concede the notion that inherent subjective beliefs and paradigms influence the actual technical work carried out.

A discerning text on the topic of 'subjective beliefs' is that by Vick (2002) which is comprehensive in content and clear in its explanations. The text describes a fair range of subjectivity, as well as tools (showing worked examples) with which to explore them. It is quite common that Vick's (2002) work finds its way into the list of references in mining engineering studies in recent times.

In addition to understanding, varying professional interpretations of a common aspect are not uncommon – particularly in geology and geological modelling. As Craig (2016) quips when referring to a recent discovery and re-interpretation related to volcanic activity "…*Ramalho*[26] *and Winkler's discovery…. is expected to revive a simmering debate among geologists*…."

The chapter below outlines the main features of subjective paradigms that may be present, albeit to different intensities, as well as errors that may occurring during the commission of technical work.

4.4.1.1 Assumptions

As in chapter 4, sub-section 4.4, the use models and principles where the founding assumptions are incorrect, as shown with example in Mikeš (2010), still persist.
Alternatively, contextual assumptions made and applied during analysis (e.g. during kinematic or stability analyses), are not communicated during the presentation of findings and reporting of the analysis.

4.4.1.2 Use, Misuse and Abuse

Following the review in chapter 4, sub-section 4.4.1.1, the aspect of rock mass classification systems remains a prime example of sub-optimal applications. Stacey (2000) outlines reservations regarding their use; Palmström, and Broch (2006) elaborate their opinions on the use and misuse - with particular reference to the Q-System; and Potvin and Wesseloo, (2012) discuss pitfalls and misuses also.
Subsequently, Pells *et al.* (2017) and Demetrious (2018) debate whether or not RQD should be put to rest – the stance of Pells *et al.* (2017) is that RQD has 'outlived its usefulness and is no longer effective as a classification and rock characterisation method'. The authors present examples in justification of their argument. In contrast, Demetrious (2018) writes in defence of the RQD system and asserts that there is no valid technical reason to discontinue its use. Demetrious (2018) also puts forward suggestions for a different approach that allows quantification of important characteristics of rock formations.

The theme of 'use and misuse' also extends to actual data – where Lock (2020) describes such instances of use and misuse' of historical data from diamond projects.

Limitations are present in some of the very information initially considered 'known and confident' i.e. the geological model. Hodgson (1993) describes the pitfalls, uses, and abuses of ore deposit models, and whereas types of mineralisation has been

[26] Ricardo *et al.* (2015).

extensively categorised – there is little description, if any, on the structural features and rock mass strength of the rocks hosting the mineralisation.
Grove and Bierlein (2007) lay out numerous problems with classification of various ore deposit types, recognizing uncertainties involved in the science thereof and propose that, whereas data reconstructions may support conceptual targeting, exploration and defined investigation be carried out to validate the occurrence of targets.
Figure 4-8 from Robb (2006) shows the distribution of ore deposit styles, classified according to orogenic (upper set of histograms) and anorogenic/continental sediment-hosted metal deposits (lower set of histograms) as a function of time, where the length of each histogram bar is an estimate of the proportion of ore formed over an interval of 50 million years, relative to the global resource for that deposit type. Periods of supercontinent amalgamation are shown as Pangea, Rodinia, and Nena, with decreasing levels of confidence further back in time. The diagram is originally after Meyer (1988) and modified after Barley and Groves (1992) in Robb (2006).
Figure 4-9, also from Robb (2006) shows the exponential decline in global heat production with time and the matching decline in production of komatiite volcanism, as well as a crustal growth curve and the period of enhanced mafic or “norite” magmatism in the late Archean and early Proterozoic (after Hall and Hughes, 1993) in Robb (2006).

The figures prompt the consideration that rock masses containing mineralisation have been subjected to different extents of volcanism, heat, and orogenic interaction that differs up to millions of years. Therefore, mineralisation aside, the rock mass properties related to different types of ore bodies are not strictly going to have the same strength properties, jointing characteristics etc. The candidate therefore contends that the ore body type e.g. narrow tabular orebodies does not guarantee similarity in other respects, and therefore, the site-specific geomechanics study and description are increasingly important.

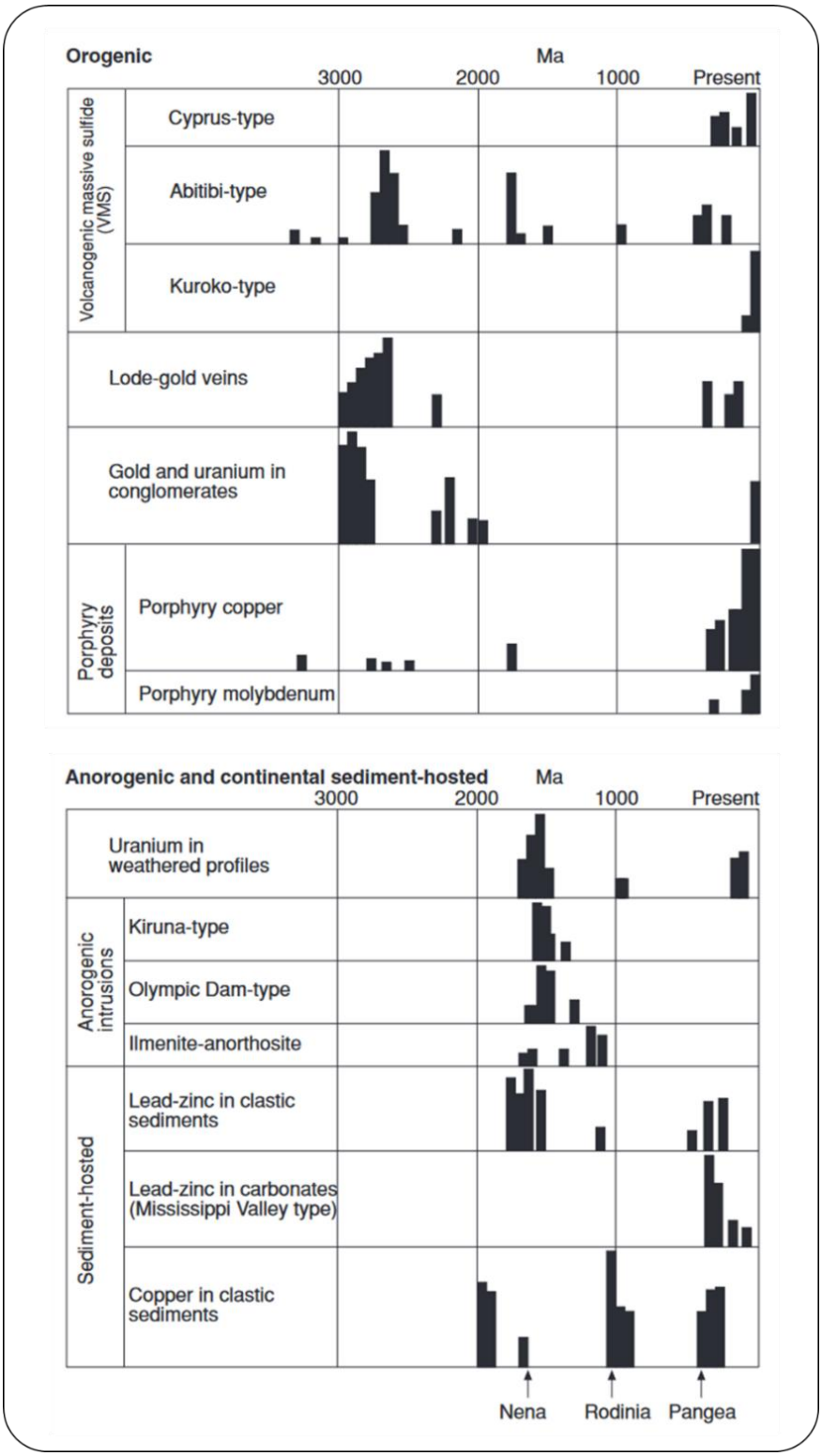


Figure 4-8: ***Distribution of ore deposit styles, classified according to orogenic (upper set of histograms) and anorogenic/continental sediment-hosted metal deposits (lower set of histograms) as a function of time. The diagram is originally after Meyer (1988) and modified after Barley and Groves (1992) in Robb (2006)***

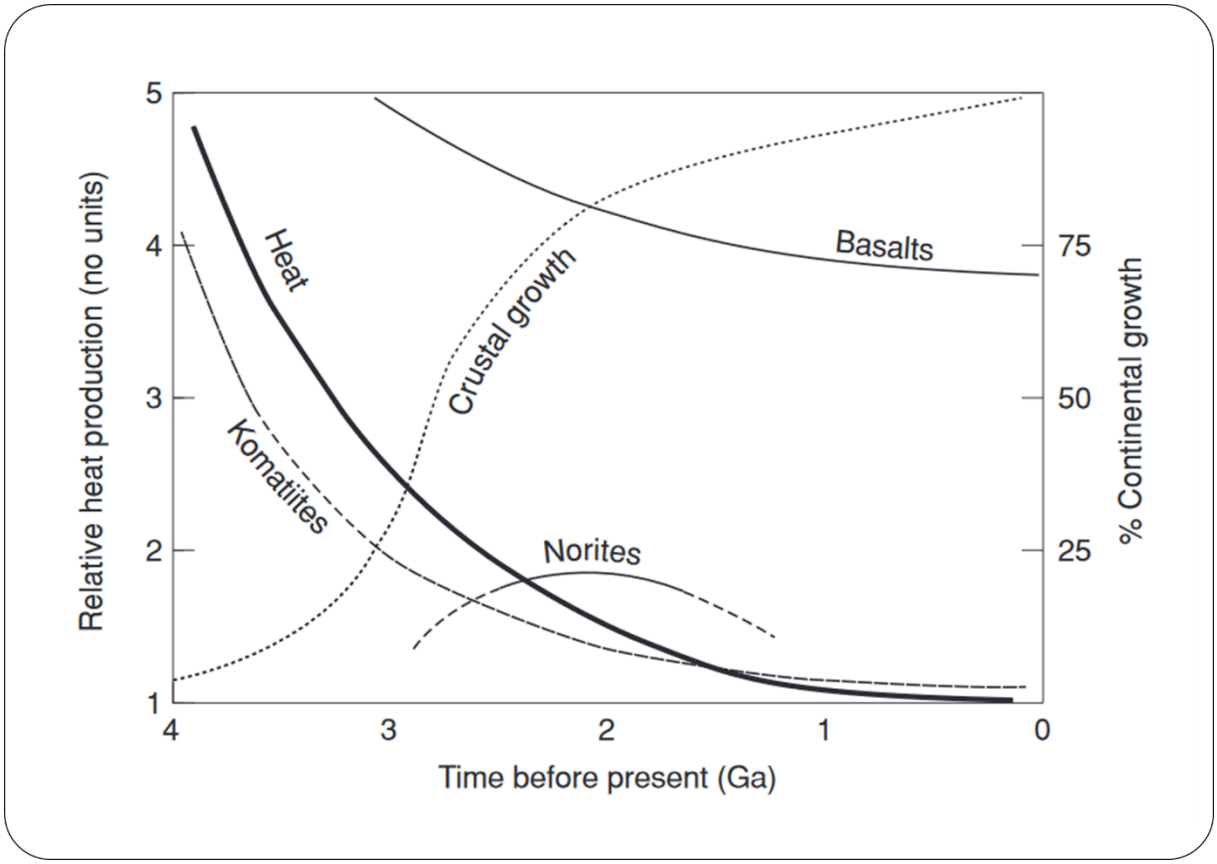


Figure 4-9: Schematic diagram showing the exponential decline in global heat production with time and the matching decline in production of komatiite volcanism (after Hall and Hughes, 1993, in Robb, 2006)

4.4.1.3 Rules of thumb

'Rules of thumb' are highly individual, often passed from mentor to mentee / boss to employee, and seldom make their way into the written record. That said, there are instances when the matter is documented e.g. Hazzard *et al.* (2011) attempts at developing 'rules of thumb for groundwater modelling in large open pit mine design'.

4.4.1.4 'Tips, Tricks, 'n Traps'

There are instances where grounded [reasonable] advice is given to assist other in adapting to challenging decisions etc. Credible examples of this are shown in the 'tips and tricks' for pit optimisers explained by Wharton (1996) and the 'tricks and traps' for seismic monitoring in mines set out by Hudyma and Brummer (2007).

Stantec (2008, p. 3) also offer a collection of 'tricks of the trade', which appear to be helpful insights to persons in earlier phases of their experiential training or career (despite that the publication does not apply bibliographic referencing as would be expected of a technical document).

That said, there are handfuls of less formalised ‘tips, tricks, ‘n traps’ used at different times during the geotechnical engineering life cycle and these seldom (if ever) make their way into the written record either. These less credible items can be equated with the notion of ‘getting things to work at face value, despite not grasping the underlying mechanisms and not ensuring the effective communication of surrounding circumstance’.

4.4.1.5 False equivalence

The informal fallacy, where equivalence based on flawed reasoning is drawn between two subjects. The phenomenon has been observed in feasibility-type assessments, where the project under assessment is likened with another project that has different mining elements in place.

4.4.2 Associated more so with ‘human factors’

4.4.2.1 Bias

Bias may occur at different phases of the geotechnical engineering life cycle, as indicated hereunder.

Sampling Bias

Sampling bias is well documented, especially for structural/discontinuity orientation data, namely:

a) Terzaghi (1965) chronicles the source of error in joint surveys,
b) Park and West (2002) give an account of sampling bias of discontinuity orientation, caused by linear sampling technique.
c) Grenon and Hadjigeorgiou (2003) explain that sampling bias often occurs when using the RQD, due to a preferential orientation distribution of discontinuities.
d) Using conventional and digital mapping of rock mass discontinuities, Fowler (2013) presents a description of data bias associated with both methods.
e) Thomas (2021) provides a narrative for visualising bias of structural orientation.
f) Elmouttie *et al.* (2020a) demonstrate the intense technical consideration in estimating the true deformation vector [from slope radar monitoring] pertaining to line-of-sight bias. The line-of-sight bias is said to be a well-recognised problem associated with radar monitoring. This is because the measurement of deformation is directed towards the detector, leading to misinterpretation of the size and rate of deformation, as well as the failure mechanism. Furthermore, these misinterpretations may lead to further miscalculation (e.g. the volume of failure), which in turn could negatively affect decision making and/or compromise safety of personnel or disruption to productivity.

g) Elmouttie *et al.* (2020a) elaborate on the finding that current methods to compensate for the bias use potentially inaccurate assumptions about the deformation vector relative to the wall/slope orientation, and while this problem may be addressed by using multiple slope monitors to observe the same region of highwall or low wall, it is understood that this is rarely implemented due to the expense associated with deploying multiple monitors for one zone.

Modelling Bias

A bias that is eventually translated into stability modelling is shown in Mathis *et al.* (2018) using the influence of fabric mapping bias, on applied DFN's and the subsequent impact on estimation of failure.

Laboratory Bias

In an interesting circumstance, the same sample yield different results between different laboratories – attributed to 'laboratory bias'. McWha (2014) then elucidates the matter of 'laboratory bias', which they state it is '*a universal problem in all branches of analytical science'* and resulting from differences in methods, techniques, equipment, and calibrations between laboratories.

Cognitive bias

The acknowledgement of potential cognitive bias into rock mechanics and geotechnical engineering is a relatively new development, where Elmo and Stead (2020b) introduce the role of behavioural factors and cognitive biases in rock engineering.

The topic of cognitive bias is more typically published through the social science, psychology etc., but is gradually permeating into technical sciences.

A summarised range of potential, but prominent, cognitive biases in rock mechanics, geotechnical engineering and risk management are annotated hereunder:

a) Anchoring – places an overt reliance on the first items of information obtained.
b) Availability heuristic – overestimates the importance of information that is available for consumption (irrespective of whether or not the information is correct, or important).
c) Bandwagon effect – compels a belief to be adopted, based on the number of people who hold that particular belief.
d) Confirmation bias – occurs as information that confirms one's preconceptions is accepted and absorbed more readily than information that contrasts the perception.

e) Pro-innovation bias – occurs when a proponent of innovation tends to overvalue it's usefulness and undervalue it's limitations.
f) Recency – is the tendency to assign greater weight to the latest information, over older data/information.
g) Salience – is the tendency to focus on the most easily recognisable features of a concept or feature.

Montibeller and von Winterfeldt (2015) demonstrate the role of cognitive and motivational biases in decision and risk analysis, as well as and risk management, and it is extrapolated that even the phenomenon of 'unconscious incompetence' may play a role in the execution of tasks (as part of the stages of competence, being unconscious incompetence (ignorance), conscious incompetence (awareness), conscious competence (learning), and unconscious competence (mastery) as summarised in Mercer County College, 2013).

4.4.2.2 Errors

There are a number of sources of error that may appear in a variety of functional areas, even though they are relatively well understood, namely:

a) Field measurements:
i. Heuze (1971) outlines both the sources of errors in rock mechanics field measurements, as well as their potential solutions.
ii. Wang and Mauldon (2006) point out the proportional error of the Terzaghi correction factors.
iii. Hadjigeorgiou and Harrison (2011a) draw attention to the uncertainty and sources of error in rock engineering.

b) During cataloguing:
i. Haberman and Creamer (1994) identify and describe catalogue errors relating to the M8 earthquake prediction algorithm[27].

c) During transmission of information from surface to underground:
i. Sanmiquel *et al.* (2020) provide an assessment of errors in the transmission of the orientation- and cartographic- system, from the surface to an underground mine.

d) During physical installation of support viz. shotcrete
i. American Shotcrete Association (2020) provide guidance and instructions on the common air system errors influence shotcrete quality.

[27] An algorithm designed for the intermediate-term prediction of earthquakes (Keilis-Borok and Kossobokov (1990), in Ismail-Zadeh *et al*., 2011)

4.4.2.3 Corrections to Measurements or Calculations

During the workflow, corrections to calculations may be needed – though are seldom articulated in the reporting of work carried out. Explanations are shown in:

a) Lato *et al* (2014), relating to over-calculation due to rockmass convergence when mapping shotcrete thickness using LiDAR and photogrammetry data.
b) Lato *et al.* (2010), relating to correction for view-limited LiDaR scanning of rock outcrops used during structural characterisation.
c) McGavin (2006), GroundProbe. (2021), Elmouttie *et al.* (2021a) and Reutech Mining (2022), relating to atmospheric corrections pertinent to radar monitoring [of hard rock, open pit mines].

4.4.2.4 Known Unknowns

There are several issues in rock mechanics that are still considered unresolved, and as far back as the 1980's key questions were scrutinised (e.g. Cundall *et al.,* 1988) at the Symposium on Rock Mechanics. The event considered inputs across the cycle of inputs from field investigation; laboratory testing; classification, statistics and design; to numerical modelling.

It is observed, that despite many an effort, the resolution of some aspects still evade us, including the matter of *in situ* stress of rock. Bishop and Bjerrum (1960) were early proponents of the discussion of the relevance of the triaxial test to the solution of stability problems. Sabitini *et al.* (2022) consider that important knowledge areas that have opportunity for improvement in industry include that of the use and role of *in situ* testing[28], and given that *in situ* rock stress is required as a boundary condition in computational modelling (as the rock is not a continuum, but rather a discontinuum) the philosophical questions arises as to whether or not the characterisation of fractures within the rock (for the purpose of engineering design) can be then be determined satisfactorily.

Malan and Napier (2021) draw discussion to the point that even after many decades of research, a number of key rock mechanics questions remain unanswered. The paper cites a number of examples and includes the matter of layout design criteria for deep gold mines. Jooste and Malan (2020) in Malan and Napier (2021) had highlighted the need for additional research by considering that two popular design criteria used in the deep gold mines of South Africa (viz. average pillar stress (APS) and energy release rate (ERR)) while assisting to greatly reduce the areas of high stress concentrations, are both of limited use. It is explained that the situation is not clear with regard to the maximum value of APS on remnants and pillars should be for safe

[28] Sabitini *et al*. (2022) also cite the interpretation of conflicting, contradicting, and inconsistent data as an important knowledge area to have opportunity for improvement in industry.

extraction, and *"it is questionable whether numerical modelling programs calculate this parameter correctly in areas where inelastic rock behaviour is prominent. Elastic ERR has a significant drawback as no dissipative mechanisms are incorporated to allow for failure of the rock mass. Improved methods to estimate the risk when mining pillars and remnants in the deep gold mines are therefore urgently required".*

4.4.3 Growing concepts

4.4.3.1 Uncertainty

The concept of 'uncertainty' in engineering has gained tremendous popularity in the last decade or so – there are a vast number of publications that cite, explore, and recall the fact that uncertainty is present in engineering design inputs[29].

It is readily accepted by the industry at large, that uncertainty exists in the rock mass – due the fact that rock masses are naturally complex and variable at all scales, having been formed, then continuously modified, by a variety of complex processes, causing physical heterogeneity that results in variations in measured physical properties, even within one rock type (Małkowsk *et al*., 2021). Concomitantly, spatial and directional variations in rock mass properties are caused by the presence of natural fractures - causing a rock mass to become inhomogeneous and anisotropic (Jing 2013) in Małkowsk *et al.* (2021).

Małkowsk *et al.* (2021) undertook an investigation through numerical analysis of four different case studies using the

1) average values (typically the most common in geomechanical data analysis),
2) average minus standard deviation,
3) median, and
4) average value minus statistical error.

The study found that different approaches applied to the same geomechanical data set may produce considerably different modelling results.
The study found that 'average minus standard deviation' produced the most conservative results – giving displacements and yielded elements zone in four times

[29] To maintain a Tversky *et al*. (1974); Wells (1976); McMahon (1985); Klir (1989); Read (1994); Klir *et al*. (1999); Morley *et al*. (1999); Zimmermann (2000); Einstein (2003); Helton *et al*. (2004); Woessner *et al*. (2005); Gholamnejad (2007); Helton *et al*. (2008); Smith *et al*. (2008); Grobler *et al*. (2011); Read (2011); Elmouttie *et al*. (2012); Erdem *et al*. (2012); Gholamnejad (2012); Montoya *et al*. (2012); Blockley (2013); Dunn (2013); Samimi Namin *et al*. (2015); van der Grijp (2015); Contreras *et al*. (2016); Birch (2017); Khan (2018); Mokhtarian Asl (2018); Adjiski *et al*. (2019); Dunn (2019); Githiria (2019); Jele *et al*. (2019); Mandisodza *et al*. (2019); Mathis (2021); Read (2021); Birch (2022); Mine Health and Safety Council (no date); Smith (1985b); Morgan *et al*. (1990b); Lilly (2006b); Hadjigeorgiou (2007a); Hadjigeorgiou *et al*. (2011a).

broader range comparing to the ‘average values’ scenario, which is the least conservative option.
The study concluded that the two other scenarios require further investigation, but overall, taking the ‘average values corrected by statistical error’ for the numerical analysis seems to be the most preferred solution for handling uncertainty of geomechanical data intended for use in numerical modelling.

Einstein (2003) reviewed the understanding and treatment of uncertainty in rock mechanics and rock engineering – both historically over forty years, and currently.
The review considered the typical progression of a study i.e. rock mass characterisation, performance analysis, updating and then decision-making. Einstein (2003) concluded that although most of the basic concepts for these aspects of a study already existed in the 1960's, they had all experienced some level of progress – which is attributed largely to expanded computational capabilities for modelling. Einstein ascribes “risk-based decision-making” as the outright leader in progress and remarks that “*its acceptance shows interesting differences between different professions*”. The sentiment matches with the themes of the current research, e.g. different users approach, interpret, implement and measure risk differently.

Treating uncertainty has been demonstrated using a variety of different aspects, including:
1) Uncertainty determination in rock mass classification when using Fuzzy Rock Mass Rating software (Namin *et al*., 2015).
2) Unconventional methods to treat geotechnical uncertainty in slope design (Contreras and Ruest, 2016); and
3) Quantification of uncertainty (Dunn, 2019).

The candidate contends that the role of ‘uncertainty’ is more complex than heterogeneity and anisotropy of a rock mass. The text by Morgan and Henrion (1990b) provides an invaluable insight into the difficulties of relating uncertainty in quantitative risk analysis with policy analysis. The candidate maintains that this type of discourse is essential to the holistic evaluation of risk in mining – because it frames, amongst others, the challenges in setting the thresholds of exposure and danger for instance, to those that may be affected by it but have no influence in the control thereof.

4.4.3.2 Confidence in data

As with ‘uncertainty, reviewed in chapter 4, sub-section 4.4.3 above, the importance ‘data confidence’ in geotechnical engineering practice has also become increasingly recognised.

‘Data confidence’ alludes[30] the extent of certainty or uncertainty that is held about the accuracy and reliability of a dataset, by considering the quality and quantity of data in the dataset.

Chapter 1.4.1, Table 1-1 and Table 1-2 show the Suggested levels of geotechnical effort and target levels of data confidence by project stage (Read, 2009c), and Suggested levels of geotechnical effort and target levels of data confidence by project stage (Read, 2009c) respectively.

Fillion and Hadjigeorgiou (2013) and Dunn (2014) have outlined methods that may be helpful in assessing the reliability of certain types of geotechnical data which are used as input into the development of geotechnical models. In a related exercise, attempts have been made to contextualise data confidence in relation to the progression of mining projects (e.g. Haile, 2004).

As pointed out by Dunn (2014), the geotechnical model comprises the amalgamation of the respective geological, structural, hydrogeological and rock mass models – and therefore, the amount of data available, the quality of data and the confidence in the data of each component may vary.
Advances in technology, or even the new application of existing technologies, are increasingly being used in an effort to improve confidence of geotechnical data. An example that demonstrates the principle is the use of laser scanner face mapping at Sishen mine, South Africa (Russel and Stacy, 2019).

[30] ‘Data confidence’ is a subjective consideration, not be confused with the a ‘confidence interval’ which is derived in statistics and refers to the probability that a population parameter will fall between a set of values for a certain proportion of times.

4.5 Part D – Decision-making

The various components for Part D of the literature review and their general flow are outlined in Figure 4-10. The content is then presented in detail in sub-sections 4.5.1 to 4.5.2.

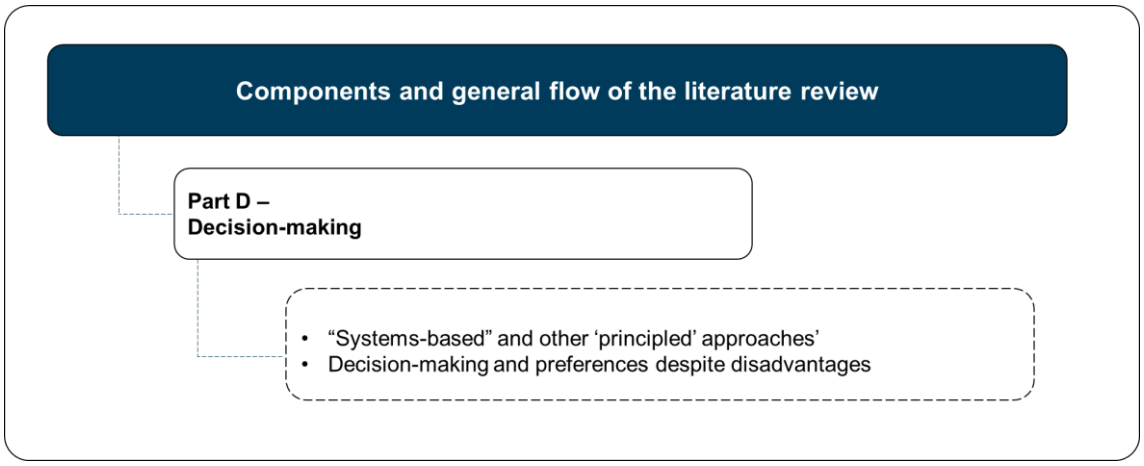


Figure 4-10:Simplified visualisation of the various components for Part D of the literature review and their general flow

4.5.1 "Systems-Based" and other 'principled' approaches

In addition to the advancement, variability, and extent of incorporation of individual scientific concepts, parameters, and technology – there is an increasing move toward using an approach based on one specific priority over others.

The relevance of this relates to the fact that, different mining companies may therefore prepare customised:

a) Standardised operating procedures,
b) Technical strategies,
c) Ground control management plans, etc.

based on resources available, corporate values drivers, etc. that are not readily comparable with or between each other, or with operations in different commodities – and there is no differentiation incorporated into current reporting norms by mining companies[31] to be able to identify the selection or implementation of those systems active in the rock mechanics and geotechnical engineering functions: A range of systems focus is listed below [32]:

[31] It is recognised that detailed descriptions are typically incorporated into topic-specific studies comprising form PhD theses etc., however, the context of the current research considers the mining industry *as a whole*, and therefore demonstrates how organisational practices are the same, similar, and different.

[32] Italic text added for author's emphasis.

a) An activity-based costing approach to fall of ground accidents in a South African gold mine (Marx, 1996),
b) A damage assessment system [at Argyle Mine, Australia] (Fernandez *et al*., 2010),
c) A *community-based, seismic system for obtaining regional and local seismic data of strategic importance* (Wesseloo *et al*., 2011),
d) The strategic and tactical use of *a community-based, regional, seismic monitoring system* (Hudyma *et al*., 2011),
e) The estimation of deformation modulus of rock masses based on Bayesian model selection and *Bayesian updating approach* (Feng *et al*., 2015),
f) A *risk-based approach* to ground support design (Joughin *et al*., 2016) ,
g) A UAV And LiDAR *mapping-based approach* to structural recognition and rock mass characterisation (Vallejos, 2019),
h) *Geotechnical risk-informed* decision-making in mining (Lupo, 2019), and
i) A *clustering-based iterative approach* to stope layout optimisation for sublevel stoping (Sari, 2021).

4.5.2 Decision-making and preferences despite disadvantages

Decision-making, in the general sense, is often conceptualised to be a relatively simple undertaking of choosing between two options, where the ‘wining’ option is selected through tally of ‘positive’ attributes. However, integrated decision-making is more complex. Soutar and O’Connor (1988) offer insight into this type of phenomenon where the introduction of mechanical shaft drilling for sinking shafts is interpreted.

In the broad framework and on an ongoing basis, through most manner of publications, opinions, analysis, recommendations and requirements – it is recognised that the South African mining industry needs to and/or will benefit from reduced operating costs. These universal pressures may promote, in some instances, or hinder, in other instances, the adoption of new or different means of work.

A severe labour-shortage in South Africa during the early 1970s is said to have given impetus to the development and introduction of mechanised mining, and in the experience of Soutar and O’Connor (1988), the use of 'drilling jumbos' and other mechanical equipment for tunnelling operations by the Gold Fields Group.

The authors very pertinently establish the context and consideration toward the investigations – expanding on explanations regarding operating costs, production rates, and the role, availability, and cost of manual labour. Faced with pressure to reduce operating costs and encountering challenges in securing manual labour – the

Group had to consider the use of mechanised equipment to undertake necessary shaft drilling.
It is reported that Group engaged with a leading drilling company in South Africa, with the request to produce effective system that could be used for drilling the shaft bottom, where the system would have to be capable of drilling the full round in at least the same amount of time that a traditional machine-crew would, and that the system was to use a reduced labour complement than the traditional crew.
The South African company involved one of the international branches who had expertise in the field to produce a number of schemes over the few years. Soutar and O'Connor (1988) state that, in general, the proposed systems were not acceptable as they were suspended from the sinking stage, however, the obvious shortcomings of the proposals (e.g. restricting stage mobility during the drilling operation) influenced the final parameters for the design of a drill rig suitable for the drilling of the shaft bottom. Following ease on the situation of the labour shortage toward the end of the 1970s, Soutar and O'Connor (1988) explain that - although efficient labour utilisation was of prime importance and the problems of spiralling costs still existed – pressure on the ideals of the development of machinery was then replaced by the attitude that the introduction of any mechanised equipment had to be economically viable.

The paper then gives a detailed portrayal of the development through time, the components, advantages and disadvantages of each step along the way – eventually concluding that through the comparison of operating costs for conventional hand-held drilling machines compared against those for the mechanical drill rig and even despite certain disadvantages, mechanical drilling was deemed preferable.

4.6 Part E – The interplay between strategy, operation, and tactics

The various components for Part E of the literature review and their general flow are outlined in Figure 4-10. The content is then presented in detail in sub-sections 4.6.1 to The Quantified Value-created Process (QVP).

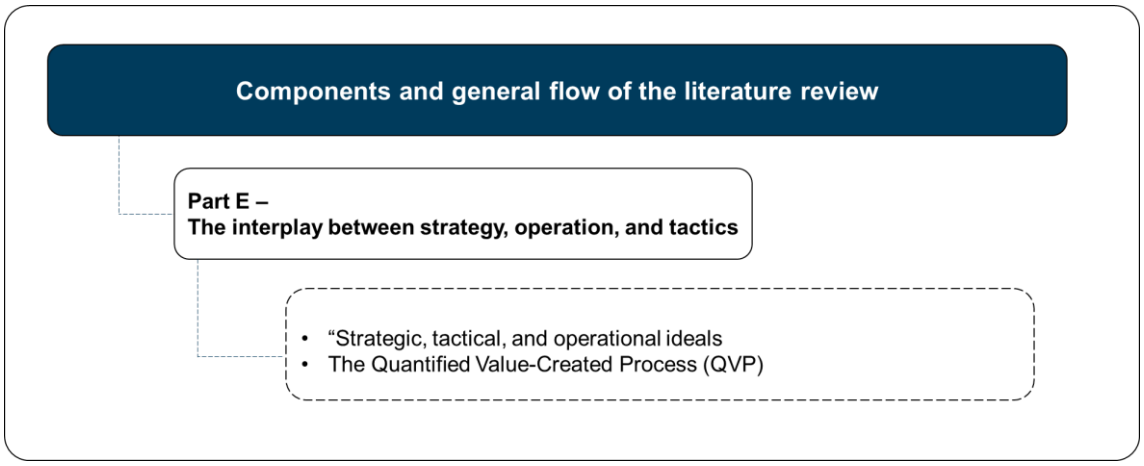


Figure 4-11:Simplified visualisation of the various components for Part E of the literature review and their general flow

4.6.1 Strategic, tactical, and operational ideals

Geotechnical mining engineering is not carried out in isolation and is simultaneously reliant on decisions made in the business environment. Integrated functions such as strategic planning [viz. the long-term, broad of the business], tactical planning [viz. the outline of short-term steps and actions to be taken to achieve the long-term goals] and operational execution provide a multi-faceted environment that requires consistent evaluation, reflection and potentially also revision.

Examples and their explanations regarding the varied duties and possibilities regarding strategic, tactical, and operational ideals and needs are shown in chapter 9, sub-section 9.4.6. The decision to present the material in the annexure is based on the prerogative to keep the document to a reasonably manageable size (in terms of volume).

4.6.2 The Quantified Value-created Process (QVP)

The Quantified Value-created Process (QVP) (Stacey and Hadjigeorgiou (2022) provides an excellent practical tool for decision making process in mine design ***and operation*** (candidate's underline for emphasis).

Stacey and Hadjigeorgiou (2022) describe the implementation of the QVP as being founded on a ten-step rock engineering design process and a ten-step strategic planning process. The QVP is therefore divided into two parts –

1). The first part deals with 'planning the process' and
2). The second part deals with 'implementing the process' and can also be considered an extension of the risk approach.

In using the QVP, all costs (i.e. direct and indirect), associated with a significant mining decision (design, operational, investment) must be quantified in advance of committing to that decision. This enables the value that will be likely be created in the short, medium, and long terms to be determined accordingly.

The authors put forward the consideration that '*ethical values, associated with health, safety, the environment, public perception, and social aspects'*, may be difficult to quantify in economic terms, but must nevertheless also be considered.

The QVP differs with 'conventional' risk assessment processes in that:

1). The QVP explores upside, positive aspects that may be realised (based on the quantitative valuation of the value that can be created) to inform the decision-making process to, whereas
2). 'Conventional' risk assessment processes tend to focus on negative aspects (e.g. potential losses and costs) to drive decision-making.

Figure 4-12 shows the QVP wheel and the involvement of all layers and functions of personnel (i.e. technical and financial, senior managers, mine managers and executive directors). Essential, active and iterative communication / engagement with upper management during the decision-making process enables executives to make more *holistically* informed strategic decisions, regarding various elements - including value and risk.

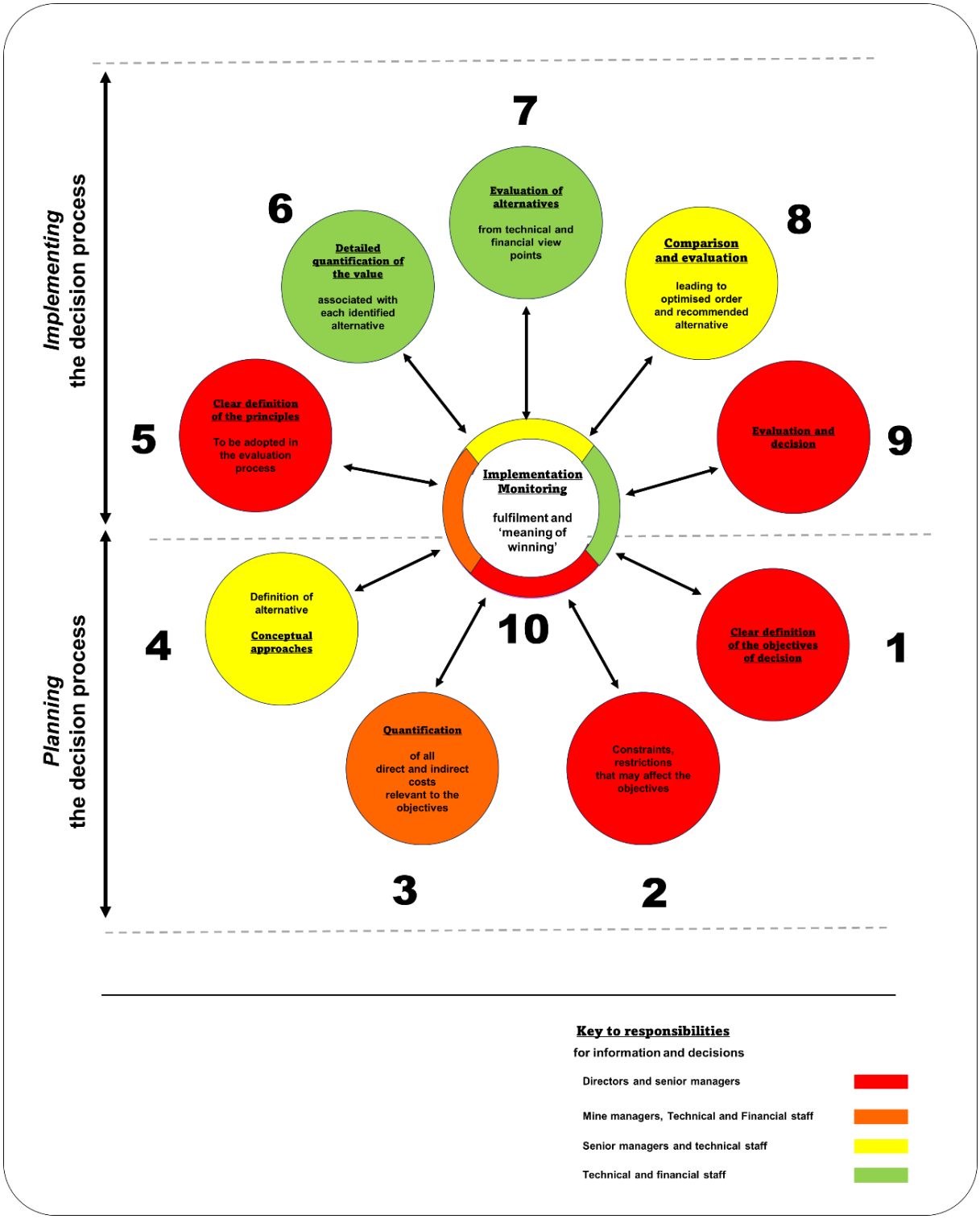


Figure 4-12: The Quantified Value-created Process wheel. The arrows of the spokes of the wheel indicate that, at each step, the requirements of previous steps must continue to be met; in particular, that the objectives in step 1 of the process are being addressed (Stacey and Hadjigeorgiou, 2022)

4.7 Part F – There is more to mining geotechnical designs than risk and rocks

The various components for Part F of the literature review and their general flow are outlined in Figure 4-13. The content is then presented in detail in sub-sections 4.7.1 to 0.

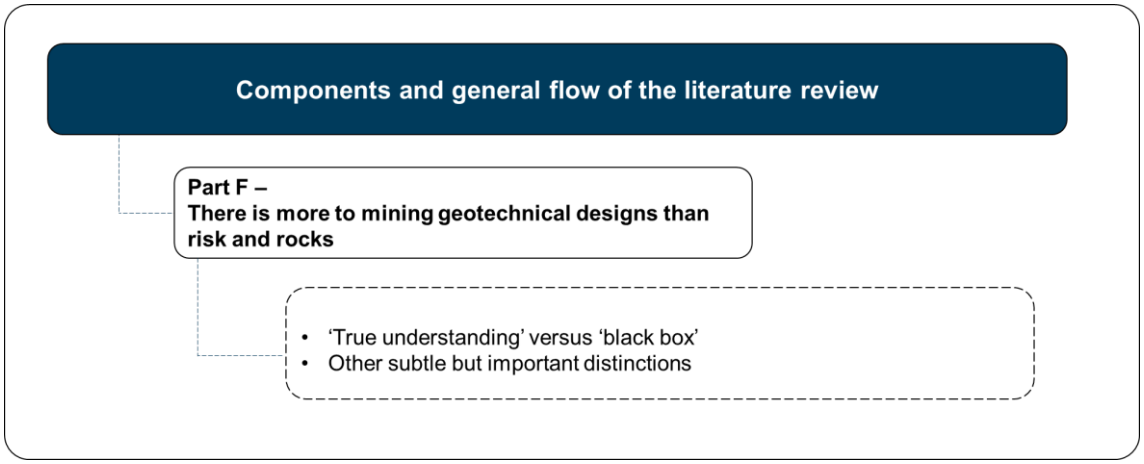


Figure 4-13: Simplified visualisation of the various components for Part F of the literature review and their general flow

4.7.1 'True understanding' versus 'black box'

Birch (2014) presents a good discourse on the issue of 'true understanding' and the concept of 'black box' in the light of the proliferation of software programs available, using a case study of a short training course presented at the University of Witwatersrand, as part of the Higher Certificate in Mineral Resource Management. Although Birch's (2014) account focuses on the geological constraints of ore body modelling (toward SAMREC compliancy) – the principles are extrapolatable to geomechanical modelling.

The evaluation considers that implicit geological modelling as a technique, uses a radial basis function to establish and update geological models relatively quickly and efficiently from various data sources (e.g. borehole data, outcrop data, manually interpreted vertical or horizontal sections, and structural data – then assays and any coded drillhole data e.g. lithology and alteration) can be interpolated.

Birch (2014) reviews the use of geological models, through software, in mine planning and compares the variations in mine plan design and financial output of different mine designs. The resultant mine designs were significantly different – even though the designs are all based on the same geological model created in the traditional way – and these consequently also produced very different resulting financial outlooks for the projects.

The findings from the review and case study prompts questions and insights relating to how significant a very detailed model in the pre-feasibility and feasibility phases of mining projects actually is, especially considering the huge costs involved in gathering the required data to build the model (which is a SAMREC-compliant geological in the text referred to).

New software is understood to be speeding up modelling processes and therefore allowing more time to deliberate the interpretation of the model, and subsequently facilitate revisions to the model/s. Similarly, the 'learning curve' is also understood to be steeper and to be being adopted faster than for traditional modelling techniques, with a simultaneous realisation that the range and depth of skills needed by persons to produce models is also therefore reduced.

The candidate accedes Birch's (2014) succinct statement that the SAMREC Code "*is very limited when it comes to specifying how the mine design is created and scheduled, which can have a major impact in the resultant net present value (NPV) and internal rate of return (IRR)",* as this is also true of the practical components of the geotechnical design and related modelling of geomechanical behaviour. The Code only requires that the modifying factors be documented and reasonably justified – where in reality, each model may be subject to great deals of variation in input, construction and interpretation – which may have material impacts on the financial determinations made, to the extent that it is not impossible that a modifying factor may theoretically "*make or break the project's success*" depending on the light it is viewed in.

4.7.2 Other subtle but important distinctions

In addition to each of the aspects reviewed in the preceding chapters, including rock parameters, rock characterisation and classification, modelling, likelihood and impact, there are subtle but important distinctions in related factors in the pursuit of stable, optimised rock engineering design, construction and performance. These include:

a) Likelihood, Probability, Prediction

The qualitative estimation of likelihood, the quantitative determination of probability and prediction are not interchangeable terms when used correctly.

b) The language of estimative probability

Estimative probability considers the potential ambiguity of qualitative descriptors, as perceived differently by different persons. Figure 4-14 to Figure 4-19 show examples of the variability in perceptions of various probability descriptors.

c) Susceptibility

The aspect of susceptibility, or being 'prone', alludes to an existing vulnerability. In context of the research, literature describing 'burst-prone' ground and 'susceptibility' often allude to rockbursts and/ seismicity in the deeper, underground South African mines – as discussed in McCreath *et al.* (1992); Brummer *et al.* (1995); Kaiser *et al.* (1995); Roy (2003); Yao *et al.* (2009); Cai (2013); Kaiser *et al.* (2013); Institute of Risk Management (undated); Kaiser *et al.* (2005a); Kaiser *et al.* (2005b); Cai *et al.* (2012b); Kaiser *et al.* (2013a); Ogasawara *et al.* (2014b); as well as Maiti and Bhattacherjee (2001) who aimed to predict accident susceptibility for underground mine workers.

d) Reliability, robustness, and resilience

Jones (2021) (with the incorporation of Shishko (1995); Allen (2001); Bell *et al.* (2002); Blanchard (2008); Murray *et al.* (2013); Madni *et al.* (2009) as relevant) differentiates between reliability, robustness, and resilience:

Reliability is considered as 'the *probability that a device, product, or system will not fail for a given period of time under specified operating conditions'.*

Robustness "*goes beyond reliability by including an ability to perform satisfactorily, if not exactly according to the stated performance requirements, under conditions that go beyond the expected environment to include known problems and anticipated variations*".

Robustness is considered to be the capability of performing without failure, under a wide range of possible conditions, and a general approach to 'robust design' is to provide a design that is insensitive to the variations normally encountered in production and/or in operational use

Resilience "*goes further than robustness, requiring some ability to perform after the occurrence of unspecified problems and changes that violate the design assumptions*" i.e. the ability to recover from or adjust easily to an unanticipated accident or change and a system is resilient if it continues to perform the intended functions in the presence of invalid assumptions.

Jones (2021) explains that these changes may be "*couched in various ways—anomalies, disruptions, discoveries—but they all ultimately had to do with changes in underlying assumptions.*
Invalid assumptions, whether due to unexpected changes in the environment, or an inadequate understanding of interactions within the system, may cause unexpected or unintended system behavior.

Resilience engineering is concerned with building systems that are able to circumvent accidents through anticipation, survive disruptions through recovery, and grow through adaptation".

e) Fragility and Anti-Fragility

The concept of fragility is presented using an example from Erberik (2015) where "*seismic fragility can be defined as the proneness of a structural component or a system to fail to perform satisfactorily under a predefined limit state when subjected to an extensive range of seismic action."* Fragile elements in engineering are also described in Wen *et al.* (2005) and Grumbach (2022).

The concept of anti-fragility extends further to include that a circumstance [system, etc.] does not only withstand the impact or shock of an incident, but improves because of it. No practical examples from rock geomechanics could be identified – the concept is reasonably new to academia and existing publications largely focus on systems and computing for the time-being (e.g. Jones, 2014 and de Florio, 2014) – with many promising recommendations for further research.

f) Compliance, Adherence, Concordance and Conformance

In contemplating the role of behaviour in mine safety, the terms 'compliance, adherence, concordance and conformance' may have relevance.

Extrapolating from the principles elucidated by Chakrabarti (2014), it is summarised that:

Compliance alludes to the obligatory requirement to do (or not do) an action – i.e. it is expected that persons will comply unquestioningly with the instruction, because they are obligated to obey the instruction.

Adherence refers to a process, in which the appropriate course of actions is decided after proper consultation i.e. the extent to which a person's behaviour, corresponds with agreed recommendations from a supervisor.

The concept of **concordance** has understood to have evolved from a narrower view, emphasizing an agreement between the receiver of the instruction, and the issuer of the instructions, that takes into account each other's perspective, to a broader process consisting of open discussions.

Lastly, **conformance** is the voluntary adoption of aspects within an organisational system.

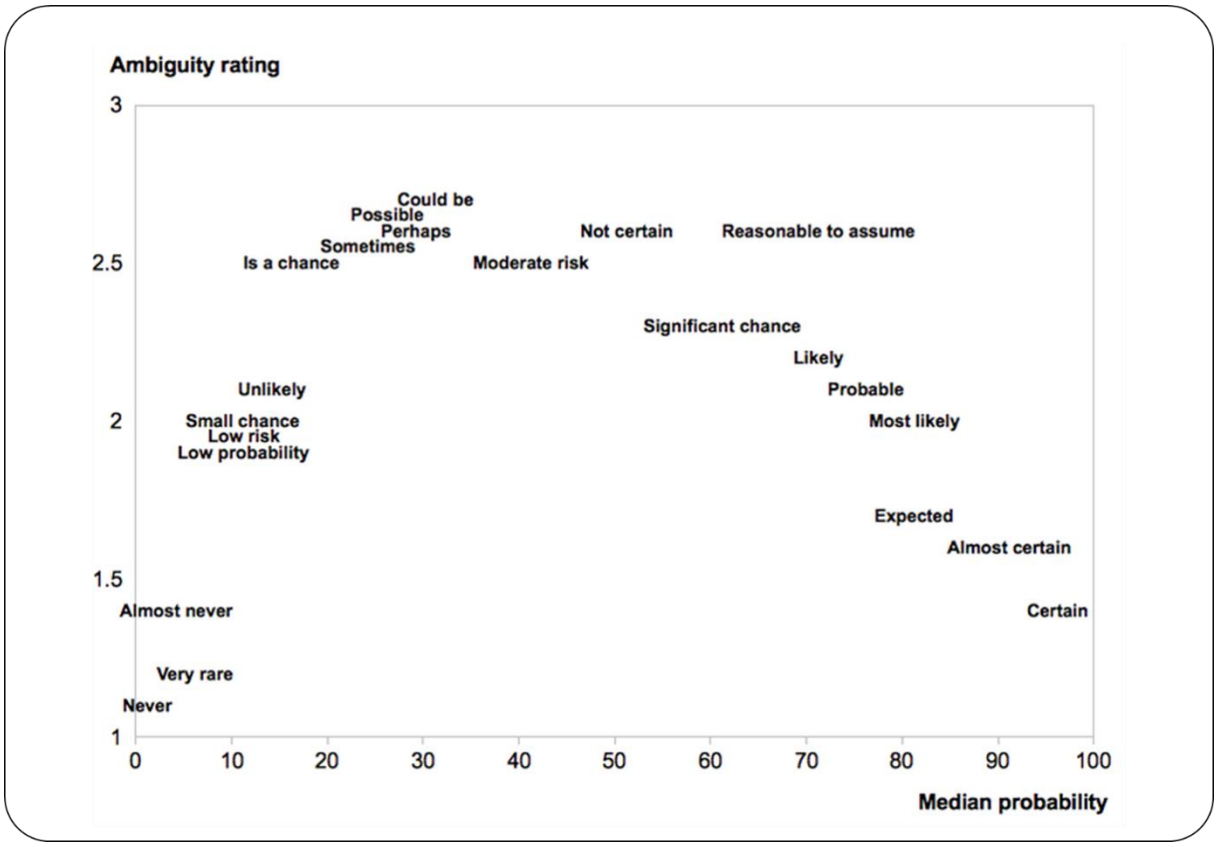


Figure 4-14:Showing the evaluation of probability expressions (O'Brien, 1989)

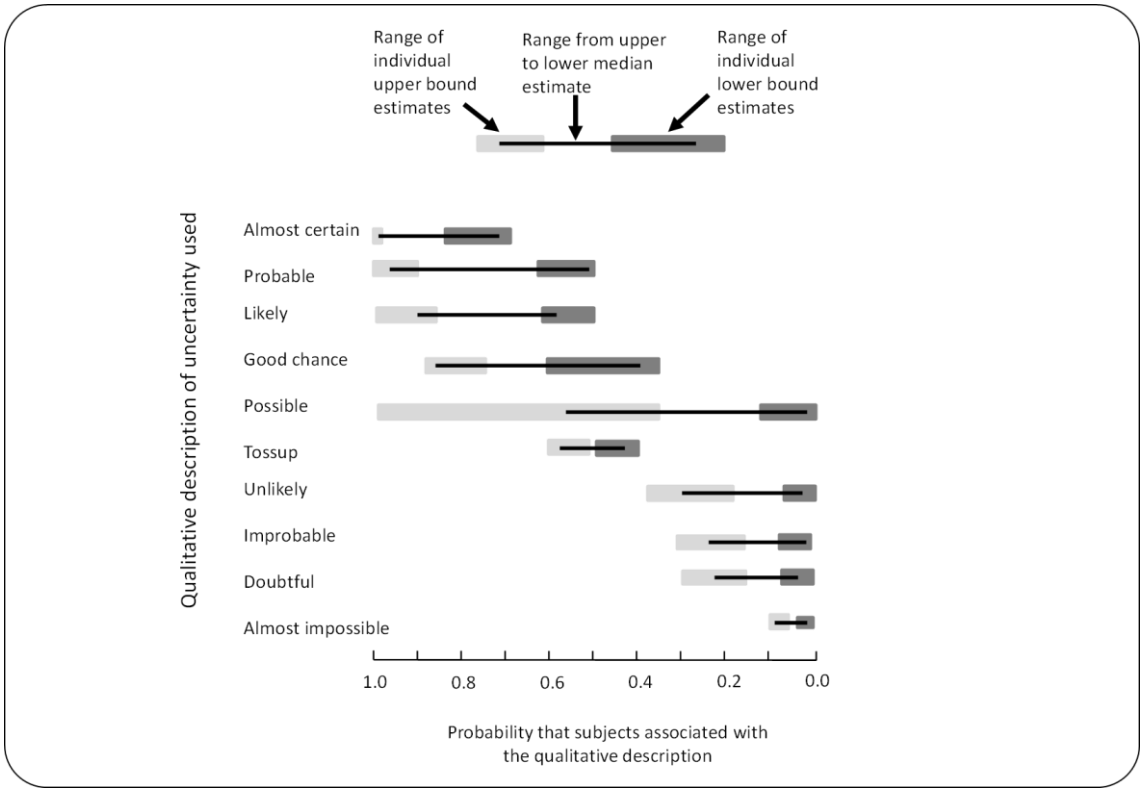


Figure 4-15:Quantification of verbal expressions (Wallsten et al. 1986 cited in Granger Morgan 2001)

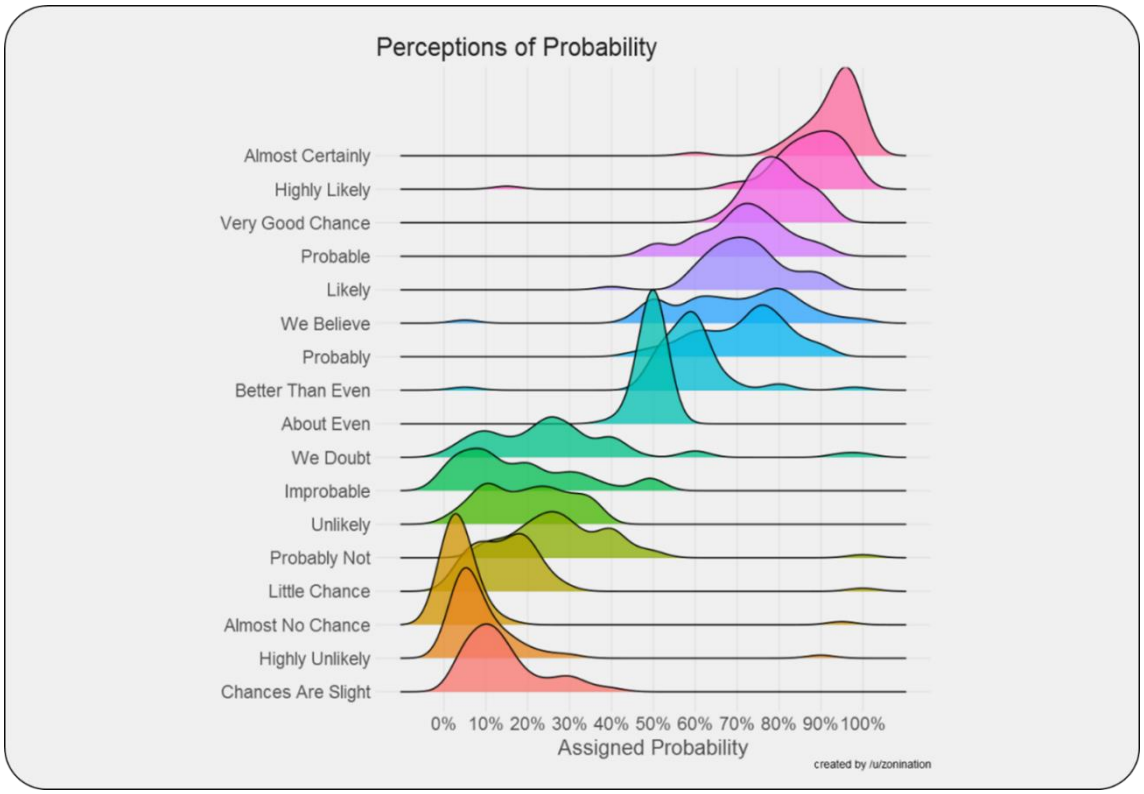


Figure 4-16: Perceptions of probability (Smith, 2017)

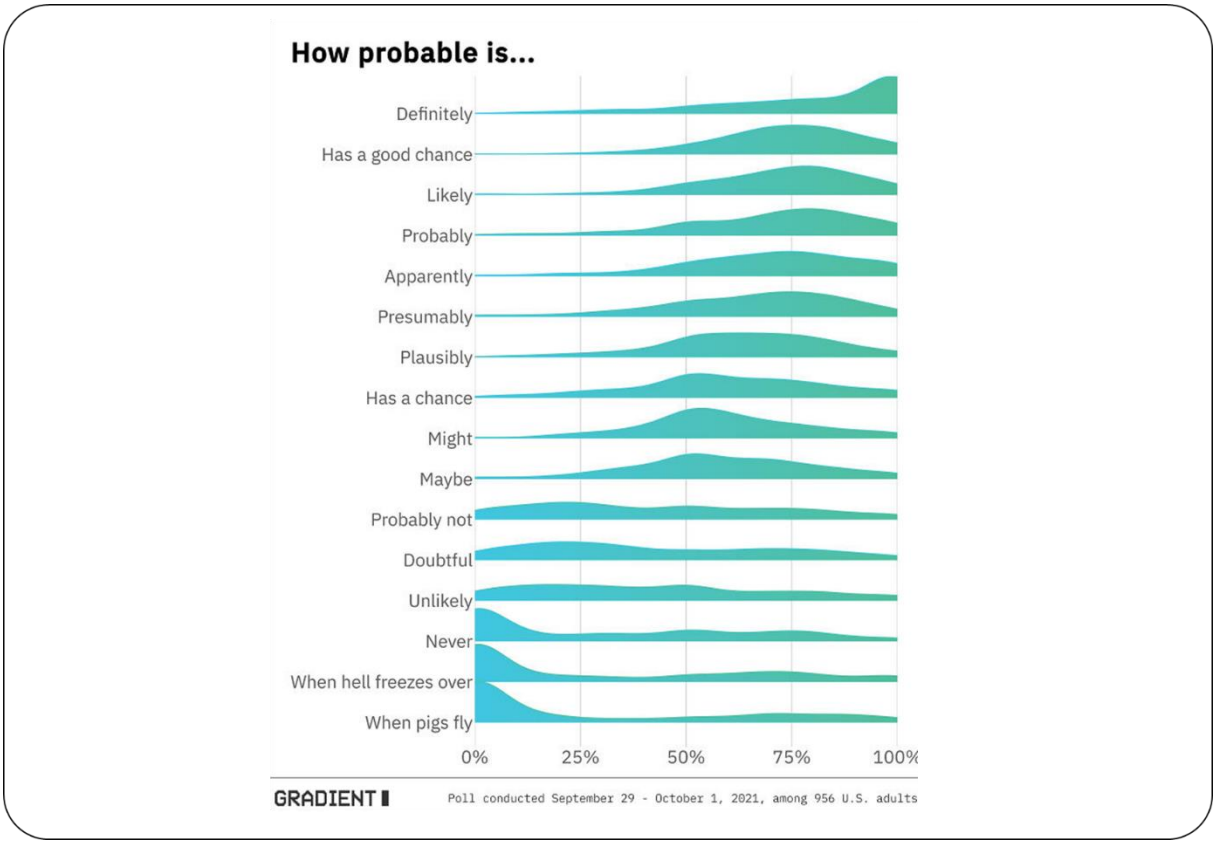


Figure 4-17: Perceptions of probability (Gradient Metrics, 2021)

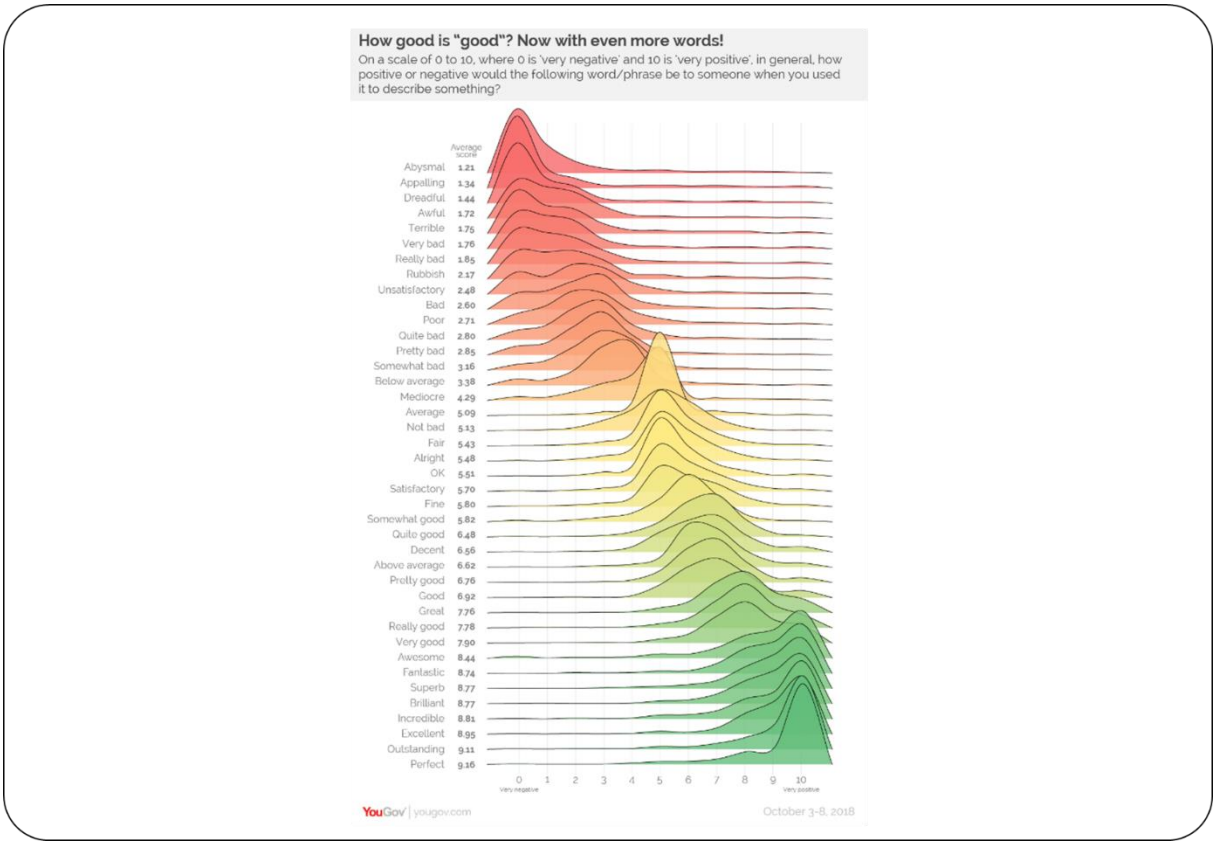


Figure 4-18: Perceptions of probability (Smith, 2018a)

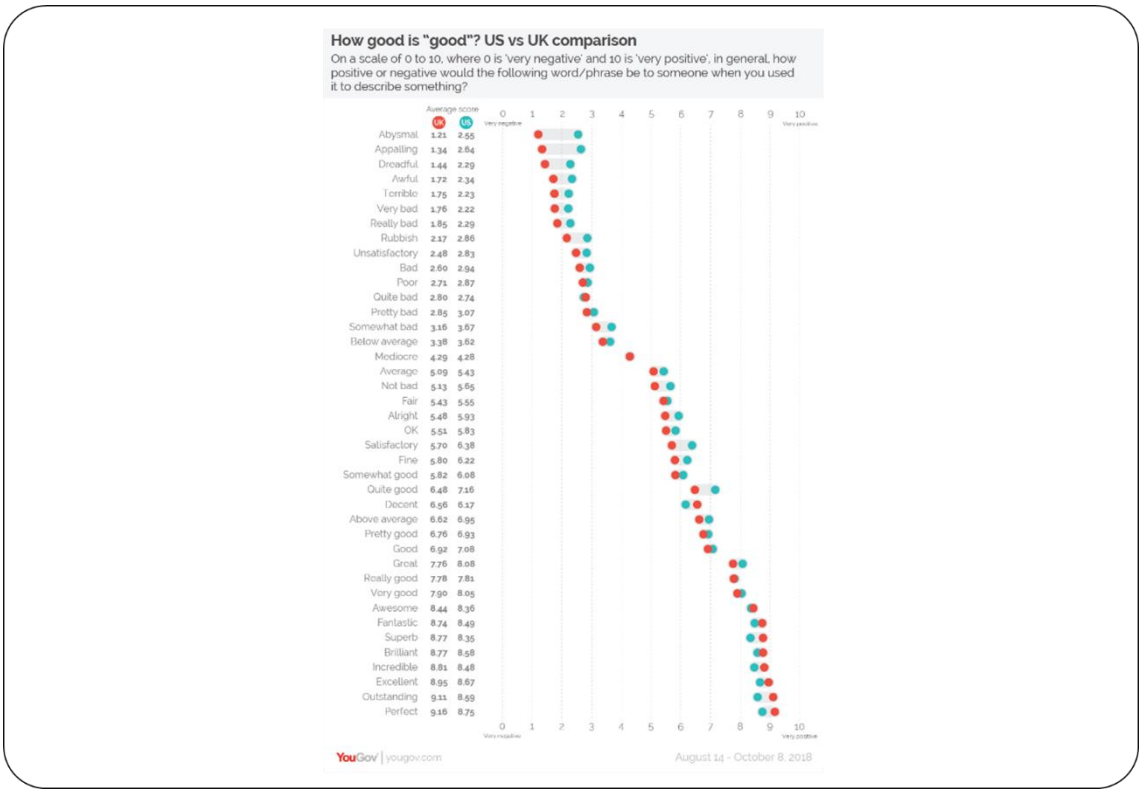


Figure 4-19: Perceptions of performance between United States and United Kingdom respondents (Smith, 2018a)

4.8 Part G – Risk as a ‘pure, independent science’

The various components for Part G of the literature review and their general flow are outlined in Figure 4-20. The content is then presented in detail in sub-sections 4.8.1 to 4.8.7.

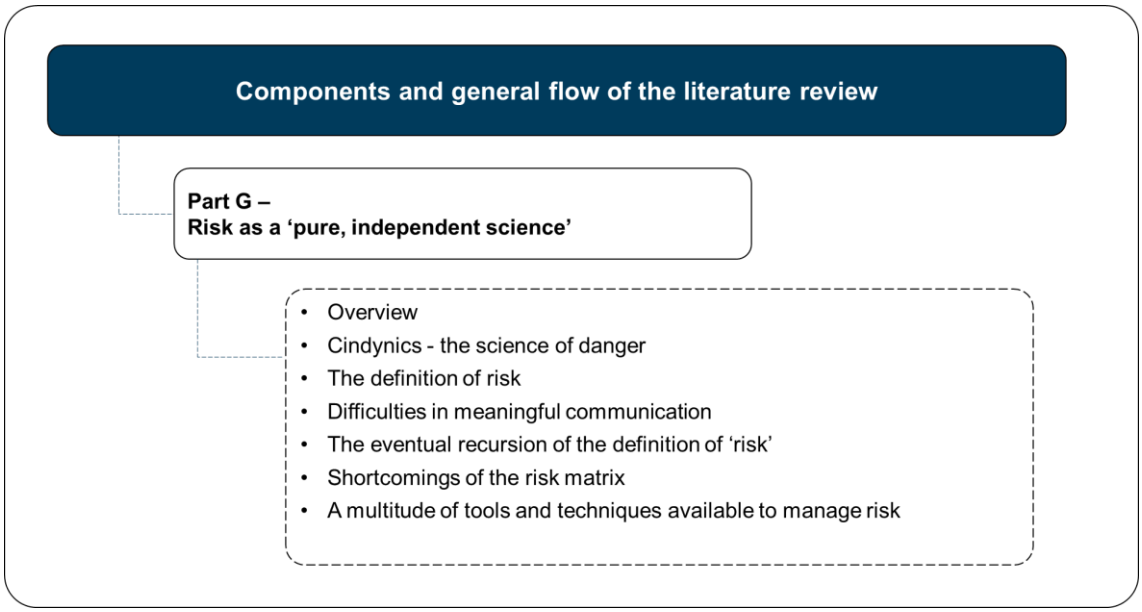


Figure 4-20:Simplified visualisation of the various components for Part G of the literature review and their general flow

4.8.1 Overview

The features, assessment and analysis of ‘risk’ exist as part of a ‘pure, independent science’. The concepts surrounding ‘risk’ are not unique and are not borne from or originated through rock mechanics and geotechnical engineering – rather, selected tools and techniques from the ‘pure, independent science’ have been assimilated into rock mechanics and geotechnical engineering practices.

The review hereunder contextualises the components and application associated with pertinent aspects of ‘risk’.

4.8.2 Cindynics - the science of danger

Wyro (1998) articulates quite elegantly that the term 'cindynics' was introduced around the 1980's / 1990's to describe the "*sciences of hazards together with a will to approach the problem of hazard as a whole taking into account all its dimensions (technical, functional, human behaviour, management procedures, goals, regulations etc.).* Cindynics concern the situations that have a potential or a real form of hazard, and tries to answer the need for a more complete representation of the hazard space - in order to group together the formalisms and methods of observation, as well as the understanding and management of hazard situations in a coherent way.

4.8.3 The definition of risk

Studies incorporating the description of a risk assessment commonly include generalised definitions of risk (e.g. Ellsberg (1961); Campbell (2005); Aven *et al.* (2009); Aven (2011); Brown (2012); Adams (2014) in more recent years). Nevertheless, the current research is going to focus on specific instances of risk terminology that are pertinent to the context of risk assessment and risk management.

4.8.4 Difficulties in meaningful communication

Difficulties establishing a common understanding to address risk in mining, and the related challenges in meaningful communication of probabilistic expressions are chronicled by Zermatten and Terbrugge (2006).

4.8.4.1 'Risk' under the Mine Health and Safety Act 29 of 1996

Section 102 of the Mine Health and Safety Act 29 of 1996 defines risk as "*the likelihood that occupational injury or harm to persons will occur".*

While the definition is sound, it is also somewhat limiting and ambiguous because it relies very simply on a [risk] matrix for correlation, whereas the assessment of likelihood is incredibly subjective, and the recognition and identification of potential harm relies on broadened and open-minded postulation of different scenarios in the technical space.

4.8.5 The Eventual Recursion of the Definition of 'Risk'

It has been observed, through a multitude of risk workshops led, through the compilation, assessment and review of numerous risk registers, that the definition of risk becomes recursive i.e. self-defined.

4.8.6 Shortcomings of the risk matrix

Cox (2018) chronicles a superlative treatise on the limitations of risk matrices (tables that map “likelihood” and “consequence” / “frequency” and “severity” ratings, to corresponding risk priority levels) and states that there is little research that rigorously validates the performance of matrix-based assessment in actually improving risk management decisions.

Examination of some of the mathematical properties of risk matrices revealed the following limitations:

a) Ambiguous inputs and outputs as categorisations of severity cannot be made objectively for uncertain consequences.
   - Inputs to risk matrices (e.g., frequency and severity categorisations) and resulting outputs (i.e., risk ratings) require subjective interpretation, and different users may obtain opposite ratings of the same quantitative risks.

b) Poor Resolution as typical risk matrices
   - Can correctly and unambiguously compare only a small fraction (e.g., less than 10%) of randomly selected pairs of hazards.
   - Can assign identical ratings to quantitatively very different risks (i.e. “range compression”).

c) Suboptimal Resource Allocation as the effective allocation of resources to risk-reducing countermeasures cannot be based on the categories provided by risk matrices.

d) Errors as risk matrices can mistakenly assign higher qualitative ratings to quantitatively smaller risks.
   - For risks with negatively correlated frequencies and severities, errors may render ratings that are “worse than useless,” leading to worse-than-random decisions.

Cox (2008) also argued that, in general,

> “quantitative and semiquantitative risk matrices have limited ability to correctly *reproduce the risk ratings implied by quantitative models, especially if the two components of risk (e.g., frequency and severity) are negatively correlated.*
>
> *Categorizing severity may require inherently subjective judgments (e.g., reflecting the rater’s personal degree of risk aversion, if severity is modelled as a random variable) and/or arbitrary decisions about how far to aggregate multiple small and frequent events into fewer and less frequent but more severe events.*

The need for such judgments, and the potential for inconsistencies in how they are made by different people, implies that there may be no objectively correct way to fill out a risk matrix".

The limitations identified by Cox (2018) suggest that risk matrices – however popular - should be used with caution, and only when accompanied by careful explanations of embedded judgments.

4.8.7 A multitude of tools and techniques available to manage risk

The International Organisation for Standardisation (ISO) standards relating to risk are systematically constructed, i.e. ISO Guide 73:2009 lays out the vocabulary that is used in risk management, ISO 31000:2018 provides guidelines in the process of risk management, and IEC 31010:2019 provides risk assessment techniques for the process of risk management.

As declared in chapter 4, it is considered impractical to include the extensive volume of material by rote reproduction, therefore, Figure 4-21 is shown to demonstrate the various tools and techniques available for the identification, analysis, evaluation, treatment, recording, monitoring and reviewing of risk during the risk management process.

The objective of the demonstration is to contrast the wide range of adaptable tools and techniques available, against the rigid and somewhat limited application of using *only* the likelihood-consequence approach in rock mechanics and geotechnical engineering risk assessments, such that it is come to be that the phrase "risk-based" is now commonplace in geotechnical journal papers.

A large selection of journal papers shows the common use of the phrase "risk based".

Examples and their explanations are shown in chapter 9, sub-sections 9.4.3 and 9.4.4. The decision to present the material in the annexure is based on the prerogative to keep the document to a reasonably manageable size (in terms of volume).

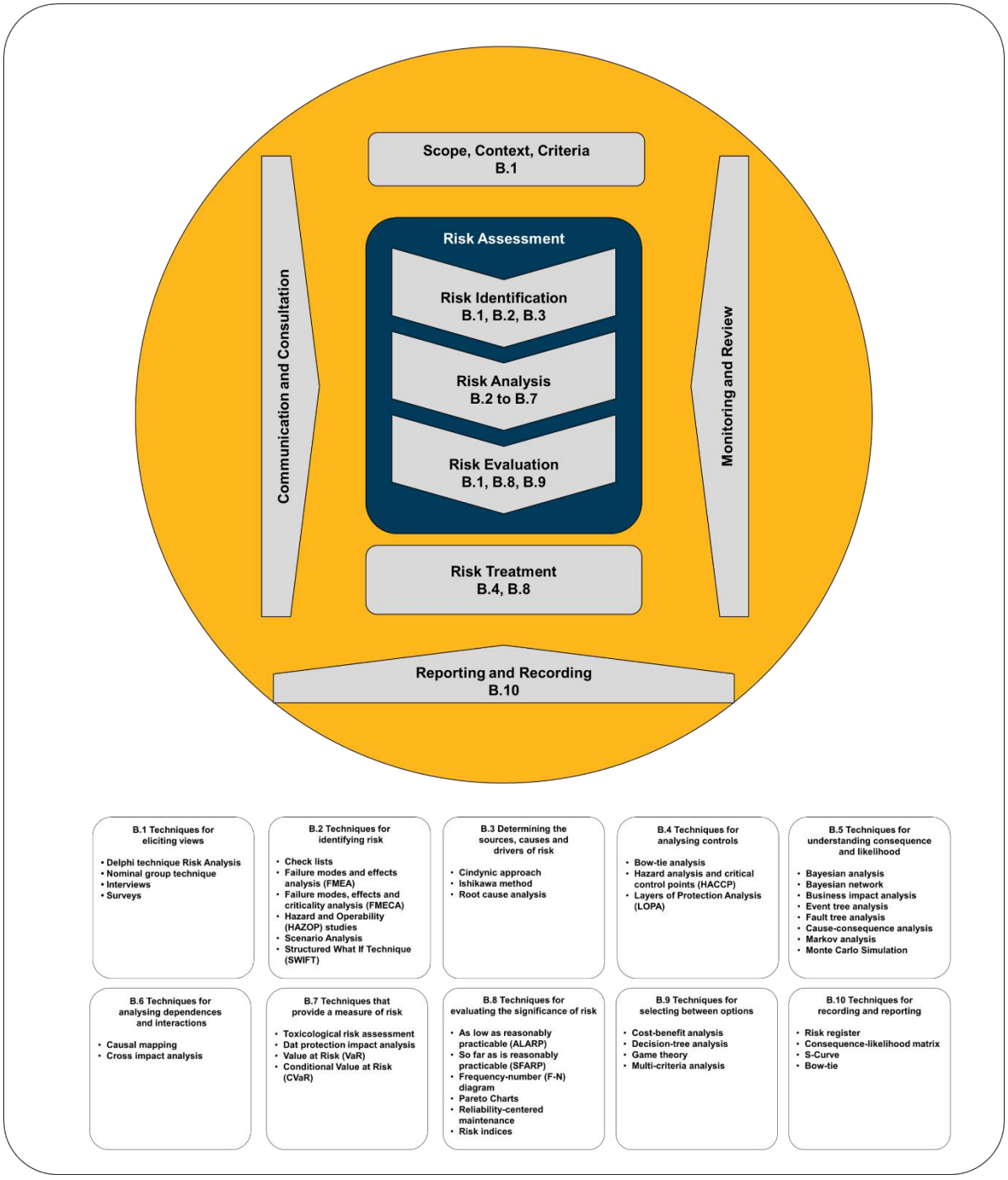


Figure 4-21:Application of techniques toward the risk management process (modified after International Organisation for Standardisation, 2009)

4.9 Part H – Regulatory environment of mining in South Africa

The various components for Part H of the literature review and their general flow are outlined in Figure 4-22. The content is then presented in detail in sub-sections 4.9.1 to 4.9.3

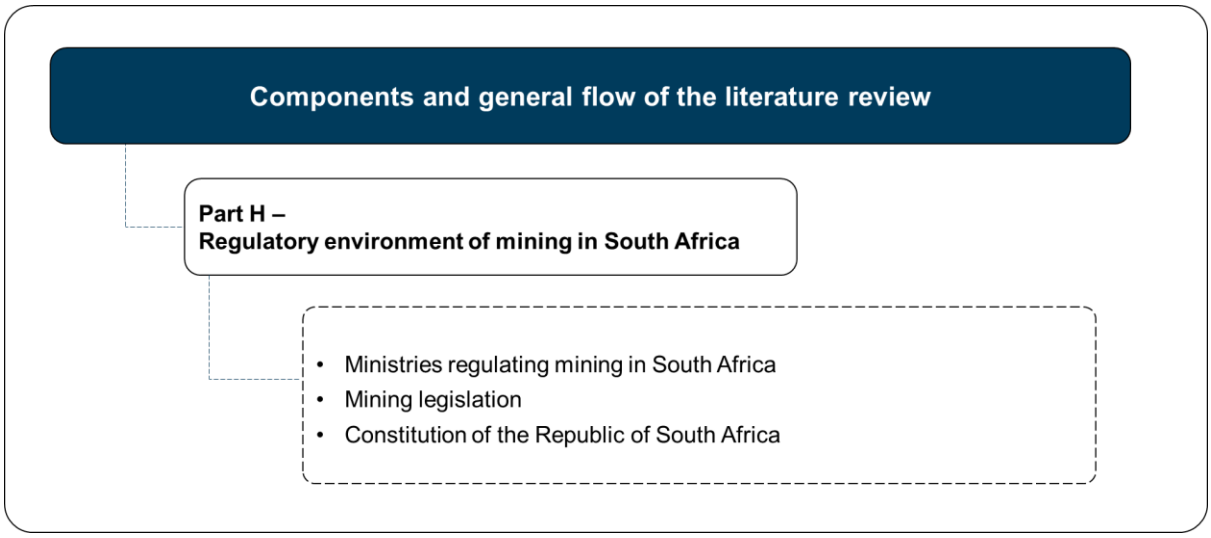


Figure 4-22:Simplified visualisation of the various components for Part H of the literature review and their general flow

4.9.1 The Ministries regulating mining in South Africa

Regarding the name and portfolio, the ministries regulating mining in South Africa have encountered various changes and developments over the years.

The Department of Mineral Resources and Energy [South Africa] (DMRE) (2023) explains that previous instances included “rare combinations, such as with labour, welfare, industry, health, immigration, sport and recreation and even with arts and science” and the phrase “Mining” appeared in the Department’s name until 1980 until the name was changed from ‘Mining, Environmental Planning and Energy’ to ‘Mineral and Energy Affairs’.

Thereafter, the name was changed to the ‘Department of Minerals and Energy’ (DME) during 1997.

Subsequently, the Ministry was separated into two during 2009 - the Department of Mineral Resources (DMR) and the ‘Ministry of Energy’ (DoE) respectively.

Thereafter, reconfiguration and merger of the Department of Mineral Resources and the Department of Energy was carried out during 2019, to form the new ‘Department of Mineral Resources and Energy’ (DMRE) to “*better capacitated and respond to strategic objectives espoused in the National Development Plan (NDP) with regard to the regulation and transformation of the mining and energy sectors*” (DMRE, 2023a).

Therefore, historical projects and/or mines may show differing elements included in their reporting, based on the framework in place at the time.

4.9.2 Mining legislation

There are a great many pieces of legislation, and their accompanying regulations, that are applicable to South African mining and its related activities. For the context of the research, only the most pertinent will be identified, and these include:

- The Mine Health and Safety Act, 1996 (Act No. 29 of 1996),
- The Mineral and Petroleum Resources Development Act 2002 (MPRDA) (Act No. 28 of 2002), and
- The Geoscience Act 1993 (Act 100 of 1993),

With their respective amendments and regulations.

4.9.2.1 The Mine Health and Safety Act, 1996

Hermanus (2020) provides a detailed review of the context and role players in the development of the Mine Health and Safety Act, as part of a study to determine whether or not the Mine Health and Safety Act has 'succeeded or failed in the objectives to improve mine health and safety in South African mines' Hermanus (2020 p. 9).

The current research does not require the same extent of historical investigation into the changes of the Act over time as reported in Hermanus (2020) (i.e. 'when did things happen'), because the research looks toward the response of the mining industry to [rock-originated and rock-associated] risks, assessments, ground deformation, injuries and fatalities occurred, and response incorporated into the risk management related thereto.

Overview

The application for a permit or right to mine is a multi-pronged undertaking, where an applicant must be able to show (amongst other aspects such as environmental, social, and labour) that:

> *Section 23(1) (b) the applicant has access to financial resources and has the technical ability to conduct the proposed mining operation **optimally**; [author's emphasis added]*
>
> *Section 23(1) (f) the applicant has the ability to comply with the relevant provisions of the Mine Health and Safety Act, 1996 (Act No. 29 of 1996);*

The Mine Health and Safety Act 29 of 1996 (the MHS Act) (as amended) intends, amongst others:

- *" to provide for protection of the health and safety of employees and other persons at mines and, for that purpose -*
- *to promote a culture of health and safety;*
- *to provide for the enforcement of health and safety measures;*

- *to provide for appropriate systems of employee, employer and State participation in health and safety matters;*
- *to establish representative tripartite institutions to review legislation, promote health and **enhance properly targeted research** [emphasis added];*
- *to provide for effective monitoring systems and inspections, investigations and inquiries to improve health and safety;*
- *to regulate employers' and employees' duties to identify hazards and eliminate, control and minimise the risk to health and safety;*
- *to entrench the right to refuse to work in dangerous conditions; and*
- *to give effect to the public international law obligations of the Republic relating to mining health and safety…"*

Subsequently, section 2 stipulates that an employer is to ensure safety and

"s. 2 (1) The employer of every mine that is being worked must—

*(a) ensure, as far as reasonably practicable, that the mine is **designed**, [emphasis added] constructed and equipped—*

(i) to provide conditions for safe operation…"

The relevance extends to the fact that Section 9 of the MHS Act, stipulates that an Employer has a duty to prepare and implement a corresponding Code of Practice on any matter affecting the health or safety of employees and other persons who may be directly affected by activities at the mines.

Tripartism

Though not strictly a regulatory prescription, tripartite involvement is entrenched in the matter of Mine Health and Safety in South Africa. Hermanus (2020) provides a recitation of the formulation and interaction of the tripartite functionaries[33] in South African mining industry.

Codes of Practice

The Mine Health and Safety Act, 1996 (Act No. 29 of 1996), as amended and its related regulations specify, amongst others, that:

> *9 (2) An employer must prepare and implement a code of practice on any matter affecting the health or safety of employees and other persons who may be directly affected by activities at the mine if the Chief Inspector of Mines requires it.*

[33] The Government, Employers Organisations, and Labour Organisations

South African Mines Reportable Accidents Statistics System (SAMRASS)

The DMRE collects the description of accidents or dangerous occurrences through the South African Mines Reportable Accidents Statistics System (SAMRASS). A codebook provides the identifying codes to be used on the official form (DMRE, 2007[34]) and the statistics used in the national reporting of health and safety incidents in South Africa are drawn annually from SAMRASS.

The Mine Health and Safety Act defines the incidents that must be reported, namely:

a) Accidents involving injuries or fatalities (in s23(1) to 23(3)(6)), and
b) Dangerous occurrences (s23(4) to 23(7)(ii).

Rock-related incidents are specifically catered in section 23 (4) as follows:

> 23(4) The employer must report to the Principal Inspector of Mines in the manner prescribed …. any of the following dangerous occurrences at the mine-
>
> ***23(4)***
>
> ***(a) Rockbursts And Falls Of Ground***
>
> *An extensive rockburst or fall of ground causing the following damage underground –*
>
> *(i) At least 10 linear metres of working face has been severely damaged and choked and will require re-establishment and re-supporting, or be abandoned;*
>
> *(ii) (ii) At least 25m^2 of working area has been severely damaged and choked rendering support units ineffectual and will have to be re-established and re-supported or be abandoned;*
>
> *(iii) (iii) At least 10 linear metres of gully has been restricted with rock clearly recently displaced from the hanging wall and gully sidewalls;*
>
> *(iv) (iv) At least 10 linear metres continuous or 30 linear metres cumulative of access ways of tunnel or travelling way has been severely damaged and will require rehabilitation or be abandoned;*
>
> *(v) (v) At least 10 m^2 of roof or 5m^3 of rock has been displaced from the roof of the mining cavity or excavation;*

[34] The Mine Health and Safety Committee (MHSC) (2013, p28) records an 'Achievement' regarding Customers/Stakeholders via "for the year, the MHSC submitted the following… SAMRASS Codebook". The correlation between the MHSC (2013) and the DMRE (2007) could not be resolved during the research.

(vi) *(vi) At least 10m^3 of rock has been freshly displaced from pillars or tunnel sidewalls.*

(b) Caving

Any unplanned or uncontrolled caving, side wall or slope failure or subsidence in the ground or workings, causing damage to the surface, which may pose a significant risk to the safety of persons at a mine.

(c) Flow Of Broken Rock

Any unplanned or uncontrolled flow of broken rock, mud or slimes in the workings of a mine which may pose a significant risk to the safety of persons at a mine.

A key performance metric released is the number of fatalities per year – where the initiative to reach 'Zero Harm' is popular amongst many mining companies in South Africa. It is noted that 'Zero Harm' is an initiative in support of the objective of safe working conditions to foster zero fatalities – the actual obligation for safe working environment is formulated through the Mine Health and Safety Act, and the Constitution of South Africa.
The results (i.e. the increase or decrease in the number of fatalities, with greater attention than to the number of injuries) are then compared to prior years' to gain insight into the performance of the mining industry against the metric of 'zero harm'.

It is very common that the statistics reported from SAMASS, through the DMRE, are cited in opening chapters of nearly all publications addressing mine health and safety. Additional, commodity specific studies rely on the SAMRASS statistics released, e.g. Bonsu *et al*.'s (2017) study of mining accident causality of ninety-one accidents from a platinum mine in South Africa.

A number of shortcomings and potential improvements have been identified regarding the efficacy of the reporting system setup, including a reasonably comprehensive description of the data shortcomings in SAMRASS and recommendations for resolution (MHSC SIMRAC, 2001a), which include aspects such as duplication of activities codes that inadvertently create permutations of the same activity being described, and incomplete information sought [by the structure of the form] in instances such as non-adherence to standards.

The Minerals Council (2021a) appears to be currently engaged in an initiative to digitise

safety data *"that could address the South African Mines Reportable Accidents Statistics system (SAMRASS) shortcomings and facilitate a better and faster analysis of safety data".* A clear mandate on the project could not be sourced to clarify how the digitisation of incomplete information would facilitated better analysis of data, though it is acknowledged that the Minerals Council may have access to information from its members or the DMRE, that is made known to other parties. Moreover, the MHSC SIMRAC (2003) have already completed a project on the collation of historical data.

Investigations into Accidents and Dangerous Occurrences in Hard Rock Mines in South Africa

The need, obligation and process of investigations into accident and dangerous occurrences are prescribed by the Mine Health and Safety Act, 1996 where

s11(5) requires that every employer must conduct an investigation into every

(i) accident that must be reported in terms of this Act-

and s23 prescribes the reporting of accidents and dangerous occurrences – giving definitions to the situations that are considered dangerous, accidents, reportable.

Figure 4-23 illustrates the flow diagram showing the incident investigation process.

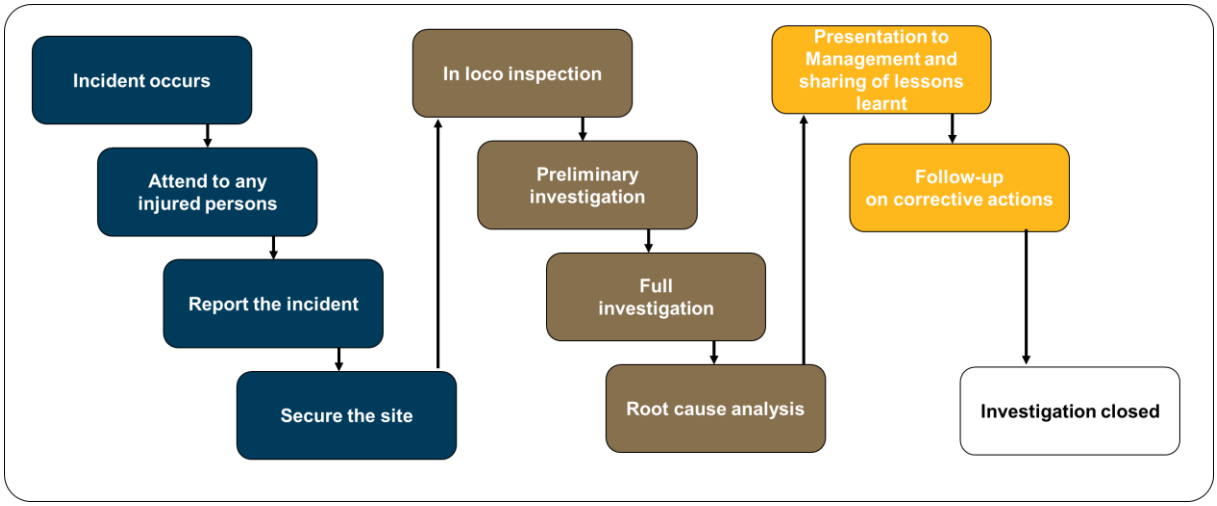


Figure 4-23:Flow diagram showing the incident investigation process (modified after Webber-Youngman et al., 2019)

There is very little literature available on the effectiveness or development in the matter of investigations into Accidents and Dangerous Occurrences in hard rock mines in South Africa, or trends in findings from the root cause analysis.

The use of technology (viz. a virtual reality (VR) experience for incident reconstruction simulations (IRS) as part of training, and the use of laser scanning to assess the

condition of the workings after an incident) is promoted by Webber-Youngman and van Wyk (2013), and Webber-Youngman *et al.* (2019) respectively.

4.9.2.2 The Mineral and Petroleum Resources Development Act, Act 28 of 2002

The Mineral and Petroleum Resources Development Act, Act 28 of 2002 (the MPRDA) (as amended), section 2 describes the aims of the Act to

> *(d) substantially and meaningfully expand opportunities for historically disadvantaged persons, including women and communities, to enter into and actively participate in the mineral and petroleum industries and to benefit from the exploitation of the nation's mineral and petroleum resources;*
>
> *(e) promote economic growth and mineral and petroleum resources development in the Republic…*

The purpose of identifying section 2(d) and (e) is to discuss during later deliberation topics regarding the skills required to participate in the mining industry with a view to transformation (and opportunities therein), as well as the economic imperative to mine optimally.

4.9.3 The Constitution of the Republic of South Africa

The Constitution of the Republic of South Africa, 1996 (Act 108 of 1996) has largely been celebrated as one of – if not the most - "*progressive constitution in the world*. *This means that it makes provision for, and fortifies, basic human rights which are often seen as privileges in other countries*" (South African Human Rights Commission, 2022).

Chapter 2 of the Constitution contains the Bill of Rights, which section 7 considers that the Bill of Rights:

> (1) *"a cornerstone of democracy in South Africa. It enshrines the rights of all people in our country….*
>
> *(2)The state must respect, protect, promote and fulfil the rights in the Bill of Rights.*

The Bill of Rights includes the provision that everyone has the right to "*an environment that is not harmful to their health or wellbeing*" (s24(a)) and "*the right to life*" (s11). Some may argue from a more purist stance that s24 and s11 refer to the natural environment, but in considering both **the spirit** of the law, as well as the letter of the law, it is put forward that mining personnel also are deserving of the "right to life" by being protected or removed from dangerous working conditions.

4.10 Part I – Reporting of geotechnical data and/or information

The various components for Part I of the literature review and their general flow are outlined in Figure 4-24.. The content is then presented in detail in sub-sections 4.10.1 to 4.10.2.

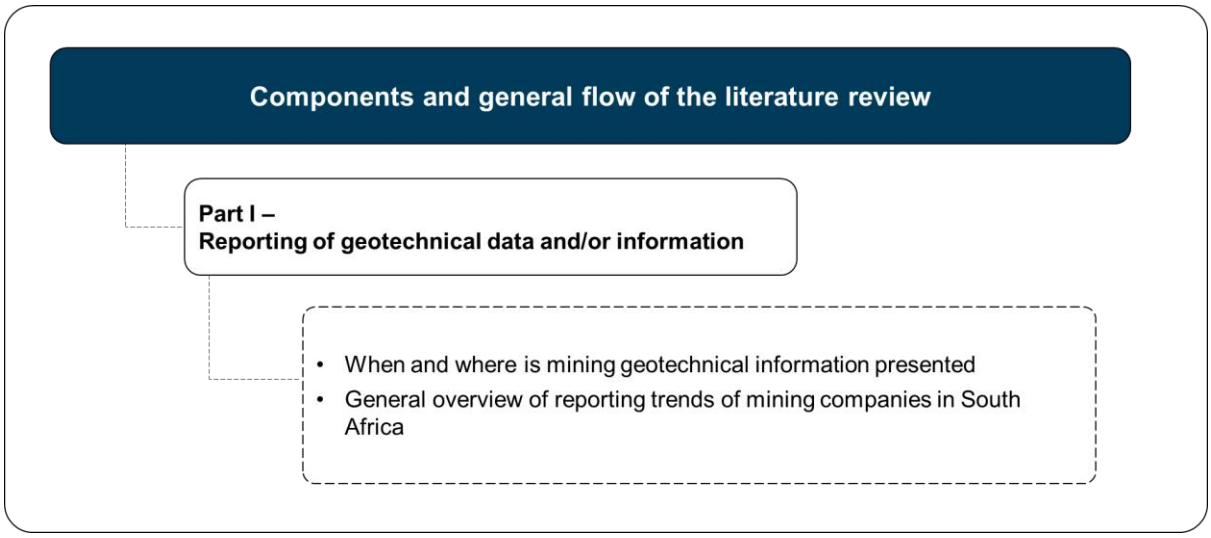


Figure 4-24:Simplified visualisation of the various components for Part I of the literature review and their general flow

4.10.1 When and where is mining geotechnical information presented?

Mining geotechnical data and information that is used toward the design, planning, implementation, or ongoing operation of the mine workings (either open pit or underground) is collected, and then documented at different times in the life cycle of the mining project.

Typically, rock mass data will begin being collected from the field during pre-feasibility, and/or feasibility studies (it is quite often that empirical values are sourced from indices and charts, etc. for use during scoping studies – and little, if any, actual field sampling is carried out for the geotechnical function. It is noted that sampling may be initiated already for geological characterisation, mineralisation estimation and resource classification).

However, the owner [company] of a mining project in South Africa is not obligated to make the information known – unless specific circumstances are relevant, such as:

1) The implementation of the Geoscience regulations, on or about 30 March 2022 – which requires that all

   “geoscience data” (being the data associated with any investigation of the natural environment associated with the Earth).

   “geoscience information”(being the information associated with any investigation of the natural environment associated with the earth).

"geotechnical report" means geotechnical site investigation reports, inclusive of all geohazard-related investigations, prepared by a competent person.
related to a prospecting right or reconnaissance permit must be submitted to the Designated Authority or
related to onshore geoscience data and information not related to prospecting and reconnaissance, must submit geoscience data and information to the Council for Geoscience.

2) *Inter alia*, when listing on the Johannesburg Stock Exchange (JSE) as a Mineral Company and declaring a Mineral Reserve compliant with the SAMREC Code. In this scenario, the geotechnical information will form part of the technical study that is used in the overall assessment of reasonable prospect for eventual economic extraction (RPEEE) reported in the Competent Persons Report (CPR).

3) A SAMREC compliant technical report is also used during the conversion of a Mineral Resource to a Mineral Reserve, though the overall technical studies (with respect to rock mechanics and geotechnical engineering) are not as onerous as that of a full CPR.

SAMREC's 'Table 1' is shown in Table 4-1, and SAMREC's 'Table 2' (shown in Table 4-2) provides guidance in terms of the level of Technical Studies.

The Code does not require that a full Feasibility Study has to be undertaken to convert Mineral Resources to Mineral Reserves, but it does require that at least a Pre-Feasibility Study or Life of Mine Plan will have been carried out to determine that the mine plan/production profile is technically achievable and economically viable, and that material Modifying Factors have been considered to an appropriate level of confidence.

Table 4-3 shows the comparison of reporting and requirements for listing on the respective Securities Exchange (for the initial listing application). Thereafter, annual reporting is undertaken, as outlined in Table 4-4. It is noted though, that annual reporting does not require the inclusion of any geotechnical engineering information or performance [of the stability of the mine workings] unless there is a material change to the operation e.g. a slope failure, and customarily, companies also report safety performance statistics (e.g. number of injuries or fatalities from a fall of ground incident).

An exception to this applies to companies that are not listed on any Securities Exchange (e.g. they have secure capital through other means). There is no obligation for private, unlisted companies to comply with the SAMCODES.

Table 4-1: SAMREC 'Table 1'

			Exploration Results	Mineral Resources	Mineral Reserves
Section 1: Project Outline					
1.1	Property Description	(i)	Brief description of the scope of project (i.e. whether in preliminary sampling, advanced exploration, scoping, pre-feasibility, or feasibility phase, Life of Mine plan for an ongoing mining operation or closure).		
		(ii)	Describe (noting any conditions that may affect possible prospecting/mining activities) topography, elevation, drainage, fauna and flora, the means and ease of access to the property, the proximity of the property to a population centre, and the nature of transport, the climate, known associated climatic risks and the length of the operating season and to the extent relevant to the mineral project, the sufficiency of surface rights for mining operations including the availability and sources of power, water, mining personnel, potential tailings storage areas, potential waste disposal areas, heap leach pad areas, and potential processing plant sites.		
		(iii)	Specify the details of the personal inspection on the property by each CP or, if applicable, the reason why a personal inspection has not been completed.		
1.2	Location	(i)	Description of location and map (country, province, and closest town/city, coordinate systems and ranges, etc.).		
		(ii)	Country Profile: describe information pertaining to the project host country that is pertinent to the project, including relevant applicable legislation, environmental and social context etc. Assess, at a high level, relevant technical, environmental, social, economic, political and other key risks.		
		(iii)	Provide a general topocadastral map	Provide a Topo-cadastral map in sufficient detail to support the assessment of eventual economics. State the known associated climatic risks.	Provide a detailed topo-cadastral map. Confirm that applicable aerial surveys have been checked with ground controls and surveys, particularly in areas of rugged terrain, dense vegetation or high altitude.
1.3	Adjacent Properties	(i)	Discuss details of relevant adjacent properties If adjacent or nearby properties have an important bearing on the report, then their location and common mineralised structures should be included on the maps. Reference all information used from other sources.		
1.4	History	(i)	State historical background to the project and adjacent areas concerned, including known results of previous exploration and mining activities (type, amount, quantity and development work), previous ownership and changes thereto.		
		(ii)	Present details of previous successes or failures with reasons why the project may now be considered potentially economic.		
		(iii)		Discuss known or existing historical Mineral Resource estimates and performance statistics on actual production for past and current operations.	
		(iv)			Discuss known or existing historical Mineral Reserve estimates and performance statistics on actual production for past and current operations.
1.5		Confirm the legal tenure to the satisfaction of the Competent Person, including a description of the following:			

			Exploration Results	Mineral Resources	Mineral Reserves
	Legal Aspects and Permitting	(i)	Discuss the nature of the issuer's rights (e.g. prospecting and/or mining) and the right to use the surface of the properties to which these rights relate. Disclose the date of expiry and other relevant details.		
		(ii)	Present the principal terms and conditions of all existing agreements, and details of those still to be obtained, (such as, but not limited to, concessions, partnerships, joint ventures, access rights, leases, historical and cultural sites, wilderness or national park and environmental settings, royalties, consents, permission, permits or authorisations).		
		(iii)	Present the security of the tenure held at the time of reporting or that is reasonably expected to be granted in the future along with any known impediments to obtaining the right to operate in the area. State details of applications that have been made.		
		(iv)	Provide a statement of any legal proceedings for example; land claims, that may have an influence on the rights to prospect or mine for minerals, or an appropriate negative statement.		
		(v)	Provide a statement relating to governmental/statutory requirements and permits as may be required, have been applied for, approved or can be reasonably be expected to be obtained.		
1.6	Royalties	(i)	Describe the royalties that are payable in respect of each property.		
1.7	Liabilities	(i)	Describe any liabilities, including rehabilitation guarantees that are pertinent to the project. Provide a description of the rehabilitation liability, including, but not limited to, legislative requirements, assumptions and limitations.		
Section 2: Geological Setting, Deposit, Mineralisation					
2.1	Geological Setting, Deposit, Mineralisation	(i)	Describe the regional geology.		
		(ii)	Describe the project geology including deposit type, geological setting and style of mineralisation.		
		(iii)	Discuss the geological model or concepts being applied in the investigation and on the basis of which the exploration program is planned. Describe the inferences made from this model.		
		(iv)	Discuss data density, distribution and reliability and whether the quality and quantity of information are sufficient to support statements, made or inferred, concerning the Exploration Target or Mineralisation.		
		(v)	Discuss the significant minerals present in the deposit, their frequency, sise and other characteristics. Includes minor and gangue minerals where these will have an effect on the processing steps. Indicate the variability of each important mineral within the deposit.		
		(vi)	Describe the significant mineralised zones encountered on the property, including a summary of the surrounding rock types, relevant geological controls, and the length, width, depth, and continuity of the mineralisation, together with a description of the type, character, and distribution of the mineralisation		
		(vii)	Confirm that reliable geological models and / or maps and cross sections that support interpretations exist.		
Section 3: Exploration and Drilling, Sampling Techniques and Data					
3.1	Exploration	(i)	Describe the data acquisition or exploration techniques and the nature, level of detail, and confidence in the geological data used (i.e. geological observations, remote sensing results, stratigraphy, lithology, structure, alteration, mineralisation, hydrology, geophysical, geochemical, petrography, mineralogy, geochronology, bulk density, potential deleterious or contaminating substances, geotechnical and rock characteristics, moisture content, bulk samples etc.). Confirm that data sets include all relevant metadata, such as unique sample number, sample mass, collection date, spatial location etc.		

			Exploration Results	Mineral Resources	Mineral Reserves
		(ii)	Identify and comment on the primary data elements (observation and measurements) used for the project and describe the management and verification of these data or the database. This should describe the following relevant processes: acquisition (capture or transfer), validation, integration, control, storage, retrieval and backup processes. It is assumed that data are stored digitally but hand-printed tables with well organised data and information may also constitute a database.		
		(iii)	Acknowledge and appraise data from other parties and reference all data and information used from other sources.		
		(iv)	Clearly distinguish between data / information from the property under discussion and that derived from surrounding properties		
		(v)	Describe the survey methods, techniques and expected accuracies of data. Specify the grid system used.		
		(vi)	Discuss whether the data spacing and distribution is sufficient to establish the degree of geological and grade continuity appropriate for the estimation procedure(s) and classifications applied.		
		(vii)	Present representative models and / or maps and cross sections or other two or three dimensional illustrations of results, showing location of samples, accurate drill-hole collar positions, down-hole surveys, exploration pits, underground workings, relevant geological data, etc		
		(viii)	Report the relationships between mineralisation widths and intercept lengths are particularly important, the geometry of the mineralisation with respect to the drill hole angle. If it is not known and only the down-hole lengths are reported, confirm it with a clear statement to this effect (e.g. 'down-hole length, true width not known').		
3.2	Drilling Techniques	(i)	Present the type of drilling undertaken (e.g. core, reverse circulation, open-hole hammer, rotary air blast, auger, Banka, sonic, etc) and details (e.g. core diameter, triple or standard tube, depth of diamond tails, face-sampling bit or other type, whether core is oriented and if so, by what method, etc).		
		(ii)	Describe whether core and chip samples have been geologically and geotechnically logged to a level of detail to support appropriate Mineral Resource estimation, technical studies, mining studies and metallurgical studies.		
		(iii)	Describe whether logging is qualitative or quantitative in nature; indicate if core photography. (or costean, channel, etc) was undertaken		
		(iv)	Present the total length and percentage of the relevant intersections logged.		
		(v)	Results of any downhole surveys of the drill hole to be discussed.		
3.3	Sample method, collection, capture and storage	(i)	Describe the nature and quality of sampling (e.g. cut channels, random chips, or specific specialised industry standard measurement tools appropriate to the minerals under investigation, such as down hole gamma sondes, or handheld XRF instruments, etc). These examples should not be taken as limiting the broad meaning of sampling.		
		(ii)	Describe the sampling processes, including sub-sampling stages to maximise representivity of samples. This should include whether sample sises are appropriate to the grain sise of the material being sampled. Indicate whether sample compositing has been applied.		
		(iii)	Appropriately describe each data set (e.g. geology, grade, density, quality, diamond breakage, geo-metallurgical characteristics etc.), sample type, sample-sise selection and collection methods		
		(iv)	Report the geometry of the mineralisation with respect to the drill-hole angle. State whether the orientation of sampling achieves unbiased sampling of possible structures and the extent to which this is known, considering the deposit type. State if the intersection angle is not known and only the downhole lengths are reported.		

			Exploration Results	Mineral Resources	Mineral Reserves
		(v)	Describe retention policy and storage of physical samples (e.g. core, sample reject, etc.)		
		(vi)	Describe the method of recording and assessing core and chip sample recoveries and results assessed, measures taken to maximise sample recovery and ensure representative nature of the samples and whether a relationship exists between sample recovery and grade and whether sample bias may have occurred due to preferential loss/gain of fine/coarse material.		
		(vii)	If a drill-core sample is taken, state whether it was split or sawn and whether quarter, half or full core was submitted for analysis. If a non-core sample, state whether the sample was riffled, tube sampled, rotary split etc. and whether it was sampled wet or dry.		
3.4	Sample Preparation and Analysis	(i)	Identify the laboratory(s) and state the accreditation status and Registration Number of the laboratory or provide a statement that the laboratories are not accredited.		
		(ii)	Identify the analytical method. Discuss the nature, quality and appropriateness of the assaying and laboratory processes and procedures used and whether the technique is considered partial or total.		
		(iii)	Describe the process and method used for sample preparation, sub-sampling and sise reduction, and likelihood of inadequate or non representative samples (i.e. improper sise reduction, contamination, screen sises, granulometry, mass balance, etc.)		
3.5	Sampling Governance	(i)	Discuss the governance of the sampling campaign and process, to ensure quality and representivity of samples and data, such as sample recovery, high grading, selective losses or contamination, core/hole diameter, internal and external QA/QC, and any other factors that may have resulted in or identified sample bias.		
		(ii)	Describe the measures taken to ensure sample security and the Chain of Custody.		
		(iii)	Describe the validation procedures used to ensure the integrity of the data, e.g. transcription, input or other errors, between its initial collection and its future use for modelling (e.g. geology, grade, density, etc.)		
		(iv)	Describe the audit process and frequency (including dates of these audits) and disclose any material risks identified.		
3.6	Quality Control/Quality Assurance	(i)	Demonstrate that adequate field sampling process verification techniques (QA/QC) have been applied, e.g. the level of duplicates, blanks, reference material standards, process audits, analysis, etc. If indirect methods of measurement were used (e.g. geophysical methods), these should be described, with attention given to the confidence of interpretation.		
3.7	Bulk Density	(i)	Describe the method of bulk density determination with reference to the frequency of measurements, the sise, nature and representativeness of the samples.		
		(ii)	If target tonnage ranges are reported state the preliminary estimates or basis of assumptions made for bulk density.		
		(iii)	Discuss the representivity of bulk density samples of the material for which a grade range is reported.		
		(iv)	Discuss the adequacy of the methods of bulk density determination for bulk material with special reference to accounting for void spaces (vugs, porosity etc.), moisture and differences between rock and alteration zones within the deposit.		
3.8	Bulk-Sampling and/or trial-mining	(i)	Indicate the location of individual samples (including map).		
		(ii)	Describe the sise of samples, spacing/density of samples recovered and whether sample sises and distribution are appropriate to the grain sise of the material being sampled.		
		(iii)	Describe the method of mining and treatment.		

			Exploration Results	Mineral Resources	Mineral Reserves
		(iv)	Indicate the degree to which the samples are representative of the various types and styles of mineralisation and the mineral deposit as a whole.		
Section 4: Estimation and Reporting of Exploration Results and Mineral Resources					
4.1	Geological model and interpretation	(i)	Describe the geological model, construction technique and assumptions that forms the basis for the Exploration Results or Mineral Resource estimate. Discuss the sufficiency of data density to assure continuity of mineralisation and geology and provide an adequate basis for the estimation and classification procedures applied.		
		(ii)	Describe the nature, detail and reliability of geological information with which lithological, structural, mineralogical, alteration or other geological, geotechnical and geo-metallurgical characteristics were recorded.		
		(iii)	Describe any obvious geological, mining, metallurgical, environmental, social, infrastructural, legal and economic factors that could have a significant effect on the prospects of any possible exploration target or deposit.		
		(iv)		Discuss all known geological data that could materially influence the estimated quantity and quality of the Mineral Resource.	
		(v)		Discuss whether consideration was given to alternative interpretations or models and their possible effect (or potential risk) if any, on the Mineral Resource estimate.	
		(vi)		Discuss geological discounts (e.g. magnitude, per reef, domain, etc.), applied in the model, whether applied to mineralised and / or un-mineralised material (e.g. potholes, faults, dykes, etc).	
4.2	Estimation and modelling techniques	(i)	Describe in detail the estimation techniques and assumptions used to determine the grade and tonnage ranges.		
		(ii)		Discuss the nature and appropriateness of the estimation technique(s) applied and key assumptions, including treatment of extreme grade values (cutting or capping), compositing (including by length and/or density), domaining, sample spacing, estimation unit sise (block sise), selective mining units, interpolation parameters and maximum distance of extrapolation from data points.	
		(iii)		Describe assumptions and justification of correlations made between variables.	
		(iv)		Provide details of any relevant specialised computer program (software) used, with the version number, together with the estimation parameters used.	

			Exploration Results	Mineral Resources	Mineral Reserves
		(v)		State the processes of checking and validation, the comparison of model information to sample data and use of reconciliation data, and whether the Mineral Resource estimate takes account of such information.	
		(vi)		Describe the assumptions made regarding the estimation of any co-products, by-products or deleterious elements.	
4.3	Reasonable prospects for eventual economic extraction	(i)		Disclose and discuss the geological parameters. These would include (but not be limited to) volume / tonnage, grade and value / quality estimates, cut-off grades, strip ratios, upper- and lower- screen sises.	
		(ii)		Disclose and discuss the engineering parameters. These would include mining method, dilution, processing, geotechnical, geohydraulic and metallurgical) parameters.	
		(iii)		Disclose and discuss the infrastructural including, but not limited to, power, water, site-access.	
		(iv)		Disclose and discuss the legal, governmental, permitting, statutory parameters.	
		(v)		Disclose and discuss the environmental and social (or community) parameters.	
		(vi)		Disclose and discuss the marketing parameters.	
		(vii)		Disclose and discuss the economic assumptions and parameters. These factors will include, but not limited to, commodity prices and potential capital and operating costs	
		(viii)		Discuss any material risks	
		(ix)		Discuss the parameters used to support the concept of "eventual"	
4.4	Classification Criteria	(i)		Describe criteria and methods used as the basis for the classification of the Mineral Resources into varying confidence categories.	
4.5	Reporting	(i)	Discuss the reported low and high-grades and widths together with their spatial location to avoid misleading the reporting of Exploration Results, Mineral Resources or Mineral Reserves.		
		(ii)	Discuss whether the reported grades are regional averages or if they are selected individual samples taken from the property under discussion.		
		(iii)	State assumptions regarding mining methods, infrastructure, metallurgy, environmental and social parameters. State and discuss where no mining related assumptions have been made.		

			Exploration Results	Mineral Resources	Mineral Reserves
		(iv)	State the specific quantities and grades / qualities which are being reported in ranges and/or widths, and explain the basis of the reporting		
		(v)		Present the detail for example open pit, underground, residue stockpile, remnants, tailings, and existing pillars or other sources in the Mineral Resource statement	
		(vi)		Present a reconciliation with any previous Mineral Resource estimates. Where appropriate, report and comment on any historic trends (e.g. global bias).	
		(vii)		Present the defined reference point for the tonnages and grades reported as Mineral Resources. State the reference point if the point is where the run of mine material is delivered to the processing plant. It is important that, in all situations where the reference point is different, such as for a saleable product, a clarifying statement is included to ensure that the reader is fully informed as to what is being reported.	
		(viii)	If the CP is relying on a report, opinion, or statement of another expert who is not a CP, disclose the date, title, and author of the report, opinion, or statement, the qualifications of the other expert and why it is reasonable for the CP to rely on the other expert, any significant risks and any steps the CP took to verify the information provided.		
		(ix)	State the basis of equivalent metal formulae, if applied.		
Section 5: Technical Studies					
5.1	Introduction	(i)	Technical Studies are not applicable to Exploration Results	State the level of study – whether scoping, prefeasibility, feasibility or ongoing Life of Mine	State the level of study – whether prefeasibility, feasibility or ongoing Life of Mine. The Code requires that a study to at least a Pre-Feasibility level has been undertaken to convert Mineral Resource to Mineral Reserve. Such studies will have been carried out and will include a mine plan or production schedule that is technically achievable and economically viable, and

			Exploration Results	Mineral Resources	Mineral Reserves
					that all Modifying Factors have been considered.
		(ii)			Provide a summary table of the Modifying Factors used to convert the Mineral Resource to Mineral Reserve for Pre-feasibility, Feasibility or on-going life-of-mine studies.
5.2	Mining Design	(i)	Technical Studies are not applicable to Exploration Results	State assumptions regarding mining methods and parameters when estimating Mineral Resources or explain where no mining assumptions have been made.	
		(ii)			State and justify all modifying factors and assumptions made regarding mining methods, minimum mining dimensions (or pit shell) and internal and, if applicable, external) mining dilution and mining losses used for the techno-economic study and signed-off, such as mining method, mine design criteria, infrastructure, capacities, production schedule, mining efficiencies, grade control, geotechnical and hydrological considerations, closure plans, and personnel requirements.
		(iii)			State what mineral resource models have been used in the study.
		(iv)			Explain the basis of (the adopted) cut-off grade(s) or quality parameters applied. Include metal equivalents if relevant
		(v)			Description and justification of mining method(s) to be used.
		(vi)			For open-pit mines, include a discussion of pit slopes, slope stability, and strip ratio.

			Exploration Results	Mineral Resources	Mineral Reserves
		(vii)			For underground mines, discussion of mining method, geotechnical considerations, mine design characteristics, and ventilation/cooling requirements.
		(viii)			Discussion of mining rate, equipment selected, grade control methods, geotechnical and hydrogeological considerations, health and safety of the workforce, staffing requirements, dilution, and recovery.
		(ix)			State the optimisation methods used in planning, list of constraints (practicality, plant, access, exposed Mineral Reserves, stripped Mineral Reserves, bottlenecks, draw control).
5.3	Metallurgical and Testwork	(i)	Technical Studies are not applicable to Exploration Results		Discuss the source of the sample and the techniques to obtain the sample, laboratory and metallurgical testing techniques.
		(ii)			Explain the basis for assumptions or predictions regarding metallurgical amenability and any preliminary mineralogical test work already carried out.
		(iii)		Discuss the possible processing methods and any processing factors that could have a material effect on the likelihood of eventual economic extraction. Discuss the appropriateness of the processing methods to the style of mineralisation.	Describe and justify the processing method(s) to be used, equipment, plant capacity, efficiencies, and personnel requirements.
		(iv)			Discuss the nature, amount and representativeness of metallurgical test work undertaken and the recovery factors used. A detailed flow sheet / diagram and a mass balance should exist ,especially for

			Exploration Results	Mineral Resources	Mineral Reserves
					multi-product operations from which the saleable materials are priced for different chemical and physical characteristics.
		(v)			State what assumptions or allowances have been made for deleterious elements and the existence of any bulk-sample or pilot-scale test work and the degree to which such samples are representative of the ore body as a whole.
		(vi)			State whether the metallurgical process is well-tested technology or novel in nature.
5.4	Infrastructure	(i)	Technical Studies are not applicable to Exploration Results	Comment regarding the current state of infrastructure or the ease with which the infrastructure can be provided or accessed	
		(ii)			Report in sufficient detail to demonstrate that the necessary facilities have been allowed for (which may include, but not be limited to, processing plant, tailings dam, leaching facilities, waste dumps, road, rail or port facilities, water and power supply, offices, housing, security, resource sterilisation testing etc.). Provide detailed maps showing locations of facilities.
		(iii)			Statement showing that all necessary logistics have been considered.
5.5	Environmental and Social	(i)	Technical Studies are not applicable to Exploration Results	Confirm that the company holding the tenement has addressed the host country environmental legal compliance requirements and any mandatory and/or voluntary standards or guidelines to which it subscribes	
		(ii)		Identify the necessary permits that will be required and their status and where not yet obtained, confirm that there is a reasonable basis to believe that all permits required for the project will be obtained	

			Exploration Results	Mineral Resources	Mineral Reserves
		(iii)		Identify and discuss any sensitive areas that may affect the project as well as any other environmental factors including I and AP and/or studies that could have a material effect on the likelihood of eventual economic extraction. Discuss possible means of mitigation.	
		(iv)		Identify any legislated social management programmes that may be required and discuss the content and status of these.	
		(v)		Outline and quantify the material socio-economic and cultural impacts that need to be mitigated, and ~~the~~ their mitigation measures and where appropriate the associated costs.	
5.6	Market Studies and Economic criteria	(i)	Technical Studies are not applicable to Exploration Results		Describe the valuable and potentially valuable product(s) including suitability of products, co-products and by products to market.
		(ii)			Describe product to be sold, customer specifications, testing, and acceptance requirements. Discuss whether there exists a ready market for the product and whether contracts for the sale of the product are in place or expected to be readily obtained. Present price and volume forecasts and the basis for the forecast.
		(iii)			State and describe all economic criteria that have been used for the study such as capital and operating costs, exchange rates, revenue / price curves, royalties, cut-off grades, reserve pay limits.
		(iv)			Summary description, source and confidence of method used to estimate the commodity price/value profiles used for cut-off grade calculation, economic analysis and project valuation, including applicable taxes, inflation indices, discount rate and exchange rates.
		(v)			Present the details of the point of reference for the tonnages and grades reported as

			Exploration Results	Mineral Resources	Mineral Reserves
					Mineral Reserves (e.g. material delivered to the processing facility or saleable product(s)). It is important that, in any situation where the reference point is different, a clarifying statement is included to ensure that the reader is fully informed as to what is being reported.
		(vi)			Justify assumptions made concerning production cost including transportation, treatment, penalties, exchange rates, marketing and other costs. Provide details of allowances that are made for the content of deleterious elements and the cost of penalties.
		(vii)			Provide details of allowances made for royalties payable, both to Government and private.
		(viii)			State type, extent and condition of plant and equipment that is significant to the existing operation(s).
		(ix)			Provide details of all environmental, social and labour costs considered
5.7	Risk Analysis	(i)	Technical Studies are not applicable to Exploration Results	Report an assessment of technical, environmental, social, economic, political and other key risks to the project. Describe actions that will be taken to mitigate and/or manage the identified risks.	
5.8	Economic Analysis	(i)	Technical Studies are not applicable to Exploration Results	At the relevant level (Scoping Study, Pre-feasibility, Feasibility or on-going Life-of Mine), provide an economic analysis for the project that includes:	
		(ii)		Cash Flow forecast on an annual basis using Mineral Reserves or an annual production schedule for the life of the project	
		(iii)		A discussion of net present value (NPV), internal rate of return (IRR) and payback period of capital	

			Exploration Results	Mineral Resources	Mineral Reserves
		(iv)		Sensitivity or other analysis using variants in commodity price, grade, capital and operating costs, or other significant parameters, as appropriate and discuss the impact of the results.	
Section 6: Estimation and Reporting of Mineral Reserves					
6.1	Estimation and modelling techniques	(i)		Describe the Mineral Resource estimate used as a basis for the conversion to a Mineral Reserve.	
		(ii)		Report the Mineral Reserve Statement with sufficient detail indicating if the mining is open pit or underground plus the source and type of mineralisation, domain or ore body, surface dumps, stockpiles and all other sources.	
		(iii)			Provide a reconciliation reporting historic reliability of the performance parameters, assumptions and modifying factors including a comparison with the previous Reserve quantity and qualities, if available. Where appropriate, report and comment on any historic trends (e.g. global bias)
6.2	Classification Criteria	(i)			Describe and justify criteria and methods used as the basis for the classification of the Mineral Reserves into varying confidence categories, based on the Mineral Resource category, and including consideration of the confidence in all the modifying factors.
6.3	Reporting	(i)			Discuss the proportion of Probable Mineral Reserves, which have been derived from Measured Mineral Resources (if any), including the reason(s) therefore.
		(ii)			Present details of for example open pit, underground, residue stockpile, remnants, tailings, and existing pillars or other sources in respect of the Mineral Reserve statement
		(iii)			Present the details of the defined reference point for the Mineral Reserves. State where the reference point is the point where the run

			Exploration Results	Mineral Resources	Mineral Reserves
					of mine material is delivered to the processing plant. It is important that, in all situations where the reference point is different, such as for a saleable product, a clarifying statement is included to ensure that the reader is fully informed as to what is being reported. State clearly whether the tonnages and grades reported for Mineral Reserves are in respect of material delivered to the plant or after recovery.
		(iv)			Present a reconciliation with the previous Mineral Reserve estimates. Where appropriate, report and comment on any historic trends (e.g. global bias).
		(v)			Only Measured and Indicated Mineral Resources can be considered for inclusion in the Mineral Reserve.
		(vi)			State whether the Mineral Resources are inclusive or exclusive of Mineral Reserves.
Section 7: Audits and Reviews					
7.1	Audits and Reviews	(i)	State type of review/audit (e.g. independent, external), area (e.g. laboratory, drilling, data, environmental compliance etc), date and name of the reviewer(s) together with their recognised professional qualifications.		
		(ii)	Disclose the conclusions of relevant audits or reviews. Note where significant deficiencies and remedial actions are required.		
Section 8: Other Relevant Information					
8.1		(i)	Discuss all other relevant and material information not discussed elsewhere.		
Section 9: Qualification of Competent Person(s) and other key technical staff. Date and Signature Page					
9.1		(i)	State the full name, registration number and name of the professional body or RPO, for all the Competent Person(s). State the relevant experience of the Competent Person(s) and other key technical staff who prepared and are responsible for the Public Report.		
		(ii)	State the Competent Person's relationship to the issuer of the report.		
		(iii)	Provide the Certificate of the Competent Person (Appendix 2), including the date of sign-off and the effective date, in the Public Report.		
Section 10: Reporting of for Coal Resources and Reserves					
10.1		(i)	Confirm that the reports on coal deposits take cognisance of sections 54-74 of the Code and Sections 1 - 9 of Table 1.		

			Exploration Results	Mineral Resources	Mineral Reserves
	Specific Reporting for Coal	(ii)	Confirm that the Coal Exploration Results, Coal Inventory, Coal Resources and Coal Reserves are reported using the South African National Standard 10320 as the guideline		
10.2	Geological Setting, Deposit, Mineralisation	(i)	Describe the project geology including coal deposit type, geological setting and coal seams / zones present.		
		(ii)	Identify and discuss the structural complexity, physical continuity, coal rank, qualitative and quantitative properties of the significant coal seams or zones on the property.		
10.3	Drilling Techniques	(i)	Report core recoveries and method of calculation. Confirm that core recoveries in cored boreholes are in excess of 95% by length within the coal seam intersection.		
	Relative Density to replace Bulk Density	(ii)	Describe the apparent relative density or true relative density of the coal seam(s) determined on coal samples from borehole cores using recognised standard laboratory methods or commonly used procedures. State the moisture basis on which the relative density determination is based and the moisture basis on which the final density value is reported (*in situ* or air-dried basis).		
	Bulk-Sampling and/or trial-mining	(iii)	Describe the purpose or aim of the bulk sampling programme, the sise of samples, spacing/density of samples recovered. Describe the applicability of bulk sampling or large diameter core samples towards providing representative samples for tests. Compare and comment on results obtained from bulk sampling versus exploration sampling.		
10.4	Reasonable prospects for eventual economic extraction	(i)	Confirm that an appropriate coal quality is reported for all Coal Resource categories. Present and discuss the type of analysis (e.g. raw coal, washed coal at a specific cut-point density) and the basis of reporting of the coal quality parameters (e.g. air-dried basis, dry basis, etc.).		
10.5	Coal Resource Reporting	(i)		A Coal Resource only includes the coal seam(s) above the minimum thickness cut-off and the coal quality cut-off(s). Present and discuss the MTIS Coal Resource tonnage and quality.	
		(ii)		State the reporting basis for the Coal Resource statement with particular reference to moisture and relative density.	
10.6	Coal Reserve Reporting	(i)			State the reporting basis for the Coal Reserve statement with particular reference to moisture and relative density.

			Exploration Results	Mineral Resources	Mineral Reserves
		(ii)			Confirm that the Coal Reserves are reported as ROM tonnages and coal quality, and also as Saleable product/s tonnages and coal quality. Present and discuss the reporting basis for the Coal Reserve statement with particular reference to moisture content and relative density.
Section 11: Reporting of Diamonds and Gemstones					
This section highlights criteria that are applicable to diamond deposits and to other gemstone deposits. Reports of diamond and other gemstone properties must also take cognisance of sections 59-71 of the Code, Sections 1 - 9 of Table 1 and the Guidance notes in the SAMCODE Companion Volume. The information required in this section (Section 11) should be included with the relevant sections and should not comprise a separate chapter.					
11.1	Geological Setting, Deposit, Mineralisation	(i)	For diamond placer occurrences, describe the overburden and gravel thicknesses, as well as bedrock topography		
11.2	Sampling of Diamond Projects	(i)	Describe the type of sample (outcrop, boulder, drill-core, RC drill cuttings, gravel, stream sediment or soil) and purpose (for example: RC drilling to identify gravel thickness, large diameter drilling to establish stones per unit of volume, bulk-sample, etc.)		
		(ii)	Discuss sample sise, distribution and representivity		
		(iii)	Identify the type of sample facility, treatment rate and accreditation		
		(iv)	Discuss sample sise reduction, bottom and top screen sises and any re-crush		
		(v)	Discuss the sample processes (e.g. DMS, grease, X-Ray, Hand-sorting, etc.)		
		(vi)	Discuss process efficiency, tailings auditing and granulometry		
		(vii)	Identify the laboratory used, type of process for microdiamonds and accreditation. Reports of microdiamond recoveries should describe the extraction process, crushing methodology and the stone counts per unit weight, as a minimum.		
		(viii)	State whether the reports of kimberlitic indicator minerals ("KIM's") or diamond indicator minerals ("DIM's") have been prepared by a suitably qualified laboratory which must be identified.		
		(ix)	Supply details of the sampling parameters for reports dealing with recoveries of diamonds or KIM's, including, but not limited to type of sample (stream sediment, soil, bulk, rock, etc.) as well as sample sise, sample frequency, representivity and screen parameters are required.		
		(x)	Discuss the relevant major and trace element chemistry of any kimberlitic indicator minerals recovered. Reference relevant peer-reviewed published research articles when reporting the interpretation of mineral chemistry data for diamond exploration projects.		
		(xi)	Provide details of the form, shape, colour and sise of the diamonds recovered and, where relevant, comments regarding the nature of the source of the diamonds.		

			Exploration Results	Mineral Resources	Mineral Reserves
11.3	Bulk-Sampling and/or trial-mining	(i)	Provide a table of relevant results , including (but not limited to) volume of sample, number of individual diamonds, total number of carats, sample grade, diamond value (it is not possible to evaluate diamond assortment from microdiamonds).		
		(ii)	Discuss micro- and macro- diamond sample results per geological domain.		
		(iii)	Discuss stone-sise and -number distribution (Sise-frequency distribution). Include the suitability of the sample sise to the stage of the project and its relevance for both SFD and valuation (assortment) purposes.		
		(iv)	State the top and bottom sieve cut-off sises.		
		(v)	Discuss diamond breakage, where relevant		
		(vi)	Define the unit of grade measure used in the document (e.g. carat per units of mass, area or volume). Where carats per unit of mass is used, include a discussion of mass to tonnage conversion.		
11.4	Estimation and Modelling Techniques	(i)	Describe in detail any estimation techniques (including geostatistical estimation, where relevant) used to determine the volume/tonnage, grade and value data, including their applicability to the deposit type.		
		(ii)	Express applicable volumes, grades and values in ranges (with appropriate clarifiers to denote lack of reliability of data). The use of "ranges" in this context has no statistical connotation	State all Diamond Resource estimates so as to convey the order of accuracy by rounding off to appropriately significant figures.	State all Diamond Reserve estimates so as to convey the order of accuracy of the estimates by rounding off to appropriately significant figures.
		(iii)	Discuss volume/tonnage, grade and value information per identified domain (where possible, even if in a very preliminary form)	Discuss volume/tonnage, grade and value information per identified domain	
		(iv)	If grades are reported then state clearly whether these are regional averages, based on microdiamond assessment, KIM analyses, or if they are selected individual samples taken from the property under discussion. The occurrence of individual diamonds or microdiamonds in surficial deposits or from inadequate samples (too small to be statistically valid) from a primary or secondary rock source would not typically qualify as an exploration target. This may not be true for marine deposits, in which case further explanation and discussion would be necessary.	State that the grades for the Diamond Resources are estimated from sampling data derived from the property itself	State that the grades for Diamond Reserves have been estimated from bulk-sampling and/or trial-mining

			Exploration Results	Mineral Resources	Mineral Reserves
		(v)	Report all diamond values in US$/ct. If reference is made to local currencies then provide the prevailing exchange rate as well as the effective date of the exchange rate. Also supply the date of valuation.		
		(vi)	Specify details of the type and sise of individual samples (including top and bottom cut-off sise, in millimetres, used in the recovery).		
		(vii)	Discuss the representivity of the type, sise, number and location of the samples		
		(viii)	Discuss geostatistical estimation (where relevant) and interpolation techniques applied and their applicability to the deposit type		
		(ix)	Specify the number and total weight (in carats) of diamonds recovered. The weight of diamonds recovered may only be omitted from the report when the diamonds are less than 0.5mm in sise (i.e. when the diamonds recovered are microdiamonds) or when the diamonds are below a specified commercial cut-off value, which must be specified.		
		(x)		Disclose the number of stones and the total number of carats used in the SFD, grade and value estimation and discuss the validity of this data.	
		(xi)		Note whether a strict lower cut-off has been applied or if the modelled results include incidental diamonds below the lower cut-off? Discuss the implications.	
		(xii)		Present aspects of spatial structure analysis and grade and value distribution	
		(xiii)		Present aspects of micro and macro- diamond sample results per domain	
		(xiv)		Present aspects of the effect on sample grade and value with change in bottom cut off screen sise.	
		(xv)		Describe any adjustments made to sise distribution for sample plant performance and performance on a commercial scale, where applicable.	
		(xvi)		Confirm that valuations have not been reported for samples of diamonds processed using total liberation methods (which are commonly used for processing kimberlite exploration samples and which are based on microdiamonds).	
		(xvii)		Justify the use of microdiamonds to extrapolate diamond value at depth through the presentation of geological and sise frequency distribution models	
		(xviii)		State the name, qualifications, experience and independence of the recognised expert responsible for the classification and valuation of the diamond parcel(s).	
		(xix)		For each diamond parcel valued, supply information relating to the number of stones and the carats and sise distribution using a standard progression of sieve sises or diamond mass ranges for each identified geological domain. For marine or alluvial placers the average price per average stone sise may be used instead of a sise distribution	
		(xx)		State that the valuation is on the run-of-mine diamond parcel (i.e. not partial parcel)	
		(xxi)		Define the unit of grade measure used in the resource/reserve estimation (e.g. carat per units of mass, area or volume). Where carats per unit of volume is used, include a discussion of mass to tonnage conversion.	

			Exploration Results	Mineral Resources	Mineral Reserves
11.5	Resource/ Reserve Classification Criteria	(i)		A Diamond Resource/Reserve must be described in terms of volume/tonnage, grade and value. A Diamond Resource/Reserve must not be reported in terms of contained diamond content unless corresponding tonnages/volumes, grades and values are also reported. The average diamond grade and value must not be reported without specifying the applicable bottom cut-off screen sise.	
		(ii)		Discuss issues surrounding stone frequency (stones per cubic metre, per tonne, or per square metre) and stone sise (carats per stone) relating to grade (carats per cubic metre, per tonne or per square metre). Consider the elements of uncertainty in these estimates and develop the Diamond Resource classification accordingly.	
		(iii)		Present relevant aspects of stone sise and number distribution, including the applicability of the parcel sise. Note that a Diamond Resource/Reserve may not be declared without reference to an SFD.	
		(iv)		Present aspects of global sample grade per geological domain and local block estimates in the case of Indicated Resources	
11.6	Audits and Reviews	(i)	State that the samples were sealed after excavation and discuss the chain of custody from source to reporting of results		
		(ii)	Discuss security standards in sampling plant and recovery sections of bulk-sampling/trial-mining programmes for macrodiamonds		
		(iii)	Describe the type of facility, treatment rate, and accreditation (if any) of the sample plant. It is especially important to discuss the bottom screen sise, top screen sise and recrush parameters, in addition to the concentration methodology (e.g. pan, DMS, Optical, etc.) and the recovery technique (e.g. grease, X-ray, hand-sorting, etc.).		
		(iv)	Discuss valuer location, escort, delivery, cleaning losses, reconciliation with recorded sample carats and number of stones;		
		(v)	State whether core samples were washed prior to treatment for microdiamonds and discuss the use of diamond drill-bits		
		(vi)	State whether any audit samples were treated at alternative facilities		
		(vii)	Discuss QA/QC of sampling results, including the process efficiency, tailings auditing and granulometry		
		(viii)	Discuss the recovery of tracer monitors used in sampling and treatment		
		(ix)	Discuss geophysical (logged) density and particle density, where relevant		
		(x)	Discuss cross-validation of sample weights, wet and dry, with hole volume and density, moisture factor		
Section 12: Reporting of Industrial Minerals					
12.1	Specific for Reporting of Industrial Minerals	(i)	Confirm that the reports on Industrial Mineral deposits take cognisance of Sections 80 of the Code and Sections 1 - 9 of Table 1.		
		(ii)	Describe the exploration or geologically specific specialised industry techniques appropriate to the minerals under investigation		
		(iii)	Describe the nature and quality of sampling or specific specialised industry standard measurement tools appropriate to the minerals under investigation		
		(iv)	Describe the appropriate saleable product qualities being reported. Describe the basis for reporting (physical or chemical parameters, air-dried basis, dry basis, etc.). Reporting of deleterious chemical elements or physical parameters is required.		

			Exploration Results	Mineral Resources	Mineral Reserves
		(v)	State assumptions regarding in particular mining methods, infrastructure, metallurgy, environmental and social parameters. Explain where no mining related assumptions have been made.		
		(vi)	Disclose and discuss the marketing parameters, customer specifications, testing, and acceptance requirements.		
		(vii)	Discuss the nature, amount and representativeness of metallurgical studies completed which form the basis for the various saleable materials which may be priced for different chemical and physical characteristics.		
		(viii)	Present the defined reference point of the reported tonnages and grades/qualities. Where the reference point is the point is a saleable product, a clarifying statement is included to ensure that the reader is fully informed as to what is being reported. State whether the tonnages and grades/qualities of the material delivered to the plant or after recovery.		
Section 13: Reporting using Metal Equivalents					
13.1	Specific for Metal Equivalents Reporting	(i)	Confirm that reports on all deposits take cognisance of Sections 73 of the Code and Sections 1 - 9 of Table 1.		
		(ii)		Discuss and describe the basis for the grade estimation for each metal relating to the metal equivalence	
		(iii)		Disclose all economic criteria that have been used for the calculation such as exchange rates, revenue / price curves, royalties, cut-off grades, pay limits.	
		(iv)		Discuss the basis for assumptions or predictions regarding metallurgical factors such as recovery used in the metal equivalents calculation.	
		(v)		Show the calculation formula used.	

Table 4-2: SAMREC 'Table 2'

General	Scoping Study	Prefeasibility Study	Feasibility Study
Resource categories	Mostly Inferred	Mostly Indicated	Measured and Indicated
Reserve categories	None	Mostly Probable	Proved and Probable
Mining method and geotechnical constraints	Conceptual	Preliminary Options	Detailed and Optimised
Mine design	None or high-level conceptual	Preliminary mine plan and schedule	Detailed mine plan and schedule
Scheduling	Annual approximation	Quarterly to annual	Monthly for much of payback period
Mineral Processing	Metallurgical test work	Preliminary Options	Detailed and Optimised
Permitting - (water, power, mining, prospecting and environmental)	Required permitting listed	Preliminary applications submitted	Authorities engaged and applications submitted
Social licence to operate	Initial contact with local communities	Formal communication structures and engagement models in place	Contracts/agreements in place with local communities and municipalities (local government)
Risk tolerance	High	Medium	Low

Table 4-3: Comparison of reporting and requirements for listing on the respective Securities Exchange

Name	Johannesburg Stock Exchange (JSE)	Australian stock exchange (ASX)	New York Stock Exchange (NYSE)	Toronto Stock Exchange (TSX)
Location (city, country)	Johannesburg, South Africa	Sydney, Australia	New York, USA	Ontario, Canada
Mineral reporting code	South African Code for the Reporting of Exploration Results, Mineral Resources and Mineral Reserves (the SAMREC Code)	Joint Ore Reserve Committee (JORC) Code	Federal Register Vol. 83, No. 246, Pages 66344-66461	CIM Definition Standards for Mineral Resources and Mineral Reserves (CIM)
Listing rule/s	Listing rule Section 12 for Mineral Companies	Chapter 5, using Guidance note 31	S-K 1300 regulations	National Instrument (NI) 43-101
Minimum project status for listing	CPR as well as other requirements (e.g. 12.5(b) b) to the satisfaction of the JSE that its management have satisfactory experience in mining and/or exploration depending on its business…	technical report must be prepared by, or under the supervision of independent + competent person disclosure of a completed Table 1 showing an exploration or mineral development project that could have a significant influence on the market value or operations of a listed company	An Initial Assessment is required for disclosure of Mineral Resources	Technical Repot summarizing the results of Mining Studies (Preliminary Feasibility or Feasibility Studies)
Study level for reserve declaration	The minimum requirement for the declaration of a Mineral Reserve is a Prefeasibility level study.	completion of a preliminary feasibility study, at a minimum, to support a maiden ore reserve declaration	while a Preliminary Feasibility or Feasibility Study is required to support disclosure of Mineral Reserves	Pre-Feasibility Study as the minimum prerequisite for the conversion of Mineral Resources to Mineral Reserves.

4.10.2 A general overview of reporting trends of mining companies

The sub-section herein under describes general overview of reporting trends of mining companies in South Africa. The purpose is to demonstrate the inadvertent emphasis that has developed regarding the reporting of 'other' elements such as production, Mineral grade, Mineral Resources, Mineral Reserves, capital and operating costs, corporate social responsibility, as well as Environmental, social and governance – to the point of exclusion of technical aspects of rock and geotechnical engineering.

In South Africa, a company is considered to be a juristic person incorporated in terms of the Companies Act 71 of 2008 (as amended). The nature of a company (that is domiciled[35] in South Africa) is detailed in their articles of association, prescribed through the Companies Act. The company may now conduct business by conforming to the rules and regulations applicable to the industry and sector of their choosing.

If the company wishes to own and/or operate a mine, it will have to meet and adhere to the requirements of the Mineral and Petroleum Resources Development Act, 2002 (Act 28 of 2002) (MPRDA) (as amended).

Furthermore, if the company wishes to list on a stock exchange, it will have to conform to various additional requirements set by the particular stock exchange.

Companies that operate mining projects – such as open pit mines or underground mines – routinely report on various aspects relating to the business undertaking.
The organisational structure may see the company form part of a larger group alongside other companies, or even constituting subsidiaries, with a holding company at the helm[36].

[35] The place or country in which a business is registered or has been incorporated.

[36] A holding company is considered a type of financial organisation that owns a controlling interest in other companies [subsidiaries], and can therefore control the subsidiary's policies as well as oversee their management decisions. However, they are not involved in the operations 'day-to-day' running.

Table 4-4: General Overview of Annual Reporting for Mining Entities in South Africa

Component	Applies to	Typical frequency	General Explanatory note
Notice of Annual General Meeting	All companies incorporated in South Africa	Every year	Section 61(7) of the Companies Act 71 of 2008 (as amended) requires that "*A public company must convene an annual general meeting of its shareholders- (a) initially, no more than 18 months after the company's date of incorporation; and (b) thereafter, once in every calendar year, but no more than 15 months after the date of the previous general meeting, or within an extended time*" .
Minutes of the AGM	All companies incorporated in South Africa	Every year	
Company Financial Statements		Every year	Section 30 of the Companies Act 71 of 2008 (as amended) provides that "*a company must prepare annual financial statements within six months after the end of the financial year*".
Group Annual Financial Report		Every year	
Integrated Annual Report		Every year	
Mineral Resources and Mineral Reserves report		Every year	
Payments to Government		Every year	
The Good Neighbour Agreement (GNA)	Specific organisations (e.g. Sibanye-Stillwater)	Every year, if applicable to the organisation	The GNA is an innovative framework for the protection of the natural environment while encouraging responsible economic development
Global Reporting Initiative (GRI) reporting	Voluntary participation	Every year	Aims to contribute to sustainable improvement by empowering organisations to understand and communicate the impacts of their activities on people and the environment using a modular system of interconnected standards in a structured way, that is transparent to stakeholders and other interested parties.

Component	Applies to	Typical frequency	General Explanatory note
King IV Disclosure	Voluntary participation	Every year	Ideals set toward transparency, where the disclosure considers a set of voluntary principles to promote sound corporate governance, that in turn requires an acknowledgement that an organisation doesn't operate in a vacuum, but is an integral part of society and therefore has accountability towards current and future stakeholders.
ICMM self-assessment	Voluntary participation	Every year	Intends actions toward inclusive and sustainable economic growth and aims to confirm the existence and the integrity of systems and/or practices…toward a safe, just and sustainable world that is enabled by responsibly produced minerals and metals.
Biodiversity management	Voluntary	Every year	Reporting content and detail is not prescribed
ESG elements	Voluntary	Every year	Reporting content and detail is not prescribed
Social and labour plans: Summary of projects in South Africa	Voluntary to report to shareholders (for listed companies), whereas the Social and Labour Plan itself is mandatory under Regulation 46 of the Mineral and Petroleum Resources Development Act 28 of 2002 (as amended)	Every year	Reporting content and detail is not prescribed
Environmental incidents (if any)	Voluntary	Every year	Reporting content and detail is not prescribed
Climate change related disclosure	Voluntary	Every year	Reporting content and detail is not prescribed

Table 4-5: General Example of Additional Detailed Reporting for Mining Entities in South Africa

Component	Typical frequency
Historical statistics by operation	Every quarter (i.e. every 3 months) (spanning from the date of acquisition of the asset [mine], to the current reporting date)
Operating update for the quarter ended (YYYY-MM)	Every quarter (i.e. every 3 months)
Operating and financial results for the six months and year ended 31 December xxxx	End Year
INTERIM Operating and financial results for the six months ended 30 June xxxx	Half Year

Component	Typical frequency
Short form: Results for the six months and year ended 31 December xxxx	End Year
Short form[37]: Results for the six months ended 30 June xxxx	Half Year

[37] A 'short form' is the summarised version of the full announcement, regarding the audited financial results for the year [with relevant date specified] and, therefore, it does not contain full or complete details pertaining to the Group's financial position.

4.11 Part J – Technical competence

The various components for Part J of the literature review and their general flow are outlined in Figure 4-25. The content is then presented in detail in sub-sections 4.11.1 to 4.11.3.7.

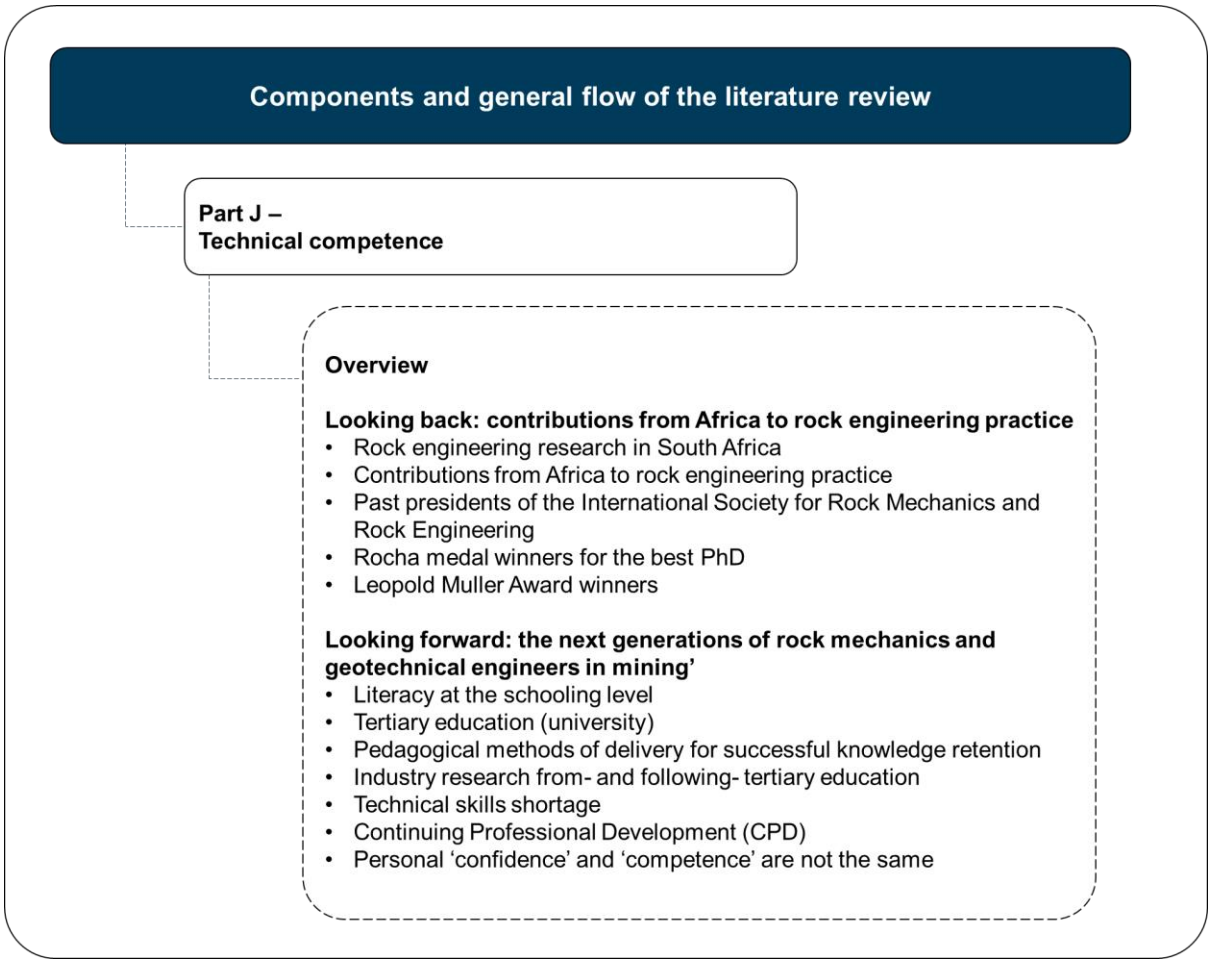


Figure 4-25:Simplified visualisation of the various components for Part J of the literature review and their general flow

4.11.1 Overview

A review of topics related to the technical qualifications, skills, and research toward mining personnel competency is included, as part of the overall explanation and justification for refined technical reporting of geotechnical engineering in hard rock mining.

The purpose of including mention of methods toward successful learning is explained further in chapter 5, in the context of occupational training carried out for adults working in mining, where the evaluation considers the employer's role in facilitating job-related training and knowledge retention (e.g. identification of rockmass hazards).

Given that eventual occupational competency may flow from schooling and/or literacy to some extent - the literature review hereunder considers literacy at the schooling level, because it is one of the precursors toward mining qualifications, and because it speaks to the long-term objectives of the National Development Plan (NDP) of South Africa where the CSIR (2018) have reported that:

> "*mining is a critical industry for South Africa as the country works towards the achievement of the National Development Plan (NDP), which aims to eliminate poverty and reduce inequality by 2030. According to the NDP, the country can realise these goals by drawing on the energies of its people, growing an inclusive economy, building capabilities, enhancing the capacity of the state, and promoting leadership and partnerships throughout society".*

Hence, we see that the human capital of the future will have an important role in actioning the work directed to the objectives of the NDP – which includes technical interpretation of complex systems in rock mechanics and geotechnical engineering.
As the operation of mines is becoming increasingly complex through the inclusion of various technologies and adaptations, as well as that the 'easier' ore bodies are nearing depletion and new mineralisation targets are likely to be somewhat more complex in respect of engineering, resulting in the situation that the decisions and challenges of the future are likely to differ from those that were experienced historically, and taught currently. It is therefore considered that the role of critical thinking, analytical reasoning, and interpersonal skills for collaborative engagement are essential tools in the metaphorical toolbox of occupational competency in mining rock mechanics and geotechnical engineering.

4.11.2 Looking back: contributions from Africa to rock engineering practice

4.11.2.1 Rock engineering research in South Africa

Stacey (2019) poses the question: "*What happened to rock engineering research in South Africa?*" in the related journal paper which follows an opinion piece (understood to have been released in the Mining Weekly[38] publication). The paper narrates the significant growth of rock engineering research in South Africa during the 1950's and after a period of approximately 20 years, South Africa (through the Chamber of Mines Research Organisation, COMRO) grew to be considered a "*major research facility unparalleled in the rest of the world*".

Unfortunately, perceptions held amongst individuals within mining companies during the 1980's are said to have been of the opinion that the research facility was *'costing the industry too much"* and *"not delivering sufficiently'*. Subsequently, the "*research powerhouse*" (as it was regarded) was effectively *'given away'* to the Council of Scientific & Industrial Research (CSIR). However, over time it became apparent that that there was no mining engineering or rock engineering research strategy with the CSIR. Consequently, the body of researchers left the organisation in a period just over 10 years, the majority of the old COMRO equipment was scrapped, the infrastructure was disposed, and the Division effectively became dysfunctional until it eventually closed (Stacey, 2019).

Stacey's (2019) narration provides an important insight into the potential – but very impactful - disconnect that may sometimes occur between industry and research.

When pursuing the commercial ideal of maximised profit, minimised expenditure – the perception of improvements generated from rock engineering research are not always immediately obvious from a profit-centric viewpoint.

It is not uncommon that the outcomes of rock engineering research to benefit a variety of aspects of the mining operation, over and above rock engineering itself. Stacey (2019) provides several examples, including where:

- The quality of blasting for an open pit mine defined the fragmentation distributions required in ore and waste rock.
- Research carried out was able to optimise blast designs as to achieve the fragmentation profile required.
- Continued research into the use of electronic delay detonators demonstrated that uniform fragmentation could consistently be achieved and at a lower financial cost.
- From the research, improvements in loading, hauling, and milling rates were achieved to the extent that financial benefit associated with milling alone – was

[38] Stacey (2019) refers to the *Mining Weekly* edition of 21 March 2014.

approximately R 30 million per month. There was also an improvement in loading and hauling in excess of 15%.

It is realised then, that *individual* actors and smaller groups (e.g. university supervisors and postgraduate students) continue to play a very important role in the ongoing advancement of rock engineering – despite the disregard they may experience from larger bands of influence (viz. corporate personnel with contrasting priorities).

Despite the loss of the “powerhouse”, South Africa (and Africa as a whole) have continued to produce world class research. Examples of these are summarised in the sub-sections 4.11.2.2, 4.11.2.3, 0 below.

4.11.2.2 Contributions from Africa to rock engineering practice

Stacey (2022) provides a personable narrative of the contributions and contributors from Africa to the practice of rock engineering over the decades. The narrative considers many of the fundamental components that comprise the practice, including rock fracture and failure, rockbursts, rock mass classification, *in situ* stress measurements, rock property testing, point load testing, rapid loading properties, rock slope stability, two- and three-dimensional finite element stress analyses, pillar design, seismicity, caving mining methods, as well as technical advances such as the development of the yielding rockbolt and conebolt for rock support.

Stacey (2022) also relates important considerations in rock mechanics and geotechnical engineering such as rock engineering design; the characterisation and classification of the rock mass; rock mass parameters; modelling; and failure prediction.

4.11.2.3 Past presidents of the International Society for Rock Mechanics and Rock Engineering

The International Society for Rock Mechanics and Rock Engineering (ISRM) is a scientific association with objectives of “*encouraging international collaboration, advance the knowledge of rock mechanics, and promote high standards of professional practice*” (ISRM, 2008).

South Africa has been represented by Professor Nielen van der Merwe, who became President of the ISRM during 2003-2007, after having acted as Vice President for Africa from 1995 to 1999.

4.11.2.4 Rocha medal winners for the best PhD

In addition to the notable professional advances described in Stacey (2022), and the leadership experience of past ISRM presidents, outstanding academic performance has been demonstrated by postgraduate students from Africa. The outstanding academic performance has been recognised through the award of the Rocha Medal.
The Rocha Medal, bestowed by the ISRM, is a prestigious award intended to stimulate young researchers in the field of rock mechanics (ISRM, 2008) and has been awarded annually since 1982. To date, six postgraduate students from South Africa have been recipients of the medal.
Subsequently, from 2010 onward, a limited number (1 to 2) of certificates are awarded to runners-up (i.e. Proxime Accessit certificates). One postgraduate student from South Africa has received the runners-up certificate.
Table 4-6 identifies the award winners and offers insight into their research through their thesis titles.

Table 4-6: Summary of ISRM awards won by postgraduate students from South Africa

Year	Winner	Award	Thesis title
1990	R.K. Brummer	Rocha medal	Fracturing and Deformation at the Edges of Tabular Gold Mining Excavations and the Development of a Numerical Model describing such Phenomena
1999	A. Daehnke	Rocha medal	Stress Wave and Fracture Propagation in Rock
2001	D.F. Malan	Rocha medal	An Investigation into the Identification and Modelling of Time-Dependent Behaviour of Deep Level Excavations in Hard Rock
2003	L. M. Linzer (nee Andersen)	Rocha medal	A Relative Moment Tensor Inversion Technique applied to Seismicity Induced by Mining
2012	B. Watson	Proxime Accessit Certificate	Rock Behaviour of the Bushveld Merensky Reef and the Design of Crush Pillars
2018	M. Plessis	Rocha medal	The design and behaviour of crush pillars on the Merensky reef

4.11.2.5 Leopold Muller Award winners

The Leopold Muller Award is made once every four years by the ISRM "*in recognition of distinguished contributions to the profession of rock mechanics and rock engineering*" (ISRM, 2013) and Stacey (2019) mentions that two members from the South African CSIR/COMRO research environment been recipients of the honour.

Contributions and contributors from Africa have played an invaluable role in the progression of rock engineering practice.
The continued research and advancement inevitably moves to the future, younger practitioners, as they prepare and make their way into the field of engineering and science.
The review hereunder follows the theme of learning.

4.11.3 Looking forward: the next generations of rock mechanics and geotechnical engineers in mining

4.11.3.1 Literacy at the schooling level

The 2019 Trends in International Mathematics and Science Study showed that South African learners in grade 9, scored the second lowest in mathematics and were the worst performing group for science (out of 39 countries that participated in the study), that is, 59 % of the learners did not have basic maths knowledge, and 64 % lacked basic competency in science. It is believed that achievement gaps continue to be linked to socio-economic backgrounds (Research News, 2020).

In the next years, fewer number of learners elected to study mathematics during their secondary schooling phase, and those that chose to study maths appeared to encounter a decrease in the pass rate for the subject (Business Technology, 2022). The situation seems to be exacerbated by the fact that learners who struggle with the maths curriculum, change course to study ‘maths literacy’ (a less intense version of study).
Maths (not maths literacy) is required to be eligible for entrance into most Higher Education Institutions (viz. universities) in South Africa and abroad. Therefore, it may be considered that South Africa’s declining mathematics metrics at the schooling level could constitute cause for concern.

4.11.3.2 Tertiary education [university]

The entry into the rock engineering profession and related roles for Mining, in South Africa is currently through several avenues – one of which is to earn a relevant qualification in Mining, Mining Engineering, Mine Surveying

Currently, the three universities in South Africa that offer mining courses are:

1) University of The Witwatersrand (Faculty of Engineering and the Built Environment, School of Mining Engineering)
2) University Of Johannesburg (Faculty of Engineering and the Built Environment, Department of Mining and Mine Surveying)

3) University of Pretoria Department of Mining Engineering (Faculty of Engineering, Built Environment and Information Technology, school of Engineering: Mining Engineering)

Table 4-7 provides an overview of potential subjects that may be required toward a bachelor's degree in Mining Engineering, where it is evident that maths and science-related subjects are included. Given the concerns regarding maths and science understanding in the foundational phases of secondary school (described in sub-section 4.11.3.1), it would seem that the future of Rock Engineering may require directed resources and efforts to ensure the needs of the industry can be met.

The very nature of the mining industry – from remote locations, complex mining conditions, to boom-and-bust cycles - create for challenging circumstances, especially for qualified graduates who have yet to develop meaningful work experience. It has also been observed that many mining companies no longer provide positions for graduates (Mining Weekly, 2006).

It has been found that only a small percentage of graduates remain in the industry as mining company employees (Stacey *et al.,* 2019) and some discourse exists on the readiness of graduates when entering the job market (The Conversation, 2017).
The apparent disconnect may be attributed, in part, to the flexibility and adaptability (or more so, the lack thereof) of graduates entering the workforce as an outcome of traditional teaching and learning methods.

On the topic of readiness and adapting, Daly (2014) provides the findings of an interesting exercise at the Faculty of Engineering at the University of New South Wales (UNSW). The exercise made use of an evaluation of the effectiveness of teamwork in a selected engineering course. It was found that the main challenges included the process of working together as a team because many (perhaps most) students had entered university with little experience of working in a team. The transition to non-individual study types was therefore identified to be potentially quite confusing, challenging, and even confronting when students have to work together in a small team to produce an outcome. Daly (2014) concludes the findings by pointing out the value of the exercise by relating it to the fact that many of the courses in mining engineering rely heavily on group participation and assessment.

Table 4-7: Overview of potential subjects that may be required toward a bachelor's degree in mining engineering

Potential subjects that may be required toward a Bachelor's degree in Mining Engineering	
Introduction to the Engineering Profession	
Engineering Chemistry	Mine Surveying and Geospatial Techniques
Engineering Analysis and Design	Digital Technologies and Mine Data Analytics
Engineering Mathematics	Computer Applications in Mining
Engineering Physics	Computer Programming for Mining
Engineering Services for Mining	Computerised Mine Design
Engineering Surveying	Mine Design
Mathematics	Mine Ventilation and Climate Control
Applied Mathematics	Mine Transportation, Automation and Robotics
Applied Physics	
	Water, Energy and the Environment
Geology	Financial Valuation
Ore Dressing and Extractive Metallurgy	
Ore Body Modelling	Professional Development
Mineral Resources Evaluation	Health, Safety and Mining Law
	Mine Management Principles and Entrepreneurship
Introduction to Underground and Surface Mining Methods	
Underground Mining Systems	Project Report
Surface Mining Systems	Mine Technical Visits
Mechanical Excavation of Rock	Vacation Work (Mining)
Explosives Engineering	
Rock Engineering	Elementary IsiZulu Language and Culture
Rock Mechanics	Elementary Sesotho Language and Culture
	International Relations: An Introduction to the Discipline
Identity and Society	Introduction to Political Studies
Introduction to Ethics	Southern Africa in the Era of Globalisation
Introduction to Philosophy: Knowledge and Reality	
Global Encounters and Contemporary Realities	

4.11.3.3 Pedagogical methods of delivery for successful knowledge retention

The review of pedagogical styles is outside the scope of the current research, however, the role of pedagogical effectiveness – which often is dependent on versatile and responsive interactions guided by the learner – is known to be an essential factor in effective learning strategies, especially during the formative and earlier years of schooling.

The effect and attributes of successful pedagogical delivery are described in detail in Husbands and Pearce (2012), Nelson *et al.* (2015), Baker and Robinson, (2017), as well as Sharma and Ahuja (2021).

Webber-Youngman and Callaghan (2011) report a comparable stance in their review of education practices in mining engineering at the university level stating that in-depth critical and evaluations of the teaching and learning strategies have been carried to improve mining engineering education where matters such as "*integration, diversity, gender, literacy and language, as well as quality of education in the South African school system, made it obvious that a different approach to teaching and learning had to be adopted*".

4.11.3.4 Industry research from- and following- tertiary education

As far back as 1977, Salamon (1977) delivered the SAIMM Presidential Address discussing the role of research and development In the South African gold-mining industry.

Since then, Creamer (2011) has reported from interview, quoting Professor Emeritus Dick Stacey of the School of Mining Engineering at the University of the Witwatersrand, that the lack of focus on rock engineering research is particularly worrying - because despite rock mechanics being an absolutely essential aspect of mining, there is a major Western world shortage of rock engineers.

During 2015, the (then) Minister of Science and technology, Naledi Pandor, reported the shortcomings of research and development in South Africa due to expenditure not reaching target (Odendaal, 2015).

Similarly, in 2019, the topic of rock research was still topical, with Stacey (2019) stating that properly managed research could produce substantial, quantified benefits – using the example that as South Africa's mines are getting deeper, hotter, and more highly stressed it is essential that '*new techniques be developed to allow mining to continue safely and efficiently under these 'extreme' conditions. The undertaking requires long-term research, based on the development of a long-term strategy to define the challenges and problems – and subsequently develop and conduct the research required to generate appropriate solutions'*. Rymon-Lipinski *et al.* (2003) echoed the sentiment in their review of rock engineering and research crucial for sustainable development in the South African mining industry.

The transfer of knowledge resulting from research is a fundamental requirement of the uptake - Durrheim *et al.* (2002) provide a critical evaluation of the transfer of knowledge produced by the DEEPMINE Research Programme. It is understood that projects by the MHSC SIMRAC are transitioning to incorporate knowledge transfer or technology

transfer at the end of the project, e.g. ‘ technology transfer on minimizing seismic risk in the platinum mines’ (MHSC SIMRAC, 2002b) and ‘technology transfer for a risk based approach to enhancing support design’ (MHSC SIMRAC, 2002a) and a very pertinent project on monitoring behaviour changes from interventions related to the people-centred adoptions of leading practices (MHSC SIMRAC, 2015).

4.11.3.5 Technical Skills Shortage

The matter of technical skills, and upcoming skills shortages, are considered a major strategic issue. As far back as 2008, the skills deficit was regarded as a ‘national crisis’ and even though skilled graduates were entering the workforce, the numbers of entrants could not keep up with the growth required (Mining Weekly, 2008 and 2008a in Stacey *et al.,* 2009).

4.11.3.6 Continuing Professional Development (CPD)

For registered practitioners in engineering and science (as introduced in chapter 3.2.7), ongoing learning must take place in a structured way, to ensure that professional knowledge and skills continue to developed as to meet the needs of society, through the process of Continuing Professional Development (CPD).
Particular types of development, and specific training courses and conferences, as an example, are used to accumulate ‘CPD points’ and thresholds for the minimum number of points are established based on category of registration.

Over and above mandatory CPD, voluntary and recognised professional organisations also hold frequent talks, presentations, training etc.
Voluntary and recognised professional organisations include the Association of Mine Resident Engineers of South Africa (AMRE); Association of Mine Safety Professionals of South Africa (AMSPSA); Geo-Information Society of South Africa (GISSA); Geological Society of South Africa (GSSA); Institute of Mine Surveyors of Southern Africa (IMSSA); Institution of Certificated Mechanical and Electrical Engineering, South Africa (ICMEESA); South African Geophysical Association (SAGA); Southern African Institute of Mining and Metallurgy (SAIMM).

4.11.3.7 Personal ‘confidence’ and ‘competence’ are not the same

As it relates to chapter 4, sub-section 4.4 in terms of cognitive and analytical bias etc. and emanates from qualifications and learning - an important acknowledgement regarding technical skills is that personal ‘confidence’ and ‘competence’ are *not* synonymous.

The motivation to include the topic originates from extensive observations in professional experience where interpretations, instructions or statements have made

by persons not informed on the mining operation being evaluated, the context, the engineering problem being investigated with such authority, that those statements are sometimes regarded as fact (specific examples include ‘confident’ statements made in support of aggressive slope design angles) – despite not being supported by any site-specific data, modelling results or, site observations made by the speaker, and in contradiction to the stability performance of the slope historically.
The candidate's observations have recognised that in practice - information stated loudly and confidently, though uninformed, is typically given more due than deliberate results explained with caution.

Cheng *et al*., (2020) and (2021) give insight into the matter of perceived confidence in the workplace.

4.12 Concluding remarks for chapter 4

The literature review drew from a wide, international setting and was presented in thematic groupings.

The literature review provided insight and demonstrated a variety of knowledge points and perceptions. These include:

- A wide range of technology has been improved since its initial introduction, continues to be improved as well as refined for bespoke application. Combinations of tools and techniques can be used together, but care should be taken to identify and address limitations that may become pertinent.
- Improved understanding in rock mechanics and geotechnical design and engineering of mine workings – both on surface and underground – has been made for different conditions of the rock mass i.e. weak, weathered and jointed.
- In jointed rock masses, the characteristics and behaviour can be assessed using a synthetic rock mass for aspects such as optimisation of mining method (viz. block caving) as well as understanding the potential extent of deformation that may not be as readily determined by traditional modelling methods (e.g. extent, height and distortion of the caving line) for purposes related with overall ground management.
- The selection and suitably of an appropriate analytical method of assessment may be a complicated decision in itself. A variety of analytical methods are available, and can by hybridised or used to complement each other. Nevertheless, the methodological ideals do not guarantee the validity of the output, because ultimately, ‘technology is not a cure for human fallibility’.
- There is range of *subjective* elements that may potentially influence the work carried out for rock engineering, geomechanics and geotechnical engineering. Differing perceptions provide awareness of the practical uncertainty, variability, and sources of risk that may exist in the mining industry.

- A number of aspects contribute to existing- and growing- complexities when interpreting the needs, performance and optimisation related to technical[39] work and business priorities. The assessment of a potential instability of a mining excavations (based largely on generalised and subjective geotechnical elements) may need to extend far beyond the simplification of 'likelihood and consequence' of a vaguely described stability incident to offer improved value. The scenario is likely to incorporate additional concepts such as susceptibility, fragility reliability, and robustness of various technical elements and outcomes.
- The principle that is central to nearly all of the assessments, studies and designs carried out in rock engineering, geomechanics and geotechnical engineering stem from the determination of '*appropriate'* rock mass parameters. While the methods of determination of the parameters are known and understood, there may be practical influences which disrupt the process, e.g. the availability of samples and specimens, access to specific lithological units, representativity of the sample group used during assessment, the number of data points used in modelling, the accuracy and precision of measurements, and/or changes in the weathering state of the rock over time.
- The regulation of mining in South Africa is equally intricate in its requirements.
- Risk as a 'pure' science is a specialised discipline.
- Learning may be perceived as a life-long journey – from schooling, where mathematics and science are learnt, to the workplace, where training on the identification of rock-related hazards is carried out and put into practice. Given that South Africa has diverse population, the manner and effectiveness of job-related training adapted in the regional or local setting, may be relevant toward the maintenance of safe working environment within the mining open pit and underground workings.

[39] rock engineering, geomechanics and geotechnical engineering in mining operations

5 ANALYSIS

5.1 Overview of chapter 5

Chapter 5 synthesises the information and data collected, processes the observations made, and begins to distil the findings of the research. Figure 5-1 provides an overview of the data items, followed by the description of the items in sub-sections 5.2 to 5.8.

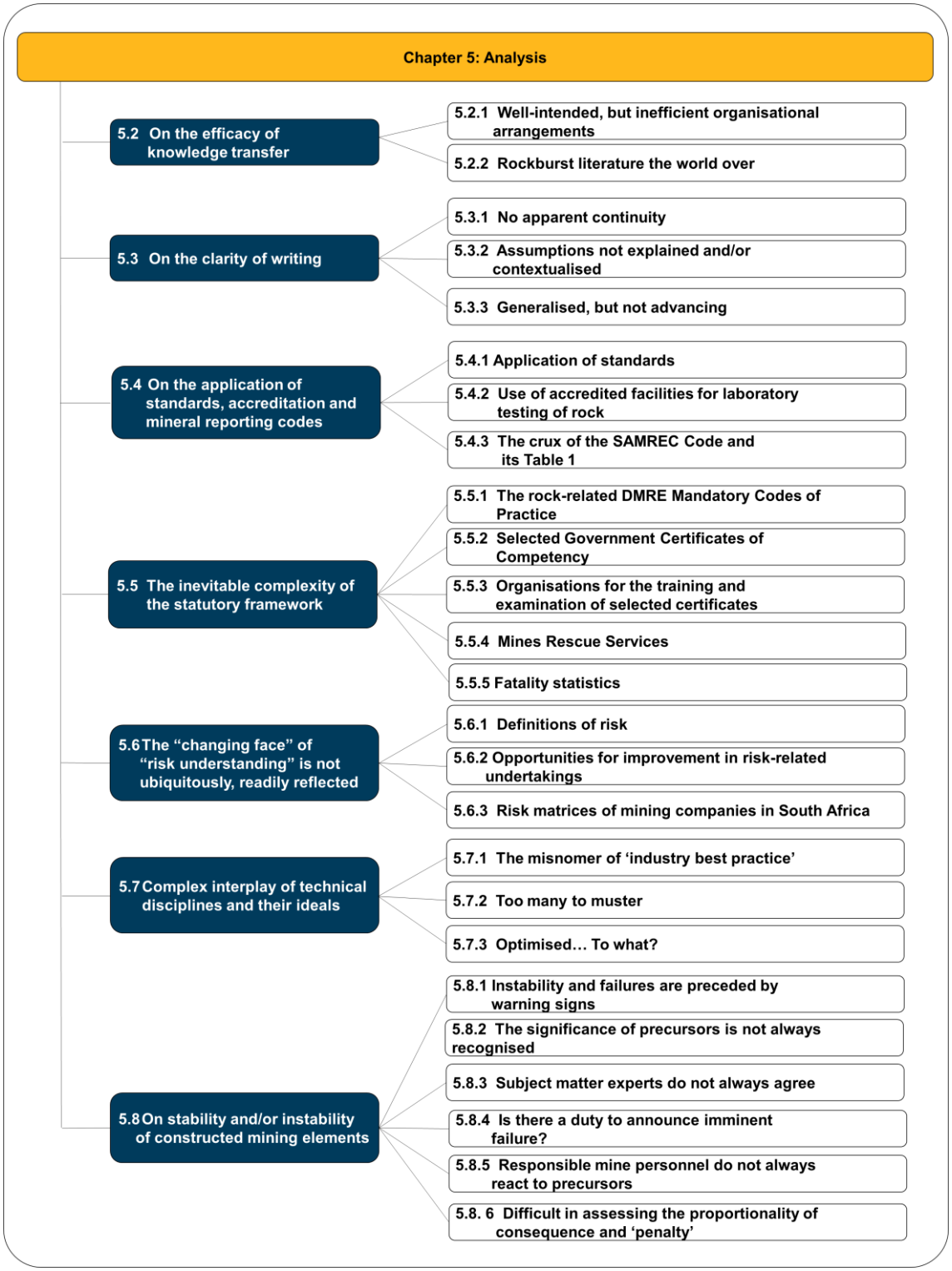


Figure 5-1: Overview of data items included in chapter 5

The information hereunder discerns the various limitations of current reporting practices and requirements.

5.2 On the efficacy of knowledge transfer in the South African mining industry

The candidate offers the insight that array of images shown in Figure 5-2 to Figure 5-14 below, took an entirely disproportionate amount of time and effort to compile.

Part of the reason is that the individual organisations report their role as part of the tripartite structure [in various forms, tones, and texts], but do not provide organisational structure – or even provide conflicting organograms. The process of reconciling the relationships, as well as the intention behind various terminology of 'thrusts, focuses, priority, risks, themes, pillars [principles], initiatives etc. did, however, generate deep insight into the interwoven network roles and organisations in the tripartite system, and perhaps aid to understanding the challenges of those organisations in ensuring effective transfer of knowledge from their various research as well as regulatory requirements.

The observation and description of several challenges are explained hereunder.

5.2.1 Well-intended, but inefficient organisational arrangements

The effort to ensure safety in mining, with particular reference to rockfall and rockburst, is an ongoing pursuit, with involvement from a number of organisations. The organisations, their structure, and institutional research 'streams' are shown in Figure 5-2 to Figure 5-14.

The purpose of including the structures of the numerous and varied organisations showing their research 'streams' is to emphasise the need for *improved integration* regarding the efficacy of knowledge transfer (rather than the creation of more research units) i.e. each of the images shows where there is a research output.

Much to the candidate's dismay, there are no indexed catalogues, or lists of the work completed from these research outputs.

Many of the reports are now out of print, many of the digital copies of the reports are lost at dead hyperlinks, several hyperlink targets do not match the source description, many documents are reflected as being in 'draft' status, and other practical impediments[40] are ubiquitous in the search for report rock aspects.

Despite this, '*more'* initiatives toward safety are being developed (viz the Mineral Council's Khumbul'ekhaya) and more research is being commissioned.

[40] MHSC, SIMRAC (1999) presents the findings of GAP 503 and GAP 535 in a single document – which can only be realised by downloading and opening the document. Moreover, the project descriptions inside the document do not delineate the separate components of GAP 503 and GAP 535.

Mining Safety (2011) – using the banner headline "*Mine groups to cut deaths via research*" - report that the Chamber of Mines of South Africa aims to improve safety among its members by creating a model for identifying problems and boosting research, with total of "*40 000 health and safety representatives together with shop stewards will be trained by 2013, and best practices will be shared among members through the Learning Hub, a vehicle created in 2009*".

The candidate contends that it may be inefficient to initiate '*more of the same'*, when the extent of completed work is unknown, and also when the ***context*** of the research is not developed (i.e. it is known and accepted that improvements in the safety of mines must be made – but it is not clear what the main causes or actual causes are that create unsafe conditions). The justification for doing research to improve safety is not contested, however, the formulation of the research questions, problems and specific objectives appears to be lacking.
To continue the example, the occurrence of fall of grounds is put forward for further discussion. Currently, SAMRASS only collects fall of ground causes as 'rock burst, strainburst, or gravity (SAMRASS Item 12, number 1), and the topic is discussed further in sub-section 5.2.2 below.

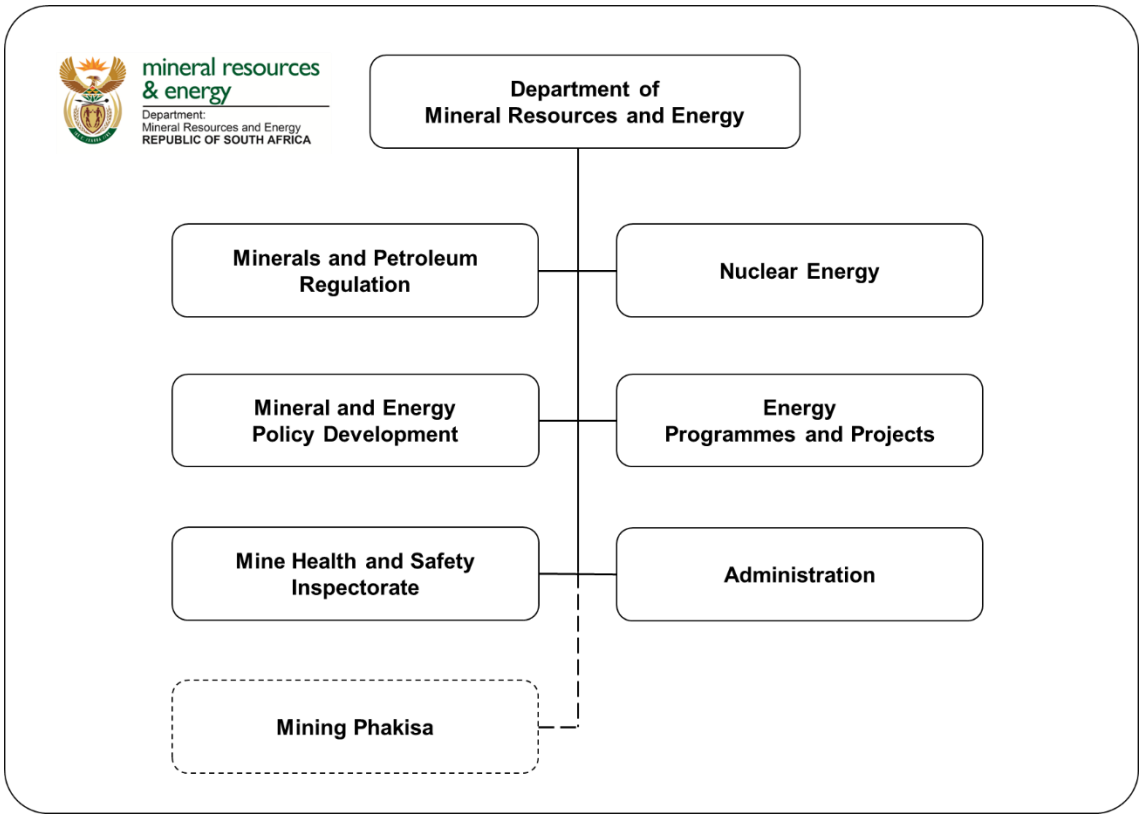


Figure 5-2: Programmes of the Department of Minerals and Energy

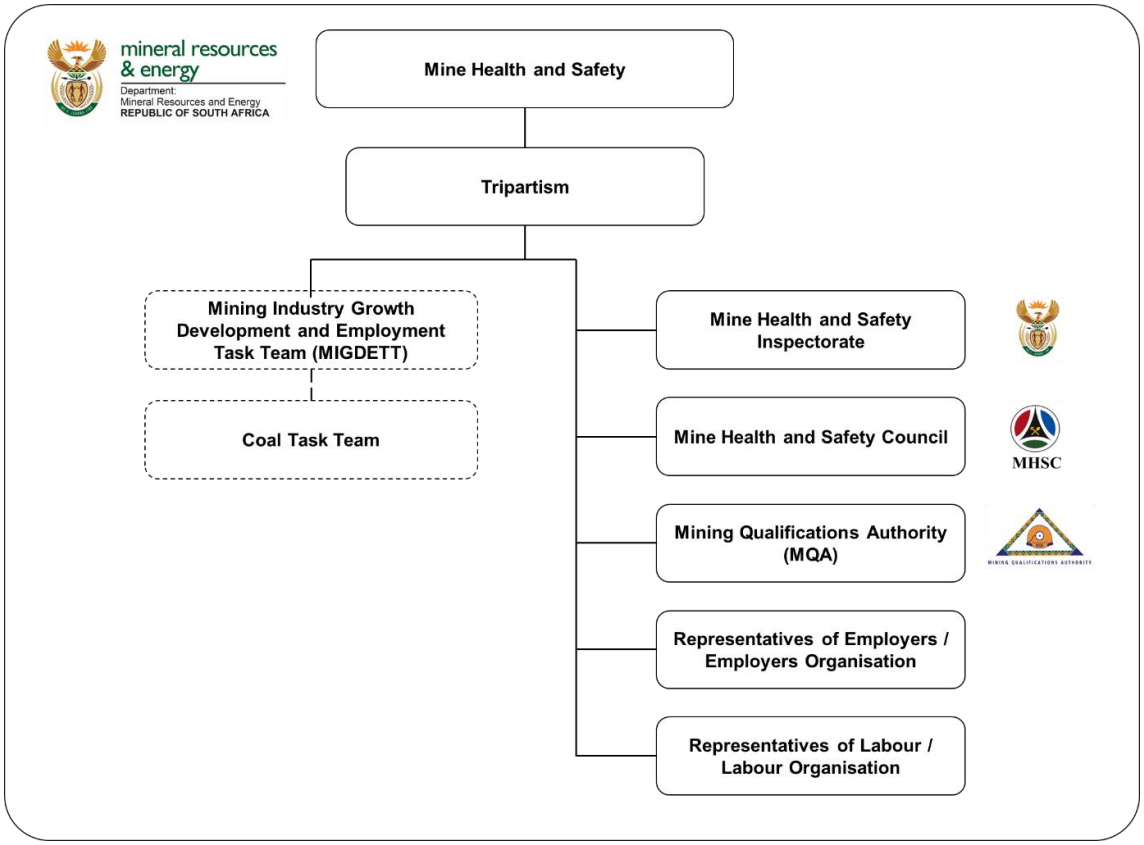


Figure 5-3: Tripartism as a fundamental component of the South African Mining Industry

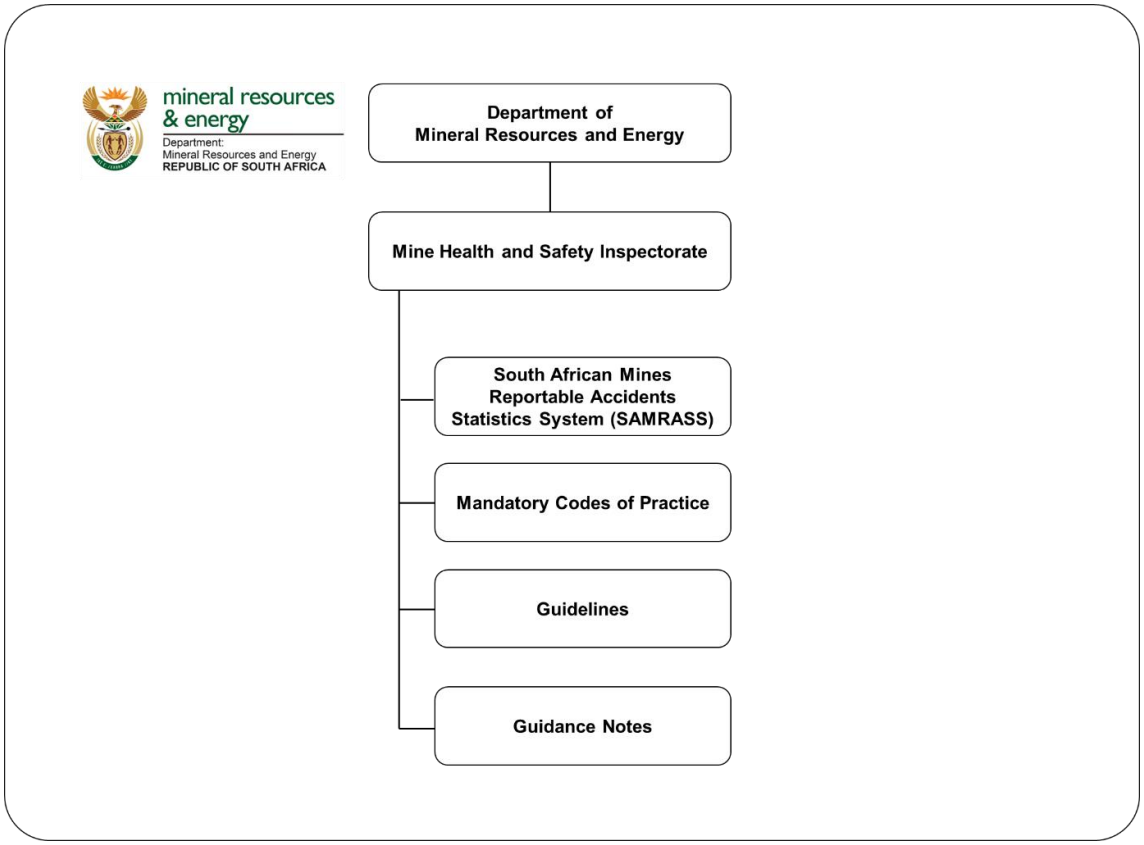


Figure 5-4: The functions of the Mine Health and Safety Inspectorate

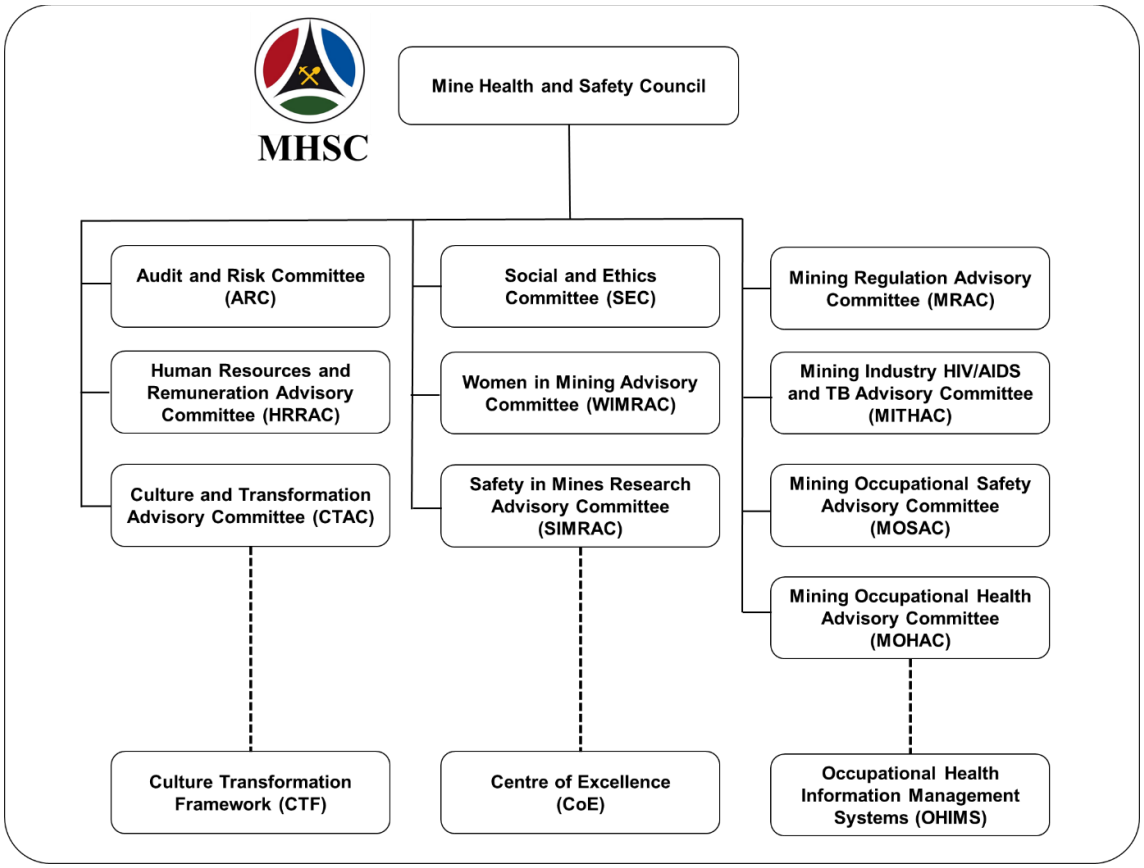


Figure 5-5: Committees of the Mine Health and Safety Council (MHSC)

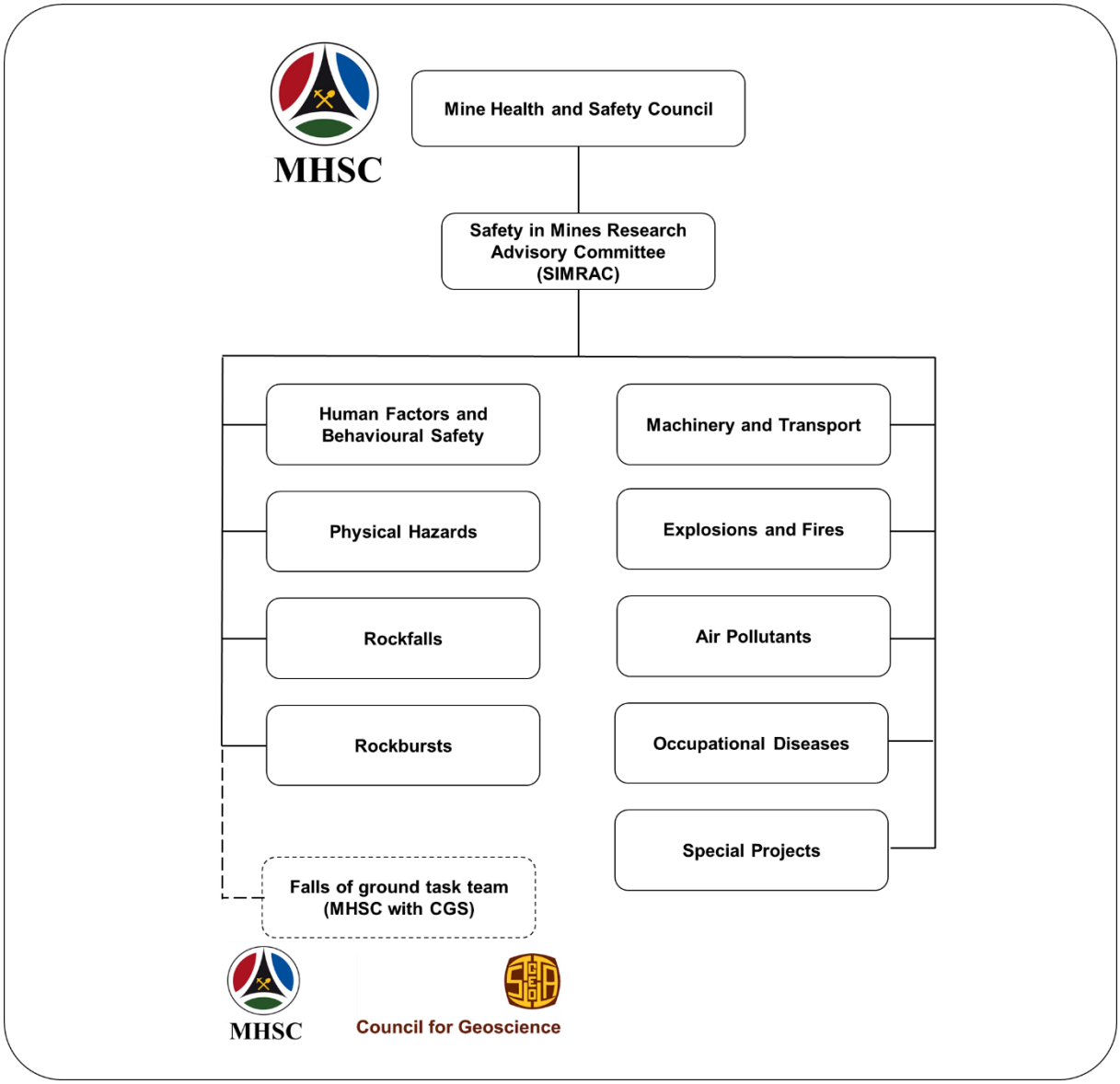


Figure 5-6: Thrust areas of the Mine Health and Safety Council (MHSC)

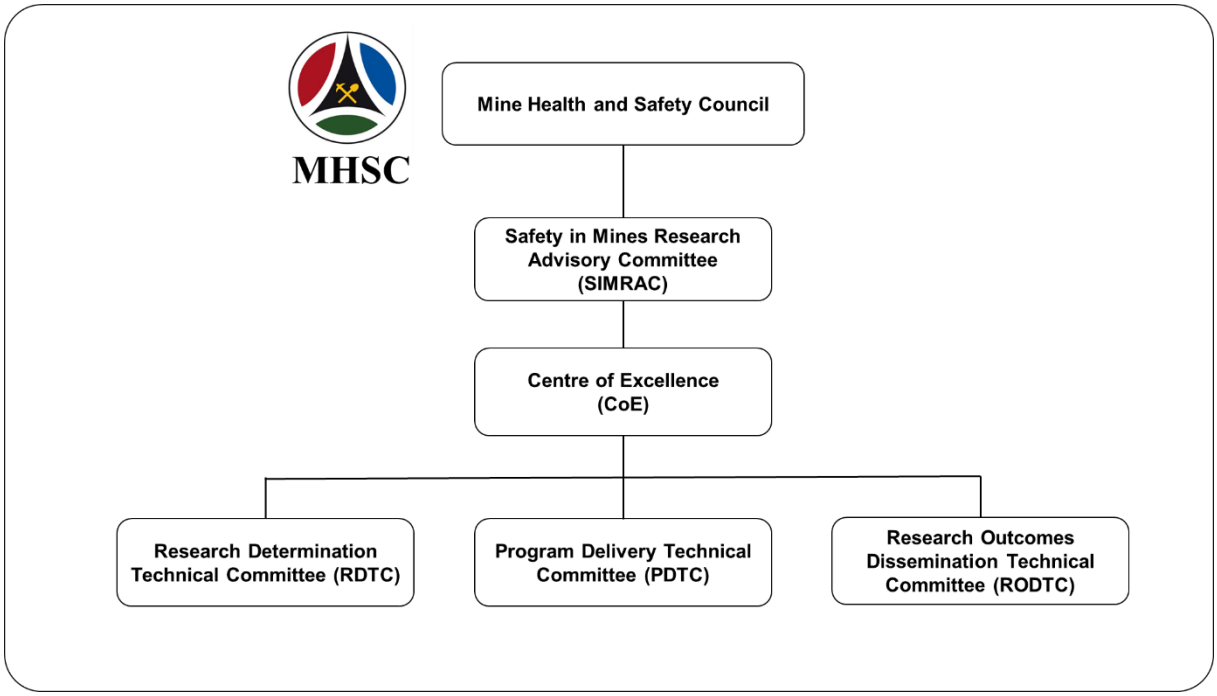


Figure 5-7: Committees of the Centre of Excellence, overseen by the Mine Health and Safety Council (MHSC)

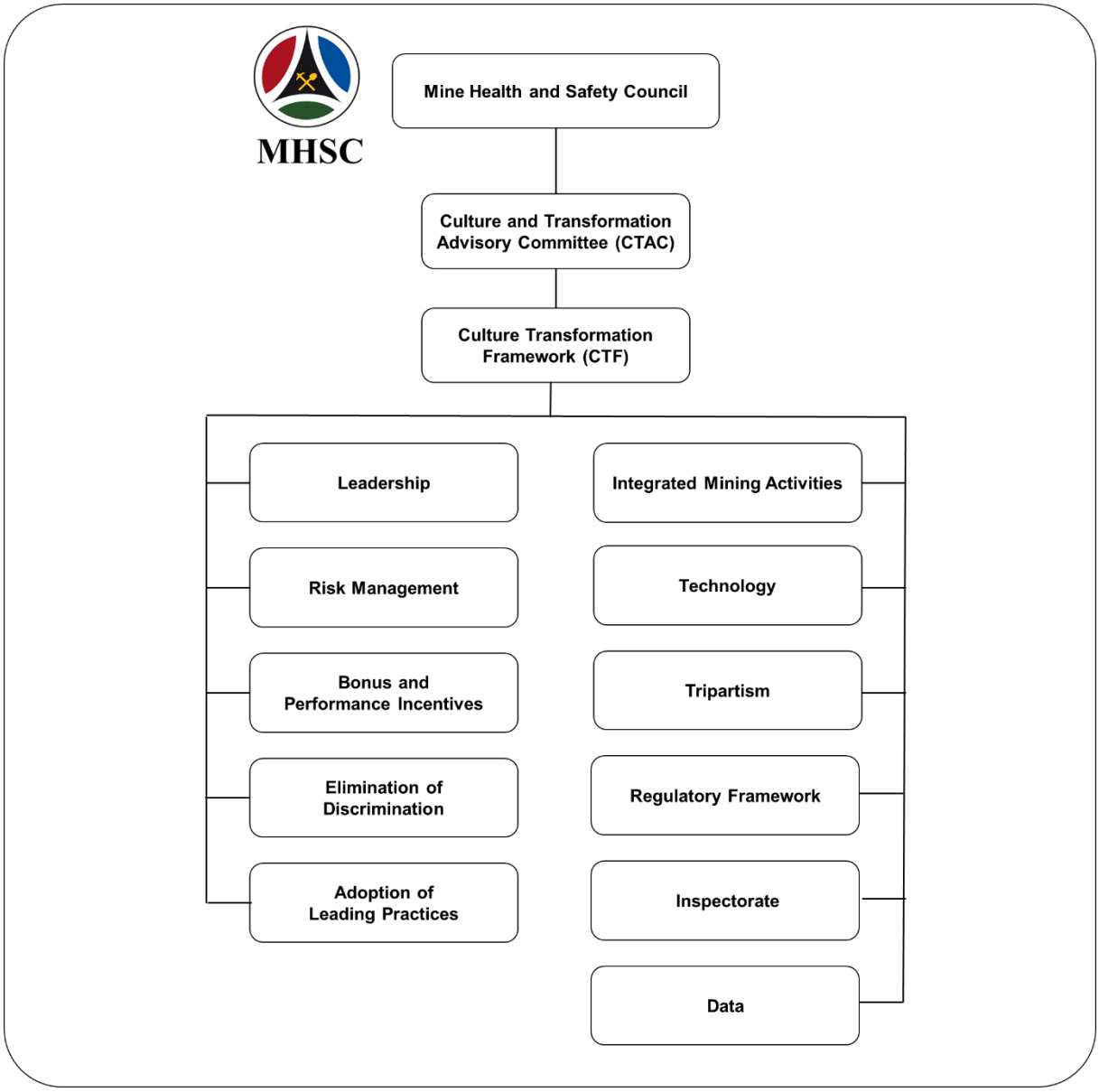


Figure 5-8: Eleven priority pillars of the Mine Health and Safety Council (MHSC)

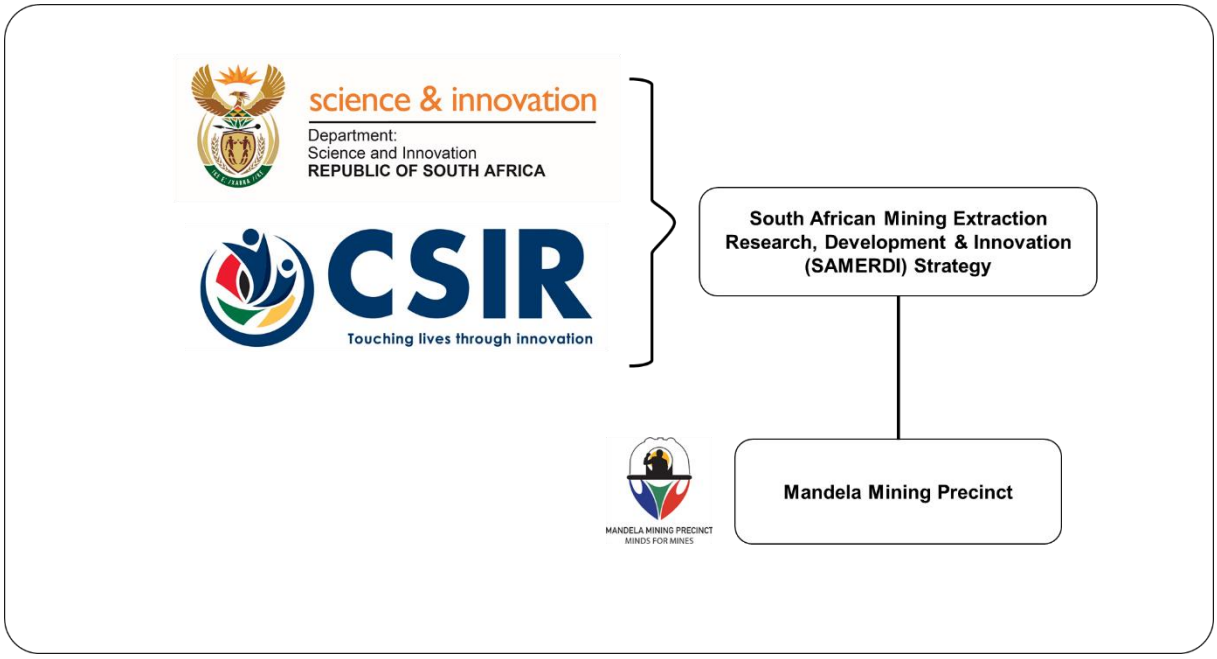


Figure 5-9: Collaboration toward the establishment of the Mandela Mining Precinct

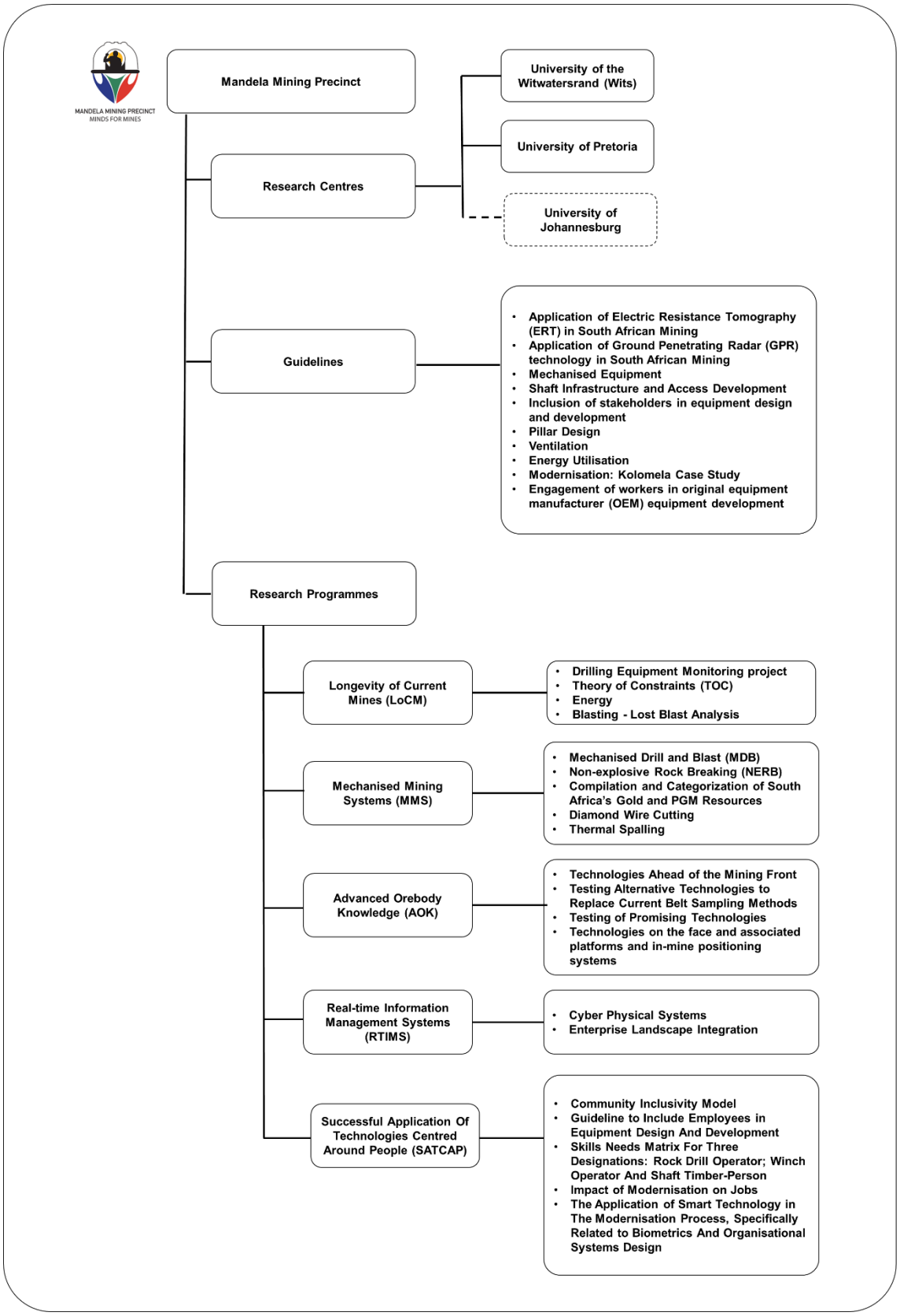


Figure 5-10: Research programmes of the Mandela Mining Precinct

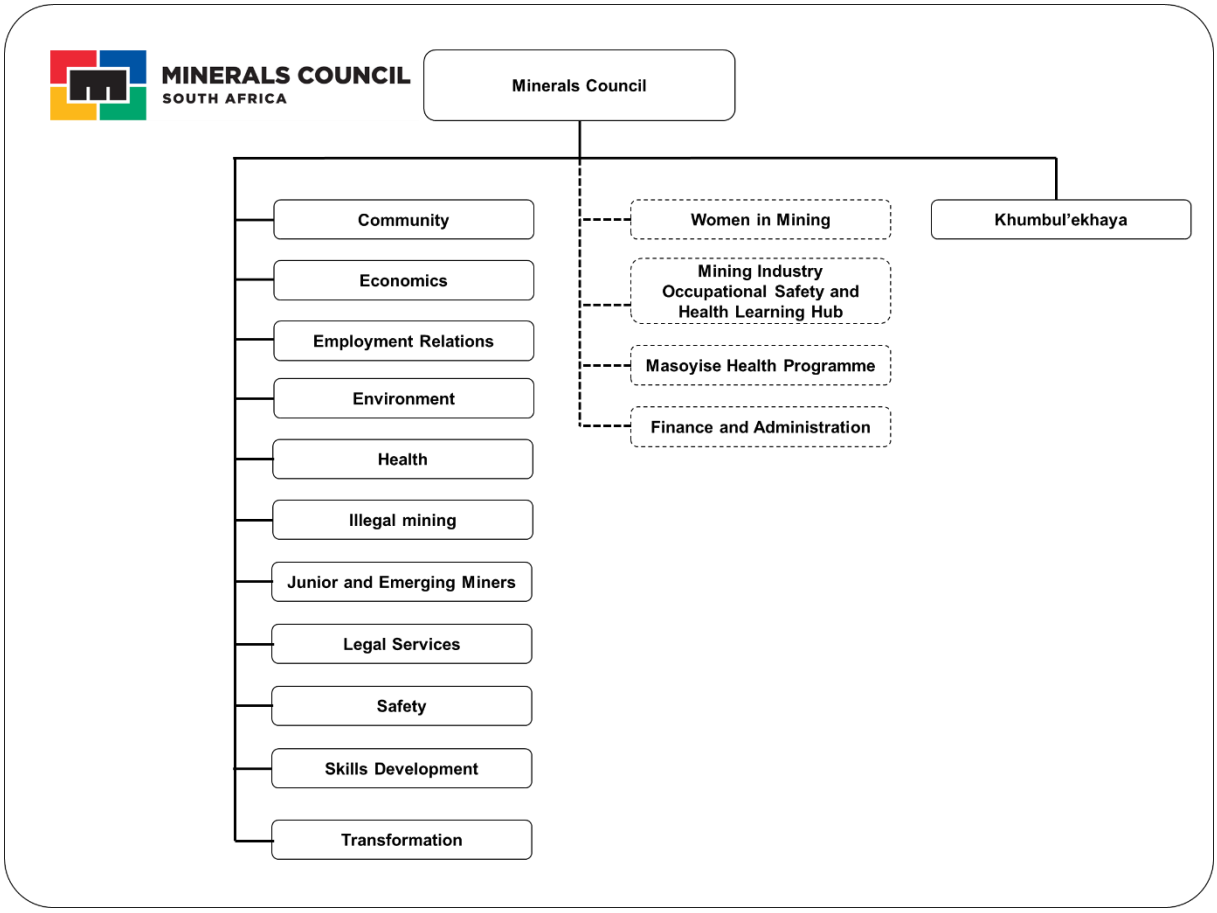


Figure 5-11:Initiatives of the Minerals Council

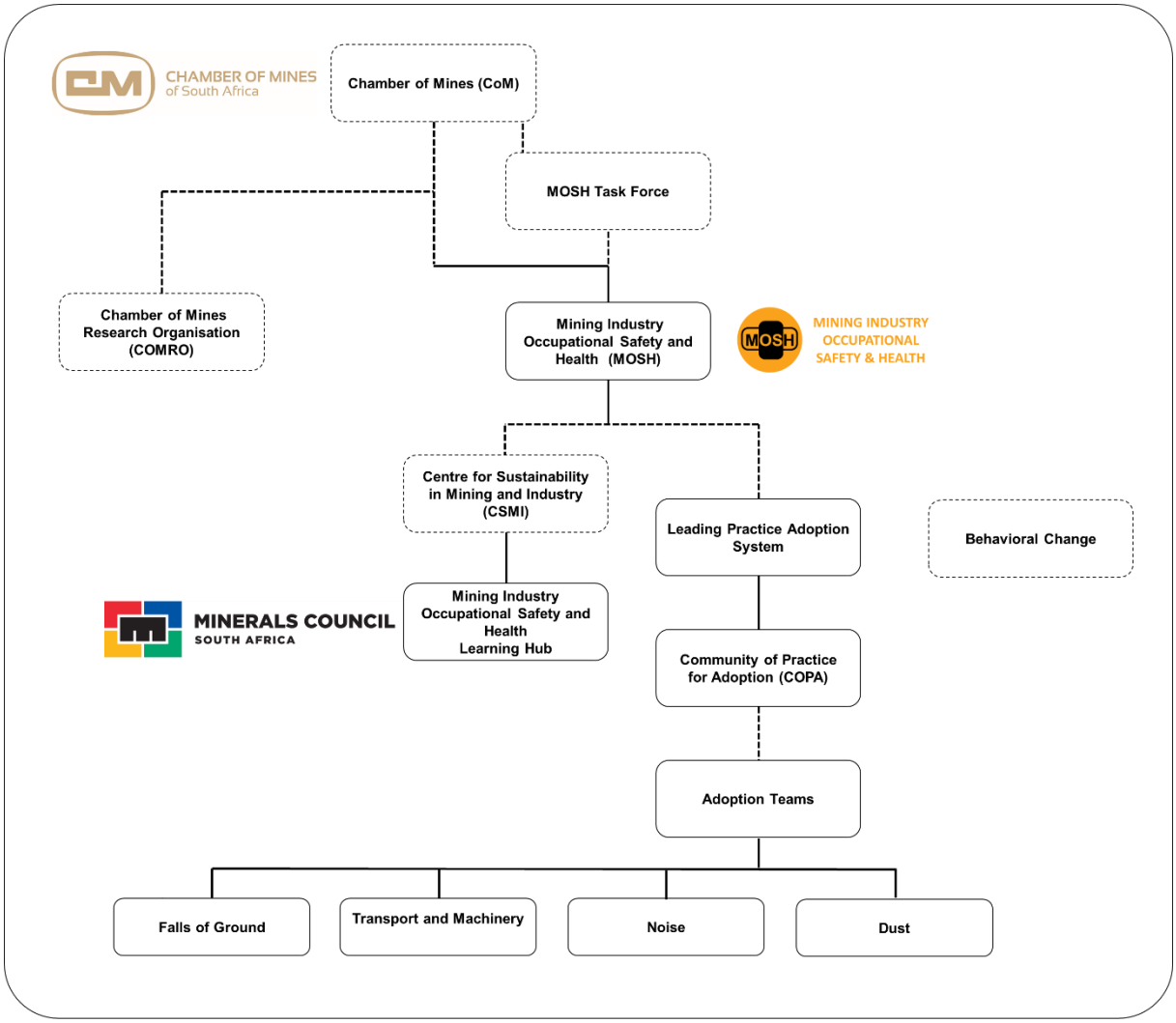


Figure 5-12:The initiatives of the [former] Chamber of Mines of South Africa

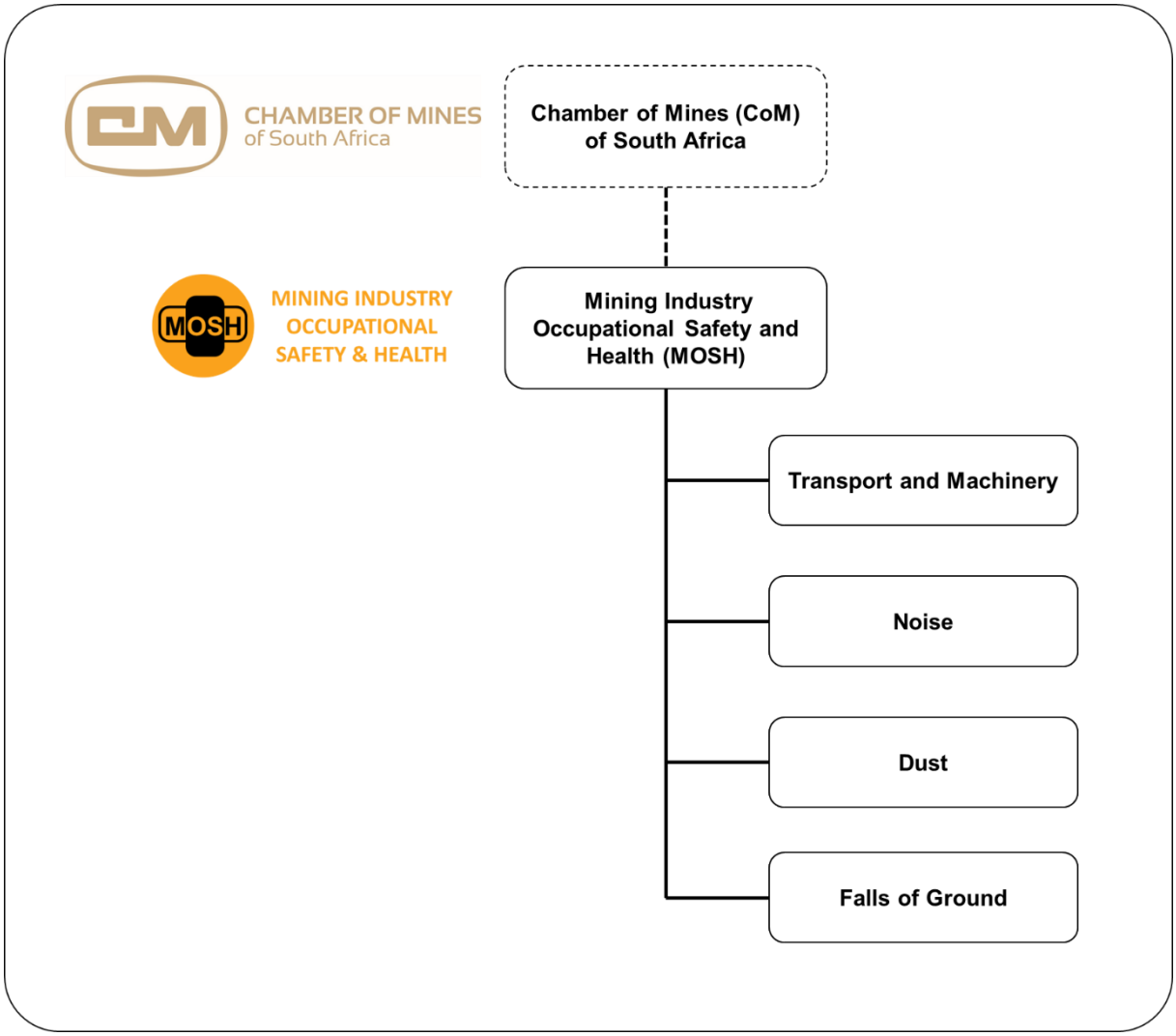


Figure 5-13:The four 'risk' areas considered by [former] Chamber of Mines of South Africa

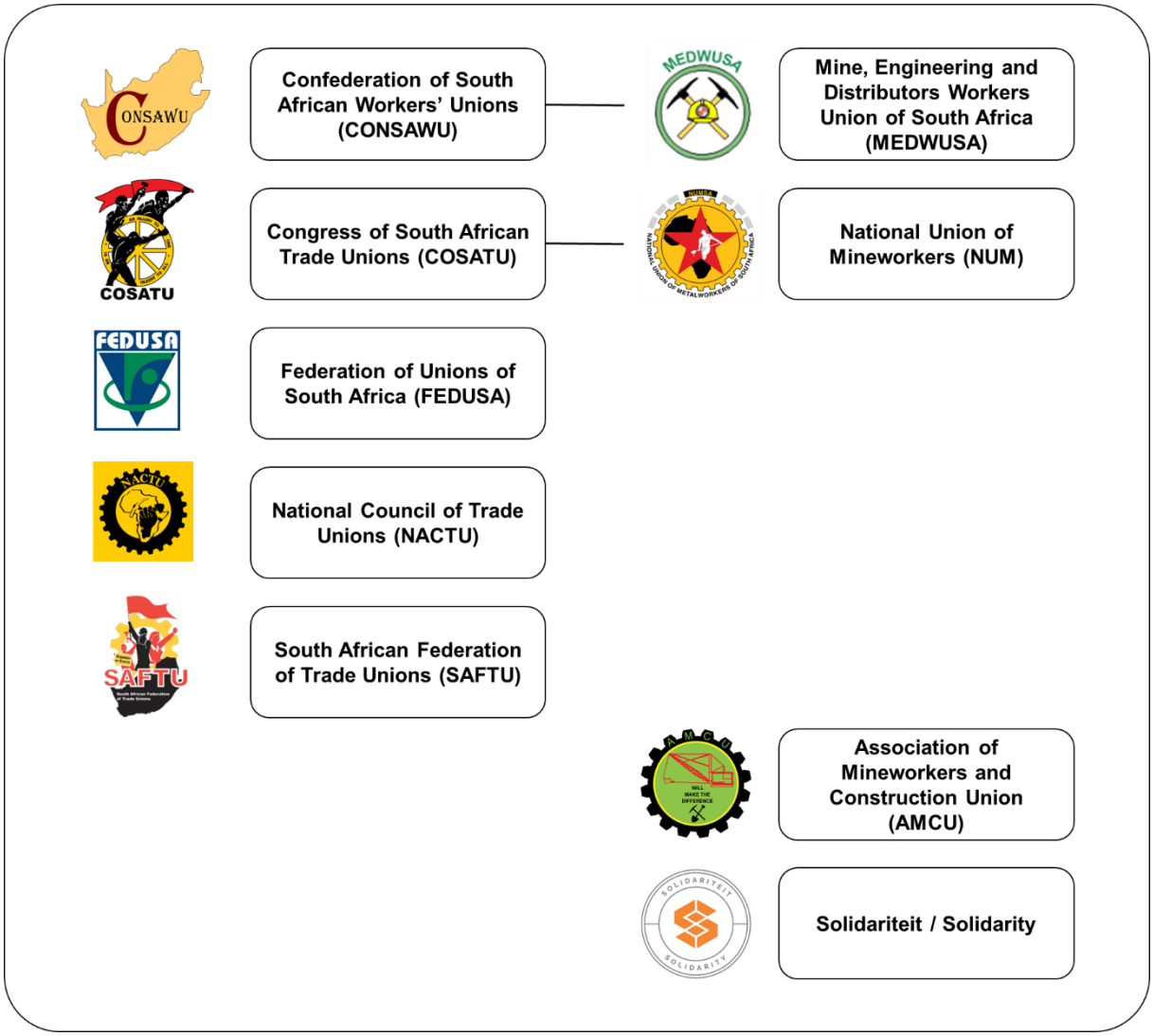


Figure 5-14: Example of the prominent labour organisations in South Africa and in the Mining Industry

5.2.2 Rockburst literature the world over

Fall of Ground incidents are one of the most prevalent causes of fatalities in South African Mining (Minerals Council, 2021 and 2022; DMRE, 2022).

The DMRE (through the intended MCOP to combat rock-related accidents (Figure 5-4), the Mine Health and Safety Council (Figure 5-6), the Mandela Mining Precinct (Figure 5-10), the Minerals Council (Figure 5-11), the Chamber of Mines Research Organisation (Figure 5-13) have all – to some extent – focussed their resource or research on the topic.

In addition to that, international published literature also expands on the research, academic and case study applications, for example [41]:

- The Chamber of Mines Research Organisation (1989) compiled guidelines from experience, relating to pre-conditioning,
- Batugina and Petukhov's (1991) annotated bibliography of rockbursts describes over 1700 entries,
- Twenty-one of the world's leading rock engineers published papers on applied rockburst research (Sociedad Chilena de Geotecnia, 1995),
- Ortlepp (1997) published an illustrative study on rock fracture and rockbursts – giving illustration to the concepts so oft only described in text,
- Gibowicz and Lasocki (1997) reported on rockbursts and seismicity in mines,
- Nussbaumer (2000) provides a comprehensive review on rockburst literature, understanding and advancements, and
- Ten years later, Durrheim (2010) – an esteemed and accomplished researcher, as well as the South Africa Research Chair in Exploration, Earthquake and Mining Seismology at the University of the Witwatersrand – published an astute review of 'a century of mining research' in pursuit of the objectives of mitigating rockbursts in the deep hard rock mines of South Africa.
- It is not only research of the theory, but practical application also e.g. Vallejos and McKinnon's (2011) investigation into the correlations of mining and seismicity for re-entry protocol development.
- The MHSC (2016) through the work of Mulenga, Zermatten and others, developed a guide booklet to assist rock engineering and mining practitioners in the selection of permanent areal support in varying underground mining environments.

To some extent, research objectives have been considered as part of an assessment as to whether or not research and development have contributed to improvements in safety and profitability of deep mines in South Africa (Durrheim, 2014).

[41] It is noted that the list of rockburst literature is not wholly comprehensive and does not strictly include the most recent publications. Similarly, the information is laid out quite concisely as to demonstrate the principles relevant to the argument put forward – as a result, an in-depth discussion of each is not required (or provided) to complete the demonstration.

Therefore, it appears as though the geomechanical mechanisms of rockburst can be learned from literature, but it is unclear what the root cause is to the recurrence of fall of ground incidents – i.e. how can we have carried out so much research, but still be no closer to understanding, identifying or responding to fall of ground hazards? The question is not posed from a stance of hubris, but rather, a stance of concerned confusion.

There appears to be a distinct shortcoming with respect to the transfer of knowledge and technology developed from research for application in the field.

5.3 On the clarity of writing

5.3.1 No apparent continuity

5.3.1.1 In reporting

Using the MHSC and SIMRAC as an example, it is possible to identify discontinuous reporting. The MHSC reports to the Parliamentary Monitoring Group (PMG) on matters such as spending and progress of projects (typically these are in the form of presentations and *summarised* documents e.g. MHSC, 2014).

In parallel, the MHSC also prepares annual reports (e.g. MHSC, 2007 and 2022).

It is observed that when tenders are advertised in the South African Tender Bulletin (e.g. South Africa, 2020 for the *Appointment of a service provider to undertake research project CoE 200106 "Impact of Implementing the Guide for the Mandatory Code of Practice on the Right to Refuse Dangerous Work (RRDW) and Leave a Dangerous Working Place (RLDWP) on Occupational Health and Safety in the South African Mines"*), there is no apparent trail or continuity in reporting to link the advertisement, the appointment, the progress or the output of the project. Each item is standalone and the matter seems to be exacerbated by the various styles and tones of reporting e.g. MHSC report to PMG on the effort toward safety in mining, the cost of research, whereas in the annual report, the importance of safety in mining is emphasised and fatality statistics and graphs are repeated, with a more 'promotional style' of language describing that research is ongoing. One simple marker viz. the project number, does not appear through the chain of reporting therefore, potential readers cannot, without substantial effort and time, trace where a project started and find the corresponding output.

In the example used above, it is unclear what the research objectives were because the 'Guideline for a Mandatory Code of Practice on the Right to Refuse Dangerous Work and Leave Dangerous Working Places' was gazetted in the Government Gazette, vol. 608, no. 39656, under Government Notice no. R. 148 during 2016. No further information could be found on the potential shortcomings of the 2016 Guideline that would have prompted for the 2020 research.

5.3.1.2 In research

Research reports typically end with conclusions and recommendations for future research – however, the future elements are seldom picked up, moreso in the case of smaller organisations and individual groups (whereas large multi-national groups appear to have a level of continuity to their research themes).

It may not necessarily be the case that the “recommended” research was abandoned, but instead may have revised the research goals, however, there is seldom, if ever, a narrative providing understanding how the work initially conceptualised has transformed to the current state of research being reported.

5.3.1.3 In practice

The apparent discontinuity in reporting, as a reflection of the clarity of writing, also appears in private organisations.

Anonymous (2005b p20) identify ongoing work in an established operation, including:

- The need for an improved modelling methodology to represent the seismic risks associated with remnant [pillars]
- The need for an improved methodology of quantifying risk (e.g. by rockburst area, injuries, fatalities), and
- Attempts to calibrate seismicity with other operations in the area.

Subsequently, there are no further revelations made known until 2019, when publication evaluated seismic activity in relation to the level of production from different sections of the mine and identified attempts to improve seismic monitoring. However the work elements posed by Anonymous (2005b) appear to still be unresolved.

5.3.2 Assumptions not explained and/or contextualised

A common observation across many forms of writing is that assumptions in the text are not explained.

Using De Beers (2009) Cave mining handbook as an example, the pattern is visible where De Beers repeatedly emphasise "procedures" in a generic sense, with insufficient context in the surrounding to be able recognise which procedures are intended, who is responsible for said procedures or alternatively, what part of the procedure was ineffectively executed:

- *"It is important that procedures are laid down for contractors so that there is no confusion on the required standards, after all the contractors are on site to do specific work (p3)*
- *The KISS [42] principle applies simple and cost-effective procedures so that results are readily available (p11)*
- *The importance of draw procedures with 'Rocking the block' [43] was standard procedure in the past to promote fragmentation (p43)*
- *The major factor of optimum ore recovery can be prejudiced by … mistaken ideas about loading procedure (p45)*
- *Adherence to all the recommended procedures will ensure a low risk operation as potential problems would have been identified at an early stage and remedies instituted before there is a risk to safety, production, environment and costs (p136).*

The handbook does make a sound recommendation that the consideration of risk must be carried out proactively, not retrospectively, and mentions in passing that "*there is a classic example of a risk analysis being done on a major mine where the mining sequence had been designed for a central layout of ore passes and crushers. This has changed, but the sequence was not changed and this led to later problems, however the risk analysis did not pick this up*".

Additional aspects where assumptions are not explained are in the phrase "low risk operation", given that De Beers is considered by some to be one of the wealthiest diamond miners in the world (owing to their Jwaneng mine, Botswana).

[42] The acronym "KISS" is not expanded, and the principle is not explained anywhere in the document. It is commonly accepted to mean 'keep it simple, stupid".

[43] The description of the process of '*Rocking the Block'* could not be sourced in any other De Beers' literature, though it is explained by others in their context (e.g. Wightman, 1949). It is not clear if De Beers incorporated any refinements or revisions to their execution of the technique.

5.3.3 Generalised, but not advancing

Observations on generalised but not advancing descriptions was frequently identified in writings about case studies – the authors allude to, but do not articulate, “important elements”

By way of example, Valent and Willams (2003) set out to elucidate the specialised studies needed for the design and implementation of the in-the-wall ramp at Marvel Loch South Pit, Australia. Under the heading of ‘strategies to negate risks’ and on the topic of de-watering, the authors recall that “*historically, ground water within the …pits has been high yielding. Sump pumping at the base of open pits cannot deal with the inflows of water…In order to negate the risk of groundwater playing a negative role in the mining… de-watering must take planned head of mining. A hydrogeological model has been developed… and will be used to develop a sound de-watering strategy*”.

On the basis that a de-watering strategy is an expected element in mine planning, and given that the authors objectives were to give detailed information on the specialised studies, the generalised statement that a ‘de-watering strategy will be developed’ does not really advance the understanding or insight on site-specific conditions and appropriate engineering response.

Another observation on generalised but not advancing descriptions was identified in writings about ‘advanced’ statistical applications. In this regard, is appears a common approach to extend a fair amount of effort to explain terms and concepts in simple form first, then explain those concepts again at a later point, in complex form. However, the inclusion of interim statistical metrics appeared to be generally excluded e.g. there is no indication on sample size etc. but only inclusion of more fundamental elements such minimum, mean, and maximum values.

5.4 On application of standards, accreditation and mineral reporting codes

5.4.1 Application of standards

It was found that a large portion of technical reports, Feasibility Studies, Competent Persons Reports. make reference to standards and norms in their literature reviews and/or reference lists, but do not demonstrate that any part of the standard or norm has actually applied during the technical study undertaken.
This is also true of field investigations that use a blanket phrase of “standards were followed” – and the company does not have a standard on the issue at hand, as well as “carried out according to best practice” – when no such codification exists, and no further contextualisation is given to orientate the potential suitability of the practice.

5.4.2 Use of accredited facilities for laboratory testing of rock

An important distinction regarding laboratories identified during the research is that SANAS issue accreditation to laboratories *for specific types of tests only*, not as a ‘broad facility’ – i.e. when a laboratory’s application to SANAS is successful, it is awarded a certificate of accreditation that lists the international standard (e.g. ISO/IEC 17025:2005) and the individual test standards, that the facility is accredited for. An example is shown in chapter 9, Figure 9-1.

Despite extensive efforts, the number of laboratories accredited by SANAS in South Africa for testing of *rock-related parameters*, could not be identified. There are approximately one hundred and forty-three accredited testing facilities. Of these, approximately seventy are accredited for Civil Engineering testing. Subsequently, examination of the certificates of accreditation for the Civil Engineering testing facilities show that the certifications are in various combinations of soil, sand, gravel, and/or aggregates, but *not rock*.
It is understood that individual mining companies (e.g. Anglo American) have their own in-house laboratories, but the research was unable to confirm the extent, location or types of rock tests carried out. The research was also unable to confirm if the tests are carried out to any specific testing standard.

Care is practiced when evaluation facilities, as the fluidity of marketing language may sometimes misdirect the understanding of the services, for example, it was observed that some facilities offer services as:

a) *“Test standards on offer in our laboratory include: ASTM, ISRM”*
b) *“Tests within our capabilities include: Point load test on rock, Rock joint shear strength, and UCS and UCM (with strain measurement and Poisson’s ratio) on soil and Rock”*

Yet evaluation of their certificate shows that their facility is only accredited for selected soil tests, and not for rock tests.
In other words, any testing of a rock sample won't comply with the standards set out.
This is not, strictly speaking, an incorrect occurrence. While the testing standards do offer peace of mind, the mining operation may potentially be satisfied with tests completed without certification. Potential reasons for such acceptance include that

- The mining operation are satisfied that the testing procedure is adequately followed by the laboratory personnel,
- The certification may be viewed as an idealised administrative element that does not improve the actual testing process, and/or
- Few (if any) organisations associated with the mining operation (e.g. shareholders, suppliers, consultants, independent reviewers, etc.) mandate that rock tests must be carried out at a certified facility. Therefore, the pragmatic needs of the mine are met (i.e. the testing of rock samples is carried out) and no damage to relationships is experienced.

5.4.3 The crux of the SAMREC Code and its Table 1

A misconception held by some practitioners in the field of mining engineering include that *all mines* are *required* to report under the SAMREC Code. Their understanding is incorrect. The SAMREC Code is a *mineral* reporting code – not a mining code. It was drawn up in response to the industry scandal involving the Bre-X project, where the attributes of mineralisation were grossly overexaggerated by the project geologist – leading to significant reputational harm and financial loss for many involved.
Hence, the focus of the SAMREC Code is that of *Mineral Resources and Mineral Reserves* – specifically for companies intending to list on the JSE. As such, the relevant documentation regarding Mineral Resources and Mineral Reserves are reviewed by the JSE Reader's panel.
It is becoming increasingly common that potential financiers and sponsors of projects [not necessarily shareholders] for companies that are not listed on the JSE will specify that the Mineral Resource and Mineral Reserve be 'SAMREC-compliant'. In other words, the geologists follow the methodology but the JSE Reader's panel does not review these reports.

Mineral Resources and Mineral Reserves will be diligently assessed based on *existing* data. The additional factors toward eventual economic extraction (e.g. mining and geotechnical design) are included in the reporting – but very often do not have the

same extent of data available to them. Their reporting therefore, inadvertently becomes a subjective evaluation of what could be anticipated.

Following from the statement put forward in Chapter 1, sub-section 1.4.1, viz. that geotechnical stability is absolutely essential for the mining operation to continue and that every aspect of the mining operation is at the root, dependant on the rock mechanical and geotechnical integrity of the excavations, the requirements of SAMREC Table 1 was considered.. Pertinent aspects of Mineral reporting from Table 1 are presented below.

SAMREC Table 1 Section 1

The very location must be ***validated*** as per s1(1.1) (iii), s1(1.2) (iii)
The history of the adjacent areas must be stated as per s1(1.4) (i) and (ii) and moreover, the statistical ***performance*** of Mineral Resources must be discussed as per s1 (1.4) (iv).

Potential future impediments must be revealed as per s1(1.5)(iii)
And in the event of legal proceedings – ***the potential influence*** on prospecting or mining ***or a negative statement thereto*** (s1(1.5)(iv))
Actions taken, or expected to materialise (s1(1.5)(v))
Liabilities, assumptions, and limitations must be described as per s1 (1.7) (i)

SAMREC Table 1 Section 2

The data density, distribution and reliability, must be discussed; the CP must confirm whether or not quality and quantity of information supports the statements made (s2 (2.1) (iv)).
Description of the frequency, size, and other characteristics of minerals are required (s2 (2.1) (v))
Description of mineralised zones, including geological controls, length, width, depth and continuity of mineralisation - as well as a description of the type, characteristics and distribution of mineralisation must be provided as per s2 (2.1) (vi), and the CP must confirm that reliable geological models and/or maps and cross-sections that support the interpretations exist, as per s2 (2.1) (vii).

SAMREC Table 1 Section 4

In processing mineralisation data toward the classification of Mineral Resources and Mineral Reserves, the CP must describe ***the model, construction techniques and assumptions,*** as well as ***sufficiency of data*** to assure continuity (s4 (4.1) (i) and (ii).
Discussion of all known geological ***data that could materially influence the estimation of the*** Mineral Resource must be provided as per s4 (4.1) (v).

The appropriateness of the techniques used as well as ***interpolation*** must be discussed for Mineral Resources and Mineral Reserves (s4 (4.2) (ii)).

Comparison of the detail in Mineral reporting to that of other technical disciplines

The expectation to provide assurance is evident in various forms and in detail for Mineral Resource and Mineral Reserve classification, as well as the related disciplines of geology and metallurgical testing, e.g.

a) History and/or performance;
b) Statement of fact or inference (i.e. measured or interpolated parameters);
c) Description and discussion;
d) Statement of reliability of data;
e) Model construction techniques; and
f) Mention of assumptions, limitations, estimations

In contrast, SAMREC Table 1 does not require the same extent of assurance in the various forms and in detail for rock geomechanics and geotechnical engineering.

Given the importance of the mine workings, it stands to reason that the level of assurance should be subjected to similar rigour.

5.5 The inevitable complexity of the statutory framework

5.5.1 The rock-related DMRE Mandatory Codes of Practice

There are a series of five Mandatory Codes of Practice with respect to combatting rock-related accidents, distributed by the DMRE, and to the best of the candidate's knowledge and experience – currently adopted by mining companies in South Africa. These are:

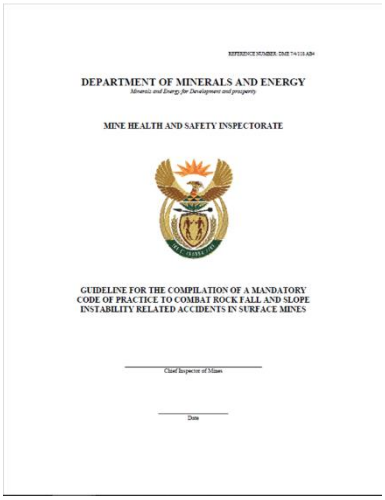
1) Guideline for the Compilation of a Mandatory Code of Practice to Combat rock fall and slope instability accidents in surface mines (Reference: DME 7/4/118 AB4)

2) Guideline for the Compilation of a Mandatory Code of Practice to Combat rock fall and rock burst accidents in tabular metalliferous mines (Reference: DME 16/3/2/1 – A3)
3) Guideline for the Compilation of a Mandatory Code of Practice to Combat roof fall accidents in underground coal mines (Reference: DME 16/3/2/1-A4)
4) Guideline for the Compilation of a Mandatory Code of Practice to Combat rockmass failure accidents in massive mining operations (Reference: DME 16/3/2/1 - A5)
5) Guideline for the Compilation of a Mandatory Code of Practice to Combat Rockfall and Rockburst in Metalliferous Mines and Mines other than coal (Reference: No reference shown).

   Table 5-2 provides an overview of the document outfacing pages. Additionally, there are eighteen other Guidelines for the Compilation of a Mandatory Code of Practice, as shown in Table 5-2.

   The relevance of the Mandatory Codes of Practice is that they are the tools with which mining companies establish and manage their safety performance of the industry.

Table 5-1: Showing the collection of Guidelines for the Compilation of a Mandatory Code of Practice to Combat rock accidents



DEPARTMENT OF MINERALS AND ENERGY

Minerals and Energy for Development and prosperity

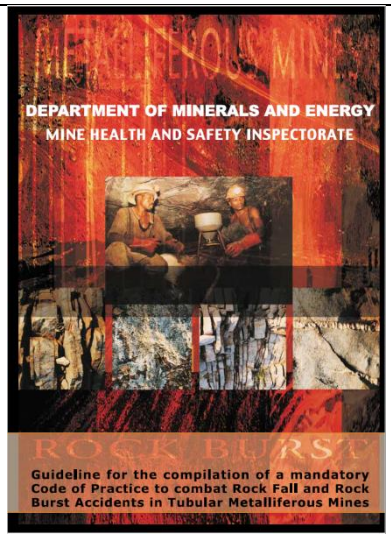
MINE HEALTH AND SAFETY INSPECTORATE

GUIDELINE FOR THE COMPILATION OF A MANDATORY CODE OF PRACTICE TO COMBAT ROCK FALL AND SLOPE INSTABILITY RELATED ACCIDENTS IN SURFACE MINES

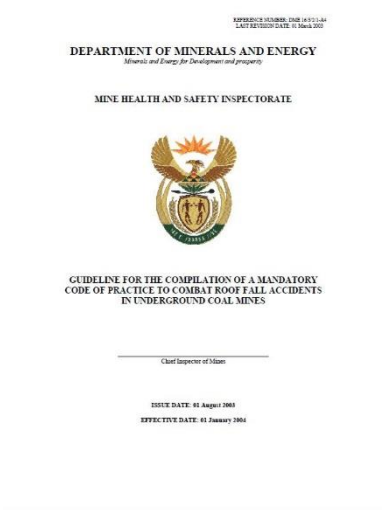
Chief Inspector of Mines

Date

DME 7_4_118 AB4



DME 16_3_2_1-A3



DEPARTMENT OF MINERALS AND ENERGY

Minerals and Energy for Development and prosperity

MINE HEALTH AND SAFETY INSPECTORATE

GUIDELINE FOR THE COMPILATION OF A MANDATORY CODE OF PRACTICE TO COMBAT ROOF FALL ACCIDENTS IN UNDERGROUND COAL MINES

Chief Inspector of Mines

ISSUE DATE: 01 August 2003

EFFECTIVE DATE: 01 January 2004

DME 16_3_2_1-A4



DEPARTMENT OF MINERALS AND ENERGY

Minerals and Energy for Development and prosperity

MINE HEALTH AND SAFETY INSPECTORATE

GUIDELINE FOR THE COMPILATION OF A MANDATORY CODE OF PRACTICE TO COMBAT ROCKMASS FAILURE ACCIDENTS IN MASSIVE MINING OPERATIONS

Acting Chief Inspector of Mines

01 - 12 - 2006

DATE

DME 16_3_2_1-A5



Guideline for the Compilation of a Mandatory Code of Practice to Combat Rockfall and Rockburst Accidents in Metalliferous Mines and Mines other than coal.

1. FOREWORD

The majority of accidents occurring at mines are as a result of rockfalls, seismically or gravitationally induced. Over the last few years the fatality rate pertaining to rockfall and rockburst-related accidents has reached a plateau and no real or meaningful improvement has been attained.

In an initiative to solve this problem, a tripartite task group was established under the auspices of the Mining Regulation Advisory Committee. The initial terms of reference of the task group were to investigate and identify root causes of rock related accidents. Current work practices and any compliance and/or non compliance with regulations, standards, directives, guidelines and codes of practice, and their impact on root causes were scrutinised. Research conducted into solutions under the direction of the Safety in Mines Research Advisory Committee was also examined.

Subsequent to the investigation it was concluded that, as a matter of urgency, a **guideline** for the compilation of a code of practice to combat rockfall and rockburst accidents and **proposed regulations** supplementing the code of practice be drafted and presented to the Mining Regulation Advisory Committee. Due to the complexity and variability of conditions at mines pertaining to the design, geometry and support requirements, rigid and prescriptive guidelines would not be in the interests of rock related safety. An approach was adopted which allowed for local expertise, experience and knowledge on the mines to be effectively utilised. In addition, the positive contribution of tripartism to initiate a process to combat rock related accidents would be enhanced.

2 TASK GROUP MEMBERSHIP

This document has been prepared by the following appointed members of the MRAC Task Group on Rock-Related Safety:

MR B J ERASMUS (Facilitator) - State

DR W K KYMON-LIPINSKI - State

MR K R NOBLE - Employers

MR J W KLOKOW - Employers

MR R C MORE O'FERRALL - Employee Organisations

MR A T FREDERICKS (Editorial) - Chamber of Mines

The following persons/organisations were also consulted :-

(No reference number)

Table 5-2: Compilation of the Notices Regarding Guidelines for a Mandatory Code of Practice, as Issued in the Government Gazette

Keyword	Gazette
Conveyor belt installation	South Africa Government Gazette, vol. 594, no. 38339, dated 2014-12-19, Government notice. Notice no. R. 1024 Mine Health and Safety Act (29/1996): Guideline for a Mandatory Code of Practice for the safe use of conveyor belt installations for the transportation of mineral, material or personnel, p. 3.
Risk-based fatigue management	South Africa Government Gazette, vol. 594, no. 38339, dated 2014-12-19, Government notice. Notice no. R. 1025 do.: Guideline for a mandatory code of practice for risk-based fatigue management at mines, p. 32.
PPE for Women	South Africa Government Gazette, vol. 603, no. 39228, dated 2015-09-25, Government notice. Notice no. 854 Mine Health and Safety Act (29/1996): Guideline for mandatory code of practice on the provision of personal protective equipment for women in the South African Mining Industry, p. 4.
Trackless mobile machines	South Africa Government Gazette, vol. 603, no. 39228, dated 2015-09-25, Government notice. Notice no. 855 Mine Health and Safety Act (29/1996): Guideline for a mandatory code of practice for trackless mobile machines., p. 23.
Cyanide management	South Africa Government Gazette, vol. 603, no. 39228, dated 2015-09-25, Government notice. Notice no. 856 Mine Health and Safety Act (29/1996): Guideline for a mandatory code of practice for cyanide management, p. 44.
Underground railbound equipment	South Africa Government Gazette, vol. 603, no. 39228, dated 2015-09-25, General Notice. Notice no. 919 Mine Health and Safety Act (29/1996): Guideline for a mandatory code of practice for underground rail bound equipment, p. 57.
Thermal stress	South Africa Government Gazette, vol. 608, no. 39656, dated 2016-02-05, Government notice. Notice no. R.146 Mine Health and Safety Act (29/1996): Guideline for a Mandatory Code of Practice for an Occupational Health Programme (Occupational Hygiene and Medical Surveillance) on Thermal Stress, p. 8.
Fitness to work on a mine	South Africa Government Gazette, vol. 608, no. 39656, dated 2016-02-05, Government notice. Notice no. R.147 Mine Health and Safety Act (29/1996): Guideline for a Mandatory Code of Practice on the Minimum Standards of Fitness to Perform Work on a Mine , p. 88.
Right to leave a dangerous place	South Africa Government Gazette, vol. 608, no. 39656, dated 2016-02-05, Government notice. Notice no. R. 148 Mine Health and Safety Act (29/1996): Guideline for a Mandatory Code of Practice on the Right to Refuse Dangerous Work and Leave Dangerous Working Places, p. 114.
Medical Incapacity due to III-Health and Injury	South Africa Government Gazette, vol. 608, no. 39656, dated 2016-02-05, Government notice. Notice no. R.149 Mine Health and Safety Act (29/1996): Guideline for a Mandatory Code of Practice for the Management of Medical Incapacity due to III-Health and Injury, p. 145.
Hearing loss	South Africa Government Gazette, vol. 613, no. 40142, dated 2016-07-15, Government notice. Notice no. R. 839 Mine Health and Safety Inspectorate: Guidance Note for the Implementation of Standard Threshold Shift in the Medical Surveillance of Noise Induced Hearing Loss.., p. 4.
Risk-based emergency care	South Africa Government Gazette, vol. 613, no. 40142, dated 2016-07-15, Government notice. Notice no. R. 840 Mine Health and Safety Act (29/1996): Guideline for a mandatory code of practice for risk based emergency care on a mine, p. 13.
Airborne pollutant	South Africa Government Gazette, vol. 634, no. 41561, dated 2018-04-06, Government notice. Notice no. 419 Mine Health and Safety Act (29/1996): Guideline for the Compilation of a Mandatory Code of Practice for and Occupational Health Programme (Occupational Hygiene and Medical Surveillance) on Personal Exposure to Airborne Pollutants, p. 46.

Keyword	Gazette
Self-Contained Self-Rescuers	South Africa Government Gazette, vol. 655, no. 42956, dated 2020-01-17, Government notice. Notice no. 27 Mine Health and Safety Act, 1996 (Act No. 29 of 1996): Guideline for the Compilation of a Mandatory Code of Practice for the Management of Self-Contained Self-Rescuers in Mines, p. 48.
Flammable gas and coal dust explosions	South Africa Government Gazette, vol. 655, no. 42956, dated 2020-01-17, Government notice. Notice no. 28 Mine Health and Safety Act, 1996 (Act No. 29 of 1996): Guideline for the Compilation of a Mandatory Code of Practice for the Prevention of Flammable Gas and Coal Dust Explosions in Collieries, p. 68.
Working in confined spaces	South Africa Government Gazette, vol. 655, no. 42956, dated 2020-01-17, Government notice. Notice no. 29 Mine Health and Safety Act, 1996 (Act No. 29 of 1996): Guideline for the Compilation of a Mandatory Code of Practice for the Management of Working in Confined Spaces at Mines, p. 125.
Covid-19	South Africa Government Gazette, vol. 659, no. 43335, dated 2020-05-18, General notice. Notice no. 280 Mine Health and Safety Act (29/1996): Guidelines for a Mandatory Code of Practice on the Mitigation and Management of COVID-19 Outbreak, p. 3.
Prevention of Flammable Gas Explosions other than coal	South Africa Government Gazette, vol. 670, no. 44427, dated 2021-04-09, Government notice. Notice no. 326 Mine Health and Safety Act (29/1996): Guideline for the Compilation of a Mandatory Code of Practice for the Prevention of Flammable Gas Explosions in Mines other than Coal Mines, p. 225.

However, it is observed that the Guideline for the Compilation of a Mandatory Code of Practice with respect to combatting rock-related accidents has not been gazetted – despite the fact that the Mine Health and Safety Act stipulates:

> Section 9 (3) "*A code of practice required by the Chief Inspector of Mines must comply with guidelines issued by the Chief Inspector of Mines"*
>
> *and*
>
> Section 49(6) states that "*The Chief Inspector of Mines must issue guidelines by notice in the Gazette".*

Table 5-2 demonstrates that the Chief Inspector of Mines has not gazetted any of the Guidelines for the Compilation of a Mandatory Code of Practice with respect to combatting rock-related accidents.

Additionally, in International Ferro Metals (SA) (Proprietary) Limited v Minister of Mineral Resources and Others (J1673/13) [2015] ZALCJHB 9 (21 January 2015), the Department of Mineral Resources, Mine Health and Safety Inspectorate's "*Enforcement Guideline*" was ruled unlawful and set aside (§[34]a) and the Respondents (i.e. the DMRE and others) were (§[34]a) "*interdicted from relying on the Guideline in the enforcement of the provisions of the MHSA*". The "*Enforcement Guideline*" had also not been gazetted.

5.5.2 Selected Government Certificates of Competency

Chapter 22 of the regulations to the Mine Health and Safety Act, 1996, defines the competency of persons and where relevant, the certification required to achieve competency. In the context of rock-related engineering:

Regarding chapter 22.10.4 on Draw Points, Tipping Points, Rock Passes and Box Fronts

> *22.10(4)(1) (a) The "competent person1" referred to in regulation 10.4(1)(a) means a person who:*
> *(a) is registered with the Engineering Council of South Africa as a professional engineer or professional technologist; or*
> *(b) has been assessed competent against a qualification recognised by the Mining Qualification Authority for this purpose.*
>
> *22.14.1(1) For the purpose of regulations 14.1.1, 14.1.5 and 14.1.7, a competent person means a person who-*
> *(a) is in possession of a valid certificate of competency, recognised for this purpose by the Mining Qualifications Authority; or*
> *(b) has been assessed competent against a unit standard, skills programme or qualification, recognised for this purpose by the Mining Qualifications Authority.*
>
> *22.14.1(8) For purposes of Regulation 14.1(8) competent person means a person who is at least in possession of either the Chamber of Mines Certificate in Rock Mechanics (Metalliferous Mines), or the Chamber of Mines Certificate in Rock Mechanics (Coal Mines), whichever is appropriate for the type of mine concerned.*

5.5.3 Organisations for the training and examination of selected certificates

The Mining Qualifications Authority (MQA) oversees the accreditation of training providers, and compiles respective lists of scarce [mining-related] skills in South Africa. Training providers must register and maintain accreditation with the MQA.

The South African Qualifications Authority (SAQA) (2023) states the requirement that anyone assessing learners against unit standards must be registered as an assessor with the relevant SETA.

5.5.4 Mines Rescue Services

Chapter 16 of the regulations to the Mine Health and Safety Act, 1996 requires that:

16.5(1) The employer at every underground mine must-

(a) provide and maintain, readily available at the mine, mine rescue teams, consisting of at least five competent persons, per mine rescue team, in the following minimum proportions determined by the maximum number of persons who could be underground at any one time.

c) enter into a contract with a mines rescue service provider to coordinate and facilitate the provision of mines rescue teams and other services, relating to an emergency, on a cooperative basis;

The number of rescue teams relevant to the number of persons underground are then specified in 16.5(1)(a)(i) to (iv).

Thereafter,

16.5(2) For the purposes of regulation 16.5(1)(c) and (d), a mines rescue service provider must

(g) ensure that the rescue team members used by them to provide mines rescue services meet the qualification requirements…

And

16.5(3) Every mines rescue service provider, referred to in regulation 16.5(2), must-

(b) implement and maintain a system to issue licences to practice to persons contemplated in 16.5(3)(a) and who meet such criteria as determined by the rescue service provider, which criteria must include at least the following-

(i) the person has not attained the age of 46 years;

(ii) the person has been declared medically fit in terms of the requirements of the mine's "Code of Practice on Minimum Standards of Fitness to Perform Work at the Mine" as may be amended from time to time. prepared in accordance with the : Guideline for the Compilation of a Mandatory Code ofPractice on Minimum Standards of Fitness to Perform Work at a Mine;

(iii) the person has undergone and passed the Heat Tolerance Test, conducted in terms of Chamber of Mines of South Africa Research Organization Research Report No. 29/87 - "A guide to the selection and classification of rescue brigadesmen on the basis of Heat tolerance", initially and thereafter at intervals not exceeding 24 months;

(iv) the person has undergone refresher-training sessions as determined by the mines rescue service provider at intervals of not more than 3 months. At least 2 of these trainings per annum must be in

a mine or simulated mine, in an atmosphere filled with smoke, whilst using a breathing apparatus; and

(v) the person has undergone and passed the Work Load Test, conducted in terms of the Chamber of Mines of South Africa S & TS Circular No. 39/93 dated 5 April 1993, initially and thereafter at intervals not exceeding 12 months.

(c) monitor compliance by persons, issued with a licence to practice by it, with the requirements contemplated in regulation 16.5(3)(b) and suspend or revoke any such licence if the person no longer meets any of those requirements, and re-issue a licence when the person again meets the requirements.

Chapter 22 specifies the qualification requirements, viz.

22.15(16) (a) For purposes of Regulation 16.5(1)(a), competent person means a person who-

(i) has passed a course of training approved for this purpose by the Chief Inspector of Mines;

OR

(ii) has been assessed and found competent against applicable unit standards, skills programme and/or a qualification recognised for this purpose by the Mining Qualifications Authority (MQA).

The South African Qualifications Authority (SAQA) (2024) shows the learning requirements of the Occupational Certificate: Emergency Service and Rescue Official.

5.5.5 SAMRASS

As introduced in sub-section 5.2.1 above, the SAMRASS reporting system appears to have several limitations. Currently, SAMRASS only collects fall of ground causes as 'rock burst, strainburst, or gravity (SAMRASS Item 12, number 1).

The SAMRASS reporting system therefore does not offer great clarity because the reporting structure is such that falls of ground are described as being caused by rockbursts - so stated very simply: "*the rock mass fell down, because the rock mass fell down*".

5.5.6 Fatality statistics in South African mining

Fatality statistics from mining incidents are the primary measure of safety performance in South African Mining industry. The research identified that there appears to be inconsistency in the methodology and/or data submissions from various organisations, used to determine fatality statistics in South African mining.

The individual approaches are not incorrect *per se,* because individually they follow internationally available methods (e.g. Ruser, 1998 and the US Bureau of Labour Statistics, 2022). However, it appears that different organisations use different methodologies, and that the DMRE uses a simplified approach. Again, a simplified approach is not incorrect, but it is also not accurate.

It is unclear whether or not all data submitted uses the same definitions, subsequently, processing of the data does not accurately distinguish between the incidence and prevalence of the occurrence.

Examples are evident in

a) Anglo American (2022 p321), who report Fatal-injury frequency rate (FIFR)[44] per one million hours in their annual report, as well as notes on inclusions of operations[45] for selected years only,
b) Whereas the DMRE provide no description on the calculation standardisation.

Furthermore, the determination of fatality rates:

[44] FIFR is the number of employee or contractor fatal injuries due to all causes per 1,000,000 hours worked.

[45] "*Data relates to subsidiaries and joint operations over which Anglo American has management control. In 2022, 2021, 2020, 2019 and 2018, data excludes results from De Beers' joint operations in Namibia and Botswana. 2017 data includes results from De Beers' joint operations in Namibia and Botswana.* ".

a) Includes employees and contractors [46], where traditionally, a contractor may have been a 'field-based function', modern evolution of the phrase recognises that a 'contractor' is a type of employment – not a function i.e. office-bound staff may also be contractors, therefore, including them in the calculation pool may have the potential effect of increasing the pool size and therefore decreasing the fatality rate.
b) Does not distinguish if travel time is included in the tally of hours (e.g. from surface to the face), or if office-based work served as a contractor is also included in the tally of hours.
c) Is later replaced by a total recordable injury frequency rate (TRIFR).

Similarly, it is not clear if fatality rates are proportioned to number of employees per year, or factorised in any way, as intimated in Table 5-3 where an example is highlighted contrasting the years 2018 and 2019.
It is observed that the smaller group of employees measured in 2018 (i.e. 81 fatalities from only 456,438 employees) suffered more fatalities than the larger group of employees measured in 2019 (i.e. 51 fatalities from 460,015 employees)

Table 5-3: Number of fatalities per year, and number of employees per year (2011 to 2021) (Minerals Council, 2021) [47]

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Number of fatalities	123	112	93	84	77	73	90	81	51	60	74
Number of employees	512,874	524,869	509,909	492,931	480,205	458,291	463,901	456,438	460,015	448,324	458,954

[46] Anglo American (2022 p309).
[47] Minerals Council (2021 p26 and p28) and Minerals Council (2022 p1) show differing number of total fatalities for the year 2002 – while the error may simply be typographic, there is no erratum or correction issued on the matter.

5.6 The “changing face” of “risk understanding” is not ubiquitously, readily reflected in South African mining

The “changing face” of “risk understanding” is not ubiquitously, and readily reflected in South African mining. The analyses considered aspects such as definitions, practical components, and risk matrices of mining companies in South Africa.

5.6.1 Definitions of risk

There is some interplay between ISO 31000 [risk management] and ISO 45001 [occupational health and safety (OH&S) management systems], and the approaches are similar in their objectives, principles and tools.

In years gone by, “risk” was defined by many as “Risk = Likelihood x Impact”. Selectively, some practitioners reduced the scope of the definition further to “risk = likelihood of fatality”.
These is no longer strictly “correct” in terms of risk as established subject matter. The ISO (2018) now defines risk as “*the effect of uncertainty on objectives*” and this is to focus on the effect of incomplete knowledge of events or circumstances on an organization’s decision making.

In practice, the old adage seems to live on, with only Likelihood x Impact commonly being used to report risk assessment and risk management in the field of geotechnical engineering.

5.6.2 Opportunities for improvement in geotechnical, risk-related undertakings

5.6.2.1 It is not always a risk

The definition, as well as the perception of what a risk is, are important to effective communication.

Goerlandt *et al.* (2021) state that risk perception is important in organizational and societal governance contexts, and furthermore, that risk perceptions are influenced by contextual factors (e.g. an individual's familiarity with the risk source, the (perceived) personal control over the phenomenon or activity, whether or not the risk is voluntarily accepted, or even the individual's trust in organizations controlling and managing the risk (Aven and Renn, 2008 in Goerlandt *et al.,* 2021).

Therefore, in reporting, it is not unusual to see 'risks' being identified, that may in fact, not be 'risks'. The alternative items include:

a) Hazard;
b) Danger;
c) Uncertainty;
d) Chance (i.e. having recognise that an incident could hypothetically occur, but having given no consideration as to the likelihood or probability of that occurrence); or
e) Issues (less substantial elements and/or more trivial matters that would ordinarily be better suited in an issue log than in a risk register).

5.6.2.2 Latency and time to be considered

It is not unusual to encounter that risks whose realisation may not be imminent, become removed from the risk register, with the intention of re-introducing them closer to the perceived manifestation of the event. This is not ideal because it means that potential changes around the risk are not monitored and therefore not detected.

In some instances, risks may be transitory, change or have knock-on effects (an appropriate examples include Dahnér *et al.'s* (2012) exposition on the transition of the Kiirunavaara Mine, Sweden, from a non-seismic mine to a seismically active mine and Erguncu Güçlü *et al's.* (2020) investigation into whether or not large seismic events in the Lappberget orebody, Garpenberg, Sweden were blast-related).

5.6.2.3 Practical considerations

Experience has shown that a myriad of practical considerations related to the risk-environment may be considered toward the benefit of the operation, these include:

a) Do not conflate

- During each step of the risk activities, do not conflate information
- It has been observed that this often occurs during identification of the risk and identification of mitigation. For example, the cause of a risk is an important component to understand what specific action must be taken to mitigation the potential consequences if that risk is realised – such as flooding underground, it is important to understand if the flooding may be caused by mechanical failure of the pumping system (in which case, mechanical and maintenance systems can be ascribed), or was flooding the result of intersecting and aquifer because cover drilling could not be carried out due to personnel issues (in which case, personnel management will be ascribed).

b) Do not Presuming Efficiency by Association

- It has been observed that many mining operations consider themselves ready, skilled and sufficiently funded to be able to mobilise and respond to a risk occurring, with the same success as they observe in bigger mining companies that have a much more substantial market capitalisation and/or mining history. This is not ideal, because not all mining operations have the same resources or systems established to be able to achieve the outcomes of much more seasoned veterans in the aspect of geotechnical risk in mining.

c) Carry and Combine

- It has been extensively observed, that only select, prominent, or popular interpretations are carried forward during risk planning (as opposed to all permutations of the risk) – despite their inherent uncertainty also.
- It is more diligent to incorporate all the interpretations of a risk, and combine them with new data to verify the interpretation.
- A prominent example of this shortcoming is the use of rock mass rating toward characterisation during preliminary assessments (e.g. the rock mass is estimated as “good quality”) that consistently produces small-scale failures during ***later*** mining, however, these small-scale failures cannot always be matched during back-analysis when using the given parameters.
- Rather, field observations (at the very least) during mining should be incorporated to refine the perceived understanding of the rock mass (e.g. it has deteriorated significantly) to be able to more accurately identify the source of the risk, to be able to formulate mitigation.

5.6.2.4 Challenges connecting

Challenges in connecting the various objectives, contents and outcomes of geotechnical, risk-related exercises are frequently observed.

From data-driven geotechnical hazard assessments (McGaughey, 2019), issue-based risk assessments using a Panel Risk Rating System (Anonymous, 2005) to geotechnical risk assessments for large diameter raise bore shafts (McCracken and Stacey, 1989a) – there is ample independent description of the components. However, it is observed that subsequent literature does not relate the initial undertaking to the current state.

Hansen (2017) provides an insightful model for contrasting drivers and characteristics of strategic and tactical steering (shown in Figure 5-15) as it contrasts the *episteme* [knowledge] and *doxa* [common belief or popular opinion] in the activities.

Extending from the definitions in Grewal and Lafreniere (2003), the telic (goal-oriented) states and paratelic (spontaneous) states are also contrasted.

The purpose of including the explanation is to further demonstrate the need for re-iterative risk-work, not just once off, because the strategy or tactics may change with time, and therefore need to be accommodated as such. Even the very aspect of doing the work can be explored in Bindarwish (2014) – where aspects such as performance and self-efficacy were related to task condition (favourable vs. unfavourable).

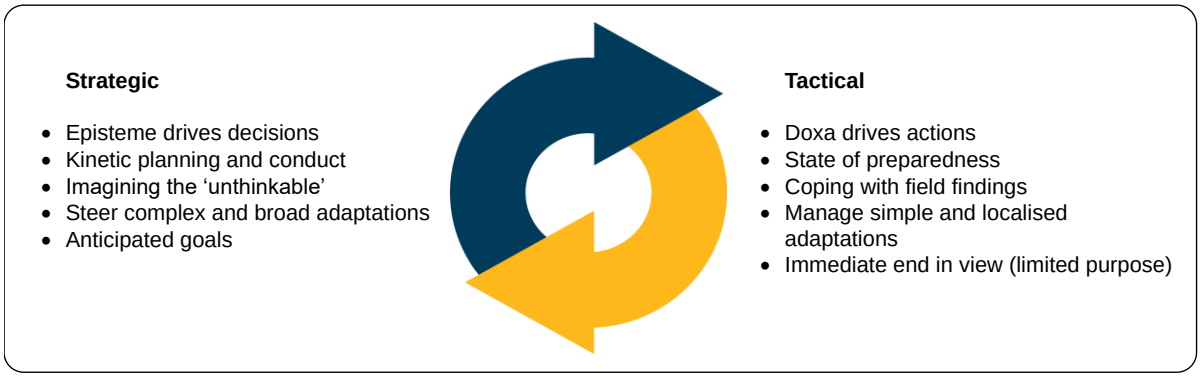


Figure 5-15:Strategic and Tactical Drivers and Characteristics (Based and modified after Hansen, 2017)

The Quantified Value-created process (QVP) by Stacey and Hadjigeorgiou (2022) (presented in sub-section 4.6.2 above and illustrated in Figure 4-12) provide an excellent practical tool for decision making process in mine design and operation.

The QVP deals with 'planning the process' and with 'implementing the process' – thereby involving all layers and functions of personnel (i.e. technical and financial, senior managers, mine managers and executive directors). The connectivity that can be achieved through the QVP enables more *holistically* informed decision-making.

5.6.3 The risk matrices of mining companies in South Africa

The risk matrix for each of the companies identified in chapter 3, sub-section 3.2.4, Figure 3-2 (i.e. Anglo American plc, Gold Fields Limited, Anglo American Platinum Limited, Impala Platinum Holdings Limited, Harmony Gold Mining Company Limited, African Rainbow Minerals Limited, Royal Bafokeng Platinum Limited, DRDGOLD Limited, Pan African Resources Limited, Wesizwe Platinum Limited, and Bushveld Mineral s Limited) was sought, however, no information was forthcoming – through literature search and review, or through request.

Figure 5-16 and Figure 5-17 are not from rock mechanical or geotechnical engineering studies, but do demonstrate the limitation created by companies not identifying their risk-related metrics, such as

a) Range of categories of consequence (e.g. financial, safety, reputational)
b) Descriptors per category (e.g. 'rare' is an occurrence 1 in 5 years)
c) Thresholds per category (e.g. 'medium' relates to <R1000)
d) Their tolerance limits (e.g. maximum tolerable loss is R1million per incident) etc.

It is not possible to deduce the company's risk appetite or tolerance regarding ground instability / deformation / failure/ movement if the accompanying framework is withheld.

Event Risk Rating/Priority (1)					
Consequence / Likelihood	1 Minor	2 Low	3 Medium	4 High	5 Major
5 Almost Certain	Medium (11)	Significant (16)	Significant (20)	High (23)	High (25)
4 Likely	Medium (7)	Medium (12)	Significant (17)	High (21)	High (24)
3 Possible	Low (4)	Medium (8)	Significant (13)	Significant (18)	High (22)
2 Unlikely	Low (2)	Low (5)	Medium (9)	Significant (14)	Significant (19)
1 Rare	Low (1)	Low (3)	Medium (6)	Medium (10)	Significant (15)

Figure 5-16: Example of a risk matrix, relating likelihood and consequence (Shangoni, 2017)

Impact			1 – Insignificant	2 - Minor	3 - Moderate	4- Significant	5 - High
Financial			<1% of budgeted EBITDA & listed assets <US$10M	>1 %<3% of budgeted EBITDA & listed assets >US$10M < US$35M	>3%< 10% of budgeted EBITDA & listed assets >US$35M < US$120M	>10% <30% of budgeted EBITDA & listed assets >US$120M < US$350M	>30% of EBITDA & listed assets > US$350M
			No disruption to operation and/or insignificant impact on financial targets (budget)	Brief disruption to operation and/or Minor impact on financial targets (budget)	Partial loss of operation and/or Moderate impact on financial targets (budget)	Partial loss of operation and/or Significant impact on financial targets (budget)	Substantial loss of operation and/or Material impact on financial targets (budget)
People- Delivery of Results			Slight impact on delivery of the business plan due to skills shortage, poor succession & talent management and inability to meet legislative requirements	Minor impact on delivery of business plan due to skills shortage, poor succession & talent management and inability to meet legislative requirements	Moderate impact on delivery of the business plan skills shortage, poor succession & talent management and inability to meet legislative requirements	Significant impact on delivery of the business plan due to a shortage of skills, poor succession & talent management and inability to meet local legislative requirements	Substantial impact on delivery of the business plan due to a shortage of skills, poor succession & talent management planning and inability to meet local legislative requirements
People - Safety			First aid case	Medical treatment case	Lost time injury	Permanent disability or single fatality	Numerous permanent disabilities or multiple fatalities
People – Occupational Health			Exposure to health hazard resulting in temporary discomfort	Exposure to health hazard resulting in symptoms requiring medical intervention and full recovery (no lost time)	Exposure to health hazards/ agents (over OEL) resulting in reversible impact on health (with lost time) or permanent change with no disability or quality loss of life	Exposure to health hazards/ agents (significantly over OEL) resulting in irreversible impact on health with loss of quality life or single fatality	Exposure to health hazards/ agents (significantly over OEL) resulting in irreversible impact on health with loss of quality of life of numerous group/ population or multiple fatalities
Environmental			Lasting days or less; affecting small area (metres); receiving environmental highly altered with no sensitive habitats and no biodiversity value (e.g. urban/ industrial areas)	Lasting weeks; affecting limited area (hundreds of metres); receiving environment altered with little natural habitat and low diversity value	Lasting months; affected extended area (kilometres); receiving environment comprising largely natural habitat and moderate biodiversity value	Lasting years; affecting area on sub-basin scale; receiving environment classified as having sensitive natural habitat with high biodiversity value	Permanent impact; affecting area on a whole basin or regional scale; receiving environment classified as highly sensitive natural habitat with very high biodiversity value
Legal & Regulatory			Technical non compliance. No warning received; no regulatory reporting required	Breach of regulatory requirements. Report/ involvement of authority. Attracts administrative fine	Minor breach of law; report/ investigation by authority. Attracts compensation/ penalties/ enforcement action	Breach of the law, may attract criminal prosecution, penalties/ enforcement action. Individual licence temporary revoked.	Significant breach of the law. Individual or company law suits; permit to operate substantially modified or withdrawn
Social/ Communities			Minor disturbance of culture/ social structures	Some impacts on local population, mostly repairable. Single stakeholder complaint in reporting period	On going social issues. Isolated complaints from community/ members/ stakeholders	Significant social impacts. Organised community protests threatening continuity of operations	Major widespread social impacts. Community reaction affecting business continuity. "License to operate" under jeopardy
Reputation			Minor impact – public awareness may exist but no public concern	Limited impact – concern/ complaints from certain groups/ organizations (e.g.	Local impact, public concern/ adverse publicity localised within	Suspected reputational damage; local/ regional public concern and reactions	Noticeable reputational damage – national/ international public attention
Likelihood / Probability	5 Almost Certain	99%	The unwanted event has occurred frequently; occurs in order of 1 or more x per year & is likely to reoccur within 1 year	11 (M)	16 (S)	20 (S)	23 (H)	25 (H)
	4 Likely	60%	The unwanted event has occurred infrequently; occurs in order of less than 1 x per year & is likely to reoccur within 3 years	7 (M)	12 (M)	17 (S)	21 (H)	24 (H)
	3 Possible	30%	The unwanted event has happened in the business at some time; or could happen within 10 years	4 (L)	8 (M)	13 (S)	18 (S)	22 (H)
	2 Unlikely	15%	The unwanted event has happened in the business at some time; or could happen in 30 years	2 (L)	5 (L)	9 (M)	14 (S)	19 (S)
	1 Rare	7.5%	The unwanted event has never been known to occur in the business; or it is highly unlikely that it will occur within 30 years	1 (L)	3 (L)	6 (M)	10 (M)	15(S)

Figure 5-17: Example of a risk matrix, relating likelihood and consequence (*South African Heritage Resources Agency *(SAHRA), 2015)

5.7 Complex interplay of technical disciplines and their ideals

5.7.1 The misnomer of ‘industry best practice’

The candidate asserts that the phrase “industry best practice”, in terms of geomechanics, geotechnical engineering, and mining, should be considered a misnomer.

The reasons put forward include the facts that:

- No universal agreement has been reached on the types of elements, or the measurement of performance of those elements, that would constitute “industry best practice”.
- There is no forum from which international or national consensus can be garnered – especially as technology changes and/or the implementation modifies the way in which a task is undertaken compared to previous norms.
- There is no codification on the matter, to allow comparison at a fixed point in time.
- Mining operations are highly variable – just because gold is being mined, for example, does not mean that the drilling practice, blasting efficiency, scheduling, mine planning, support installation etc. are carried out the same way, using the same equipment or tools, or even achieving the same extent of efficacy.
- Different standards, guidance, codes and technology are available and are applied differentially depending on experience, budget, site conditions and other circumstances, including geographic location of the operation.
- The recommendation of ideal action determined through professional judgement is often balanced against the reality of budget constraints, resulting in the adoption of ‘agreeable action facilitated by budget’.

Given the wide variety of ore bodies, skills of professional personnel, mining performance on site, differing decision-making outcomes – there is no international or national consensus of “*best* practice”, however, the candidate concedes that there could foreseeably be “*good* practice”.

The phrase ‘best practice’ [in the context described above] is misleading because it implies that the company or mine has achieved maximum level of excellence at each specific element – when in reality, that has not happened. In terms of reporting transparency and accuracy, it is more fitting to describe the actions as “good practice” or as “the best approach given the circumstances”.

Examples of the phrase in use include -

Example 1

"The selection of an external review consultant was discussed as a best practice approach to managing geotechnical risk at medium to large mining operations such as L [48]" [subsequently no further information given on the topic].

Example 2:

"GEOMECHANICS RISK MANAGEMENT

The scope of work for this GPR [geotechnical performance review] did not include a compliance audit of B Ground Control Standard. However, this review did focus on key areas of material importance and interest to L, including their preparedness for such an audit that other operations are receiving this year. Focus of this review was on the quality of the Ground Control Management Plan (GCMP), risk assessments and emergency preparedness, in terms of L's geotechnical target action response plan (TARP). B's global operations are reviewing how ground fall incidents and larger scale geotechnical events are defined and how they are reported. It was noted during this review that L identifies and tracks geotechnical risks and documents progress in resolving them in their monthly reports. The tracking style used by L is an example of industry best practice [49]".

Example 3:

"have acquired the physical data used as the basis of this report from geological mapping, sampling and various drilling techniques. This work has been conducted in accordance with best exploration practice principles throughout [50]" .

Best practice guidelines exist in other contexts, as the result of directed effort, for example:

a) Department of Water Affairs and Forestry (2006). Best Practice Guidelines for Water Resource Protection in the SA Mining Industry; and
b) European Commission (2012) Best practices and methodological guidelines for conducting gas risk assessments.

[48] Anonymous (2016, p14).

[49] Anonymous (2016, p13).

[50] Anonymous (2007, p6).

5.7.2 Too many to muster

If we consider the cycle shown in in Figure 5-18 with the notions postulated and Table 5-4, it becomes plausible that interwoven aspects, having different extents of favourable configurations at any given time, would be incredibly difficult to prescribe minimum performance for.

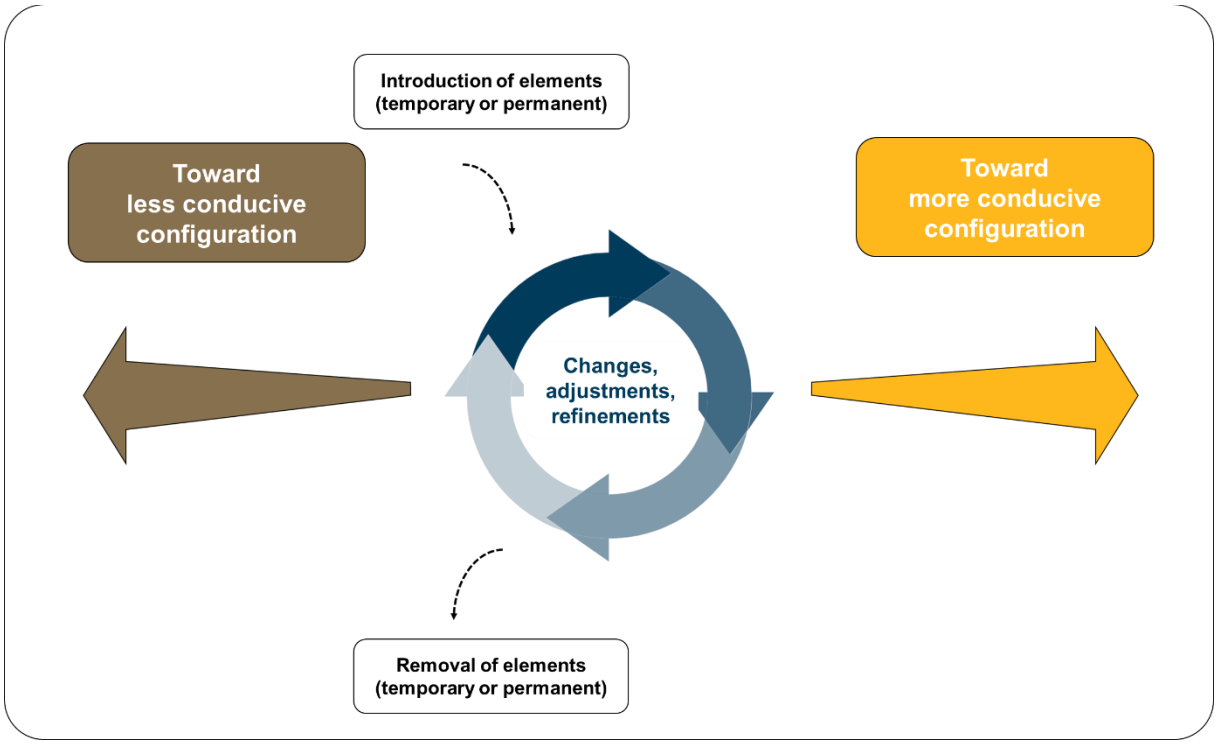
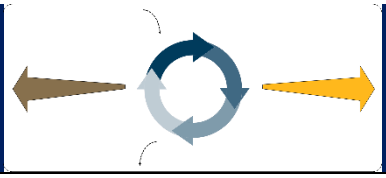
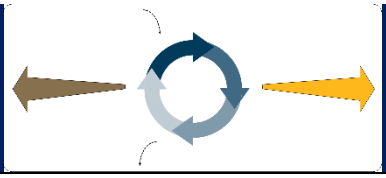


Figure 5-18:Sketch to indicate the constant flux, and the continuum of, a potential state of being (with respect to geomechanical parameters)

Table 5-4: Conceptual notion of interwoven aspects, having different extents of favourable configurations at any given time

Aspect	
Lithostratigraphy ("geology")	Simpler, stratiform Complex, folded, faulted, weathered
Structure	Blocky, jointed, faulted
Rock mass	
Hydrogeology	
Hydrology	
Database (toward design)	
Computational resources (hardware and software)	
Comprehensiveness of deliberation and/or assessment of stability	
Implementation (of intended design)	Correct Incorrect
Stability/deformation monitoring	Comprehensive monitoring system Integrated Ongoing basis “spot” monitoring Intermittent basis No monitoring
Groundwater regime	Water levels and recharge
De-watering efficacy	Sufficient volume and rate Insufficient volume and rate
Emergency Preparedness and Response	Training, equipment, facilities, performance
Operational Documentation (for instruction and/or guidance)	Codes of Practice, Standardised Operating Procedures,
Information Management	Articulate records Integrated systems Unique numbering Indexed and/or searchable database Ongoing inclusion of new information Ongoing retention of records No documentation
Labour	Manual labour: Qualification and/or training, skills, experience, behaviour, continuity of service, familiarity with operational elements (knowns and unknowns) Mechanised: Equipment, extent of mechanisation, as well as integration of components meets the needs of the operation

Aspect	
Technology	Type of technology, extent of implementation, as well as integration of components meets the needs of the operation

5.7.3 Optimised… To what?

A novel inclusion in literature nowadays, is the notion of ‘optimisation’ – viz. optimisation of a design.

However, the description of the optimisation is often (not always) juxtaposed with preceding explanations on topics such as uncertainty, data confidence, variability, insufficient understanding, and/or limited data entries – as to how the design is highly dependent on many unknown factors, before ultimately concluding that optimisation has taken place.

The candidate admires the reasons and efforts toward optimisation but finds frustration in the contextual abyss that accompanies the forementioned stye of writing – and posits the following fundamental question: “Optimised to what?”.

Pages and pages of text describing data suffices and indicators of slope instability, followed by little mention of organisation context, strategy, or decision-making culminate in ambiguous pragmatics and semantics where it is incredibly difficult to ascertain the optimised element.

Potential options include any or combinations of the following:

a) A geotechnical design and/or support implemented at the lost costs [cost-optimised]?
b) A geotechnical design and/or support implemented for abject safety, even if at the highest costs imaginable [safety-optimised]?
c) A geotechnical design that enables maximised mine production and development rates in the short term to benefit current market conditions [pricing] for Shareholder value?
d) A versatile design that will allow adaptability in future years with minimum disruption?
e) A holistic compromise to achieve consistent, reliability performance across all business objectives?

The notion of optimisation of a geotechnical design is often alluded to in the field of geomechanics, but inevitably assigns conclusions across all areas of the business, without having decision-making capability in those areas.

5.8 On the stability and/or instability of constructed mining features

5.8.1 Instability and failures are preceded by warning signs

Instability and failures of constructed mining features are preceded by warning signs. Recounts of types [of warning signs] often appear in

- Instructional/learner materials, and in
- Publications with specific and directed intent to identify the warning sign in relation to the failure event that followed it. Szwedzicki (2001) is a thorough example of a publication that has compiled information for various rock mass collapse events and their geotechnical precursors (shown in Table 5-5 below).

Table 5-5: Summary of geotechnical precursors to rock mass collapse (Szwedzicki, 2001)

Mine	Country	Type of mining	Type of collapse	Geotechnical precursors
Coalbrook Colliery	South Africa	Underground	Pillar and rock mass collapse	Crushing of pillars Strata collapse Cracks appearing on the surface Rock noises Air blasts Acoustic emissions Release of methane
Mufulira Mine	Zambia	Underground	Formation of a sinkhole and tailings inrush	Sinkhole developments Deterioration of ground conditions Mud from the surface extruded 500m below Surface subsidence
Noble Nob Mine	Australia	Underground	Crown pillar collapse	Ground movement Crack opening Acoustic emission Rock falls
Otjihase Mine	Namibia	Underground	Pillar failure	Roof spalling on the up-dip side of the pillars Floor heave on the down-dip side of the pillars.
Perseverance Shaft	Australia	Underground	Crown pillar collapse	Seismic activity Ground movement Pillar crushing
San Manuel Mine	USA	Underground	Caving of the ore	Cracks on the surface Formation of depression on the surface Progressive caving
Sons of Gwalia	Australia	Open pit/ underground	Pit wall collapsed	Tension cracks Vertical movement of ground Concrete cracking in underground excavations.

Mine	Country	Type of mining	Type of collapse	Geotechnical precursors
				Ground deterioration Rockfalls Acoustic emissions Rock bolts failure Ground movement
Scotia Mine	Australia	Underground	Crown pillar collapse	Hangingwall deterioration Rock falls Airblast Ground movement across a shear zone Pillar collapse
Telfer Mine	Australia	Open pit	Pit wall collapse	Movement of a toe of the slope Cracks on the surface Deformation of face plate of bolts Footwall heave at the toe of the slope Movement of the ground Rock falls
Warrego Mine	Australia	Underground	Crown pillar collapse	Change in water inflow pattern Ground fretting and cracking Ground movement Acoustic emission

5.8.2 The significance of geotechnical precursors is not always recognised

Geotechnical precursors as warning signs are not always recognised for what they are and what they represent. Szwedzicki (2001) articulates that, unfortunately, *"geotechnical precursors have not always been recognized as warning of potential failures".*

A tremendous example of geotechnical precursors being overlooked as warning signs is described by Ross (2017) as part of the lessons learnt from the Bingham Canyon Manefay slide.
Ross (2017) explains various incidences of precursors, including cracks observed at the visitors centre; field inspections to find and plot cracks (that actually showed the large mass of material above the Manefay bed was accelerating – not just moving), cracks appearing in the dump (indicating instability), identifying cracks in a darkened environment using lights from a dozer, and the expansion of cracks that had been observed on surface. Despite this, Ross (2017) reports that "*unfortunately, independent consultants were not consulted to review or provide feedback on the failure mode, and the…. failure was not challenged outside of the Geotechnical group*".
The Geotechnical group:

- Had assumed that that a normal rock-fall landslide would occur over a number of hours or days – as Bingham Canyon mine had experienced many such failures over its "*107-year life*".
- Were hesitant to estimate the volume of failure, due to their struggles in determining the shape of the failure (having considered a wedge-type and a circular-type failure).

Subsequently "*one of the young engineers with less than three years out of university and [who] had been recently retained by his superintendent… to prepare mine designs*" built a 3D model of the failure. However, the estimate of the volume of the failure was discounted because it was not based on the ***typical*** failure modes that the mine had experienced previously [candidates own emphasis using bold text].

Within two months, the failure occurred. Ross (2017) describes the event as he was held association with the operation at that time:

> *"As the four men talked, they could hear rocks and detrital material falling down the highwall. Then at 9:30 p.m. on April 10, 2013, it happened—the Manefay mass literally exploded out of the highwall. It did not fail slowly over hours or days, as previous Bingham Canyon Mine failures had. In 90 short seconds (Pankow et al. 2014[51]), a large section of the Bingham Canyon Mine highwall went from a solid wall of stone to an exploding mass of rock traveling a distance of 1½ miles and dropping thousands of feet as it travelled to the bottom of the Bingham Canyon Mine".*

[51] Pankow, K.L., Moore, J.R., Hale, J.M., Koper, K.D., Kubacki, T., Whidden, K.M., and McCarter, M.K. (2014). Massive landslide at Utah copper mine generates wealth of geophysical data. GSA Today 24(1) pp. 4–9. *Cited in* Ross, B. (2017). Rise to the Occasion: Lessons from the Bingham Canyon Manefay slide. Published by Society for Mining Metallurgy and Exploration (SME), Littleton, Colorado, United States of America, pp. 244. ISBN 978-0-87335-4318.

A second failure occurred shortly thereafter:

> *"After the word went out that the Manefay had failed, managers and superintendents rushed to the mine to evaluate the impact and start the process of returning to production…..*
> *[The men] were looking up at the slope…. [they] listened as the rock fall became louder and louder. Then they began to hear and feel a loud rumble in the ground. … The rock fall and rumble continued to increase until 11:05 p.m., when a loud C-R-A-C-K was heard, and, as they watched, the entire skyline to the east fell away into nothingness as a second major landslide occurred. This was a tremendous shock, because everyone believed that the Manefay slide was over and the critical danger had passed.*
>
> *According to the seismic data from the College of Mines and Earth Sciences at the University of Utah, the second slide happened as quickly as the first. Within approximately 90 seconds, the second mass fell more than 2,000 feet in vertical distance. The seismic recordings were able to capture the entire duration, which indicated that the failure mass started as solid ground, travelled more than 1½ miles, and came to a full stop in 90 seconds".*

And a third event occurred:

> *"Those [persons] in the IC Center were in the process of moving to the Administration Building when a third event occurred.*
> *…. [during a telephone call] more rock fall could be heard on the phone. The ground was shaking again…. This occurred at 11:16 p.m. and at the time everyone thought it was a third landslide.*
> *It was later determined by seismologists at the University of Utah that the third event was actually an earthquake that was the result of having the tremendous weight of the Manefay mass move into to the void of the pit, which relieved a tremendous amount of pressure below the failure area".*

5.8.3 Subject matter experts do not always agree

Subject matter experts with learned opinions do not always agree on the interpretation when viewing the same information. Phrased differently, different observations can be drawn by keen minds.

5.8.3.1 Vaiont Dam, Italy

Pells (2015) provides a valuable and well-written narration of several case studies. One such case study that very clearly demonstrates that subject matter experts are not always in agreement, is that of the Vaiont dam, Italy.

Pells (2015) writes "*Whilst Leopold Muller accepted the geomorphological evidence, others did not, and debate raged as to whether there would be small slides, large slides, slow slides or fast slides. There was 'continuous rejection of the worst case scenario — a gigantic single landslide — by the authorities, by the electric power company and the government' (Genevois & Ghirotti 2005).*

Nobody predicted what happened and, to this day, there is no consensus as to why it moved so suddenly and so quickly".

5.8.3.2 Bingham Canyon, USA

Ross (2017) also states important lessons regarding consensus – i.e. the importance of engaging ***independent*** expertise [the candidate's own emphasis using bold text]. Subject matter experts and independent reviewers are often skilled at interrogating the foundational assumptions, and identifying any potential (albeit unintentional) complacency that may have found it's way into the rock engineering and geotechnical environments.

Ross (2017) explains the lesson learned:

> *"Basically all of the geotechnical analyses leading up to the Manefay failure were performed by internal geotechnical engineers and the one consulting firm that had performed the geotechnical analyses for the mine for several decades. Although having one group conduct the analyses was efficient in that everyone was familiar with the mine and the analyses done to date, this method did not lend itself to challenging basic assumptions or ideas.*
>
> *Consequently, there was not a good understanding of the failure mechanism or the way the failure would act and cover the entire bottom of the pit and destroy a significant amount of equipment. It is not known if bringing in additional independent experts to challenge the analytical work would have identified more accurately how the failure would have acted, but they may have been able to question some of the basic assumptions."*

5.8.4 Failure does not occur spontaneously – so is there a duty to announce imminent failure?

Using slopes in hard rock, open pit mines - the principle that failure of a design in a rock mass is not spontaneous is reiterated by the Western Australian Government (2004), Kumar and Villuri (2015), de Menezes *et al.* (2019), as well as a myriad of additional publications i.e. "*slope failures do not occur spontaneously. There is scientific reasoning for each failure, and failures do not occur without warning*".

Call and Savely (1990) contextualise the statement through explanation of three general principles of slope mechanics:

a) Slope failures do not occur spontaneously – this is, in part, because one or more of the forces acting on a potentially unstable rock mass must change to cause any part of the slope to become unstable.
b) Most slope failures tend toward equilibrium – i.e. a slope fails because it is unstable under the existing conditions and failure tends to bring the slope to some sort of equilibrium. This may involve a:
    - reduction in the driving forces,
    - an increase in the resisting forces, and/or
    - both a reduction in driving forces combined with an increase in the resisting forces of the failed zones.
c) A slope failure does not occur without warning. Prior to failure, measurable movement and/or the development of tension cracks occur and they indicate that slope failure is imminent. The slope may subside over a period of time to achieve stability.

Szwedzicki (2001 and 2003) provides information and examples of geotechnical precursors to large-scale ground collapse in mines and rock mass behaviour prior to failure.

Strictly speaking, the mining rights conferred by the MPRDA do not require that a geotechnical instability must never occur – rather, it requires that no person should be injured in any such incident. In an international context, the Bingham Canyon mine in the USA, encountered a slope failure during May 2013. The company was aware – early as February of that year, regarding movement of the slope, installed monitoring systems during April of that year and then released a press announcement approximately "*seven hours before the collapse*" (NASA, 2013), confirming that the monitoring facilitated safe extraction of personnel from the pit.

5.8.5 Responsible mine personnel do not always react to precursors

Unfortunately, responsible mine personnel do not always react to precursors. In these instances, the realisation of a mining accident or disaster is followed by a section 72 investigation (under the Mine Health and Safety Act 1996), and if necessary, an inquest investigation (under the Inquest Act of South Africa 1959). The findings of these types of investigations often describe events in depth and detail that is unsurpassed by any mining reporting available voluntarily from mining companies. Examples of this also evidence deceptions and failures regarding record-keeping.

5.8.5.1 Regarding inquest investigations

Oosthuizen (2003) has helpful context where the Court reminded itself:

> "The underlying purpose of an inquest is to promote public confidence and satisfaction, to reassure the public that the deaths from unnatural causes will receive proper attention and investigation so that, where necessary, appropriate measures can be taken to prevent similar occurrences, and so that persons responsible for such deaths may, as far as possible, be brought to justice" [52].

5.8.5.2 Evidence of inaction by responsible mining persons

The Rovic diamond mine disaster of 1996

Oosthuizen (2003) presents information regarding the legal liability of the mine manager, mine captain, and mine owners as a result of the Rovic diamond mine disaster of 1996.

The mine had underground workings (approximately 1000 m below surface) which were situate below an historic surface pan. The disaster was found to have happened when a disturbance on surface caused a mud seal to break in the pan, leading to inundation as water and mud rushed into the underground workings. Twenty workers were killed, and only four bodies could be retrieved.

Oosthuizen (2003) states:

> *"After 56 persons gave evidence and after much discussion on why the disaster happened so suddenly and at that time, it was revealed that a hole had been discovered in the pan area. The fact that the hole was there about 24 hours before the disaster occurred, gave warning that a disaster was waiting to happen. This also meant that there was a definitive visible warning sign that a mud-rush was imminent".*

[52] Appeal Judge Smalberger in Marais NO v Tiley, 1990(2) SA 899 A. *As cited in* Oosthuizen (2003)

The Lily Mine disaster of 2016

The University of Cape Town (UCT) 2021 summarises the incident at Lilly mine, i.e.

> "*the crown pillar located between the roof of level three and four underground collapsed and caved into the old underground workings of the mine.*
> *As a result, the lamp room, which was part of the surface infrastructure also fell in and was buried under the rubble".*
> There were three individuals inside the lamp room.

UCT (2021) explain that the investigation report showed rock engineers never viewed the crown pillar as a potential risk, from as far back as 2008. However, careful examination of the testimonies given during the inquest investigation reveal a more complicated setting. The inquest findings released at the end of 2023 included that:

> *"The deaths were brought about by the omission of the employer and/or mine owner and/or mine management to do a proper assessment as required by section 11 of the MHSA to determine the possible hazard the crown pillar might have posed to the structures and employees on top of the backfill and to assess the associated risks in connection therewith, thereby failing to put into place the necessary reasonable measures to mitigate the risk and/or to regularly and effectively monitor the risk in order to contain it."*

5.8.5.3 Evidence of deceit by responsible mining persons

The Rovic diamond mine disaster of 1996

Regarding mine plans and records of mining activities, Oosthuizen (2003) states:

> *"Evidence that was presented to the court showed that no proper or definite plans or records of mining activities were kept.*
> *It was clearly showed to the court that the plans of the mine were not up to standard and that Mister Olivier did not keep them in order."*
> *From day one, the plans of the mine had been neglected.*
> *The Court was convinced by a preponderance of probabilities that many of the plans of the mine were updated only after the disaster".*

Furthermore, the investigation found further evidence of deceit, i.e.:

> *"After 56 persons gave evidence and after much discussion on why the disaster happened so suddenly and at that time, it was revealed that a hole had been discovered in the pan area…*
> *The existence of the hole was initially concealed by Mister Smith, Mister Olivier, and Mister Exley as well as Mister van der Merwe at the preliminary mine inquest that was held at Kroonstad.*
> *Judge Dirk Kotze found that there was a definite conspiracy to mislead.*
> *The following reasons were given for this finding:*
> ** Firstly, there was no mention of it in the affidavit of Mister Olivier that was submitted at the preliminary mine investigation.*
> ** Secondly, nothing was said of it by Mister Smith, Mister Exley or Mister van der Merwe at the preliminary mine investigation.*
> ** Thirdly, Mister Olivier said nothing about it in his affidavit which was handed to the court by his advocate.*
> ** Fourthly, Mister Olivier did not say anything about it in his evidence-inchief.*
> ** Fifthly, Mister Smith remained silent about it in his evidence-in-chief*
> ** Sixthly, Mister Exley told the court that on their way to the previous trial, Mister Olivier had told him not to mention anything about any hole.*
> ** Seventhly, Mister Olivier had told Mister Exley on the night of 27 November 1996, just after the disaster, to keep quiet about the hole.*
> ** Eigthly, it is clear that after the disaster many discussions had taken place between Mister Olivier and others as stated by him.*
> ** Ninthly, Mister G. van der Merwe, in the words of Mister Olivier blackmailed the management to keep quiet, while he did as he wished [53].*

[53] Footnote in Oosthuizen (2003) cites Rovic Mine Disaster Investigation 1998:113-114.

5.8.6 Difficulty in objectively assessing the proportionality of consequence and 'penalty'

5.8.6.1 The Merriespruit disaster of 1994

Mail and Guardian (M&G) (1996) reports on the apportionment of fines arising from the Merriespruit slimes dam disaster. The disaster killed seventeen people, injured a further six hundred people, and caused R80-million in damage to property:

- Harmony Gold Mine: R120 000 (and it noted that the company's profits for the year 1995 were approximately R56-million after tax)
- Former Harmony manager Dan Jordaan: R15 000
- Harmony metallurgical engineer Johan Mouton: R8 000
- Harmony plant superintendent Wayne Hatton- Jones: R8 000
- Engineering company Fraser Alexander: R150 000
- Fraser Alexander regional manager Frikkie Botha: R30 000
- Fraser Alexander regional manager Theuns Linde: R25 000
- Foreman Adam Uys: R15 000
- Botha was fired after the disaster, while both Uys and Linde are still employed at Fraser Alexander.

The Mail and Guardian (M&G) (1996b) states that "*An expert in construction law, Philip Loots, expressed surprise that the people found guilty were not jailed*".

5.8.6.2 The Rovic diamond mine disaster of 1996

Traumatic death of personnel

Oosthuizen's (2003) description of facts includes salient details on the deaths of mine workers. The medical descriptions of the injuries and the traumatic causes of death of the personnel, contrast sharply with the inanimate nature of information normally reviewed when debating the attributes and influences of mining excavations.

The post-mortem examinations on the bodies of the 4 mine workers whose bodies had been retrieved from the mud, approximately 1,000 meters underground, were performed by Doctor Leon Wagner, a Forensic Pathologist. A brief summary of the major pathologic findings of Doctor Wagner are compiled in Table 5-6. The cause of death in all four cases was defined as traumatic asphyxia with the aspiration of mud [54].

[54] Footnote in Oosthuizen (2003) cites 'Report of Doctor Wagner'

Table 5-6: Information major pathologic findings of Doctor Wagner (compiled from Oosthuizen, 2003)

Case number 1	Case number 2	Case number 3	Case number 4
a) 32-year old well fed black man. b) Multiple fractures of the ribs with torn diaphragm. c) Traumatic lacerations of the lung tissue. d) Traumatic lacerations of the liver. e) Fracture - dislocation of the thoracic vertebral column. f) Trachea filled with mud. g) Esophagus filled with mud. h) Irreversible brain trauma. [54]	a) 30-year old well fed black man. b) Nose cavities occluded with mud. c) Mouth cavity filled with mud. d) Esophagus filled with mud. e) Trachea filled with mud. *f)* Congestion and oedema of the lungs. g) Presence of mud in the stomach. [54]	a) 30-year old well fed black man. b) Traumatic lacerations of the thoracic wall to the extent that the thoracic organs were displaced and the thoracic cavity filled with mud. c) The lungs were collapsed and covered with mud. d) A total traumatic avulsion was present of the abdominal aorta. e) Traumatic tears were present of the stomach and the intestines. f) Traumatic tears were also present of the pancreas and both kidneys. *g)* Fracture / dislocations of the lumbar vertebrae. h) Fracture of the left lower limb. [54]	a) 30-year old well fed black man. b) Trachea filled with mud. c) Aspiration of mud was demonstrated on the cut surface of the lungs. d) The stomach was filled with mud. e) Mud was present in the anal canal. f) The nose and mouth cavities were occluded with mud. [54]

Findings of the inquest investigation

Oosthuizen (2003) reports the outcomes of the inquest investigation:

The owner of the mine - Rovic (Pty) Ltd

The owner of the mine - Rovic (Pty) Ltd was:

> *" Fined with R300 000-00 (three hundred thousand rand) of which R100 000-00 (one hundred thousand rand) was suspended for a period of 4 (four) years on the condition that the accused must not be found guilty of:*
> *i. Culpable homicide resulting from mine activities; or on*
> *ii. Contravention of section 37(a) of the Minerals Act 50 of 1991; or on*
> *iii. Contravention of section 37(b) of the Minerals Act 50 of 1991 committed in the period of suspension".*

Managing agent of the mine - Metorex (Pty) Ltd

The Managing agent of the mine - Metorex (Pty) Ltd was:

> *"Fined with R150 000-00 (one hundred and fifty thousand rand) of which R50 000-00 (fifty thousand rand) was suspended for a period of 4 (four) years on the condition that the accused is not found guilty of:*
> *iv. Culpable homicide resulting from mine activities; or on v. Contravention of section 37(a) of the Minerals Act 50 of 1991; or on*
> *vi. Contravention of section 37(b) of the Minerals Act 50 of 1991 committed in the period of suspension".*

The mine manager

The mine manger:

- *"was negligent not to realise that people … were in danger.*
- *He was negligent when he did not prevent the miners from going underground on the night of 26 November 1996.*
- *He was also negligent in not stopping the miners going underground …. the morning of the 27 November 1996.*
- *Lastly, he was negligent not to inspect the surface and level 3 and also not to question the mine workers .*
- *[His] failure to act reasonably was the direct cause of the death of the deceased. A causal link was therefore established The requirements set for culpable homicide had been complied with.*[55] *"*

Furthermore, the mine manager was

> *"Fined with R30 000-00 (thirty thousand rand) of which R20 000-00 (twenty thousand rand) was suspended for a period of 2 (two) years on the condition that the accused is not found guilty of:*
>
> > *vii. Culpable homicide resulting from mine activities; or on*
> > *viii. Contravention of section 37(a) of the Minerals Act 50 of 1991; or on*
> > *ix. Contravention of section 37(b) of the Minerals Act 50 of 1991 committed in the period of suspension".*

[55] Footnote in Oosthuizen (2003) cites Rovic Mine Disaster Investigation 1998:210.

The mine captain

The mine captain had the same responsibility as the mine manager to care for the safety of the underground workers.

The judgement against the accused mine was still pending at the time of Oosthuizen (2003) but could not be found during the finalisation of the thesis in 2024.

5.8.6.3 The Lily mine disaster of 2006

In addition to the findings [that the employer and/or mine owner and/or mine management failed to do a proper assessment as required by section 11 of the MHSA], the Senior Magistrate reported that, in terms of the provisions of section 17 of the Inquest Act, the record of the inquest proceedings will be forwarded to the Director of Public Prosecutions to consider the possibility of instituting criminal proceedings.

5.8.6.4 The proportionality of consequence and 'penalty'

In each of the instances, the candidate formed their own opinion regarding the proportionality of consequence and 'penalty', but could not find a suitable means to describe that opinion without resorting to editorialization. Such editorialization could potentially undermine the objectivity of the thesis. Therefore, it is noted that

- The opinion itself is not presented but the difficulty of the task is acknowledged.
- Individual/ personal values and empathy influence the perceived proportionality of consequence and 'penalty'.

5.9 Concluding remarks for chapter 5

The research has demonstrated that there very many options and applications available to a mine with respect to their rock mechanics and geotechnical engineering function. These options and applications:

- May be used in whole, in part, not at all,
- May be implemented correctly by competent person/s (or inadvertently implemented poorly through lack of understanding, lack of training, lack of resources, etc),
- May be used for limited durations (or introduced permanently),
- May be used as-is, and/or
- May be modified (either in limited parts of the process or across the full range of the process).

It is therefore difficult to develop deep insights into the potential geotechnical environment if one is not the geotechnical engineer for that particular operation (as it is observed that this feature is exacerbated by the circumstance that the geotechnical information is seldom reported publicly, or reported at a very high level, or only reported to direct employees of that particular mining operation).

Mining companies do not all have the same access to capital and funding, to be able to endure the same extent of disruption or instability of the rock mass, or to be able to implement remediation and rehabilitation to the ground. Therefore, knowing the risk tolerance as well as understanding the reliability, robustness and resilience of the geotechnical design are key parts toward uninterrupted production.

Mining companies are expected to benefit from improved transparency in reporting of geotechnical performance, as the uncertainty of imminent failure is reduced, and simultaneously, understanding so systematic risk may be improved to allow for appropriate risk management strategies to be devised.

6 FINDINGS

6.1 Compilation of geotechnical information from hard rock mines

6.1.1 Intended compilation of geotechnical information from hard rock mines in South Africa

The research recognised that there is no comprehensive mining geotechnical database available to guide insight into the quantity, quality, type and spatial distribution of data which has supported mining operations to date, and subsequently set out to establish such a database.

The database would provide insights into the balance of quantity of data needed, and good judgement applied to designs. It would *not* be a prescriptive tool i.e. it would not dictate that *n* number of boreholes must be drilled on a grid of 20 m x 20 m to a depth of 333 m for platiniferous igneous deposits.

Conversely, it would provide information such as – *based on A' type of drilling, with B' mining method, the mine at Farm C' was able to reach steady state production using twenty-seven boreholes within 111 m of the portal, and weekly face mapping of 10m ^{2} per day.*

The research was optimistic – but not unfounded, as Fillion and Hadjigeorgiou (2016) had shown the implications of collecting additional data for slope design in an open pit operation, had quantified the impact of additional laboratory tests on the quality of a geomechanical model (2017) and quantified the influence of geotechnical borehole inclination on collecting joint orientation data (2018a).

However, despite the monolithic volume of publications sourced, no contiguous geotechnical data could be compiled for the mines identified in chapter 9, Table 9-25.

The data sought was conceptualised as follows:

1) Date (year), location (co-ordinates) and purpose of geological drilling programme
2) Date (year), location (co-ordinates) and purpose of geotechnical drilling programme
3) Length of core logged, and log sheets showing the field measurements
4) Area of face mapped, and log sheets showing the field measurements
5) Date (year), type and results of laboratory testing
6) Date (year), location (co-ordinates) and purpose of photogrammetric collection exercises
7) Date (year), location (co-ordinates) and purpose of LiDaR collection exercises
8) Pit shell (for open pit) showing sub-division of domains or mine plan (for underground) showing shafts, vent columns, levels, sub-levels etc.

9) Slope angles, stack angles and bench geometry for each successive cut back, for each domain
10) Ground support design (including types of bolts, spacing, pattern etc).
11) Groundwater de-watering values (historical showing date, volume and location of pump stations)
12) Rock mass parameters for each geotechnical unit during Year (Y)1, Y2, Y3 etc.
13) Hazard register and risk register
14) Register of rockfall and rock burst, including description, date, co-ordinates, volume of material

6.1.2 Results of compilation

The compilation of an extensive geotechnical database was not possible because it is not supported by the public disclosure of historical information by mining companies.

There was insufficient information to allow the formulation of a factual comment regarding the extent and significance of differences perceived between open pit and underground hard rock mining operations in South Africa, with regard to collection, organisation and availability of data.

Efforts to secure information privately were also unsuccessful (i.e. the requests were not rejected by mining companies, rather, they were delayed to such an extent that their inclusion in the thesis was not possible due to the timeline for submission of the thesis for examination).

The candidate asserts that a ‘negative finding’ in research, still constitutes a valuable finding.

6.2 Risk understanding appears somewhat haphazard

Sometimes, geotechnical risk appears to be referred to and applied in a haphazard way. The definitions of true risk sciences differ from those adopting in mining engineering. However, by adopting the formal elements of the true risk sciences into mining engineering, the benefit of improved alignment with shareholders and well as decision-making processes may be realised.

6.3 SAMREC and its Table 1

the SAMREC Code is focused toward the classification and reporting of Mineral Resources and Mineral Reserves. As such, it is the requirements regarding the assessment and reporting of rock engineering, geomechanics and geotechnical engineering are discordant within the SAMREC, when compared with the detail and rigour applied to Mineral Resources and Mineral Reserves.

6.4 The rock-related DMRE Mandatory Codes of Practice

The rock-related DMRE Mandatory Codes of Practice have not been gazetted. Additionally, legal precedent has been established in International Ferro Metals (SA) (Proprietary) Limited v Minister of Mineral Resources and Others (J1673/13) [2015] ZALCJHB 9 (21 January 2015), where the Department of Mineral Resources, Mine Health and Safety Inspectorate's "*Enforcement Guideline*" was ruled unlawful and set aside (§[34]a) and the Respondents (i.e. the DMRE and others) were (§[34]a) "*interdicted from relying on the Guideline in the enforcement of the provisions of the MHSA*". The "*Enforcement Guideline*" had also not been gazetted.

Therefore, as a result of the failure to issue guidelines by notice in the Gazette, as well as legal precedent, the specific items intended toward the prevention of rock-related accidents circulated by the Department of Minerals and Energy, are potentially invalid under the Mine Health and Safety Act 29 of 1996 (as amended).

The relevance of this is that tools with which mining companies aim to establish and manage their safety performance are not in place, and therefore, there may be a gap in the effective control of mine safety, related to rock-fall incidents.

6.5 Government Certificate of Competency and the National Certificate: Strata Control Operations

The National Certificate: Strata Control Operations is not identified in the Mine Health and Safety Act, 1996 as providing competency.

Similarly, it is not reflected as an approved programme by the Mining Qualifications Authority.

No bespoke document could be identified allowing exemption against having to meet the requirements set out by the MQA and SAQA.

As such, the certificate does not appear to meet the requirements to confer competency.

6.6 Organisations for the training and examination of selected certificates viz. SANIRE

No documentation could be secured to confirm that the South African National Institute of Rock Engineering (SANIRE) is accredited with MQA, or that is registered as an assessor, per SAQA requirements.

No bespoke document could be identified allowing exemption against having to meet the requirements set out by the MQA and SAQA.

As such, the activities carried out by SANIRE to train and assess (through examinations) different certificates does not appear to meet the requirements for approved training providers and/or assessors.

It is unclear if, and how, the status of the certificate is subsequently affected.

6.7 Mines rescue services

There appears to be only one provider of mines rescue services in South Africa, i.e. the Mines Rescue Services (Pty) Ltd (i.e. MRS), with separate locations in Carltonville, Evander, Steelpoort, and Welkom.

The South African Qualifications Authority (SAQA) (2024) shows the learning requirements of the Occupational Certificate: Emergency Service and Rescue Official.

No documentation could be secured to confirm that the MRS is accredited with MQA, or that is registered as an assessor, per SAQA requirements.
No bespoke document could be identified allowing exemption against having to meet the requirements set out by the MQA and SAQA.
As such, the activities carried out by the MRS to train and assess (through examinations) different certificates does not appear to meet the requirements for approved training providers and/or assessors.
It is unclear if, and how, the status of the certificate is subsequently affected.

The arrangement and maintenance of a “licensing” system could not be found, despite an extensive search.

6.8 SAMRASS

The structure of the SAMRASS reporting system does not lend itself to being able to identify specific areas of shortcoming, for the purpose of formulating directed and appropriate research.

The available information on accident reporting seems to suggest that falls of ground are predominantly either

a) A result of phenomenal coincidence in terms of rock mass behaviour, or
b) The result of behavioural errors by personnel.

Subsequently, the review considers overt acts of commission or omission, seemingly without room for clarification e.g. perhaps support was being installed, but not completed quickly enough due to unrelated disruption to the work crew, or that a relevant procedure was “communicated” to personnel, but the communication process did not adequately determine that training was properly understood (e.g. as an unconscious incompetence).

Lastly, the SAMRASS forms for all operations are administered and collected by the DMRE, therefore, accessing the information has substantial logistical challenges. An alternative is for mines to conduct their own research based on their own safety incidents – but there may be a potential 'perceptual blindness' present which may hamper objective research.

6.9 Reporting in South African mining

6.9.1 Opportunity to improve reporting of competency at the National level

The current annual reporting by the DMRE includes the number of applicants writing examinations, and the number of applicants passing examinations for their respective Government Certificates of Competency in *related* mining functions (e.g. blasting).

The number of applicants writing examinations, and the number of applicants passing examinations for their respective Government Certificates of Competency in rock-related mining functions (e.g. rock mechanics) is not reported.

The opportunity to improve the perception our nation's rock-related competency and related capacity exists toward the eventual goal of skills retention and professional development in the long term.

6.9.2 Opportunity to improve reporting of mine rescue services at the National level

Although the statutory framework requires contracting with a mine rescue services provider, the number of of applicants writing examinations, and the number of applicants passing examinations for their respective Certificate of Competency mine rescue activities is not reported.

The opportunity to improve the perception our nation's competency in mine rescue and mine emergency response exists.
Additionally, the opportunity to improve our nations understanding of the capacity of the services exists, toward the eventual goal of skills retention and professional development in the long term.

This also has relevance to intended mitigation measures for various rock-related risks viz. emergency response and rescue.

6.9.3 Opportunity to improve reporting of geotechnical aspects at the operational level

The South African context has particular relevance to the proposition for the voluntary disclosure of relevant technical data and performance. This is attributed to various aspects such as:

- Mining is a primary industry (therefore various types of data are not proprietary as they originate from the earth itself);
- Some data is amenable to sharing, others are not;
- The Constitution of the Republic of South Africa, 1996 – that creates a right to protection of the natural environment and a safe environment for persons in the Republic;
- The MPRDA, 2002 – that confirms that the nation's mineral wealth belongs to the people of South Africa;
- The Geoscience Act, 1993 - that confirms ownership of selected earth-science data is not the confidential asset of the mining operation; and
- The Mine Health and Safety Act, 1996 – that creates an obligation for employers and mine owners to ensure safe working conditions.

6.9.3.1 Basis for integration

Mining companies in South Africa are already required to report extensively on various issues – including Mineral Resource and Mineral Reserve, production, environmental and social governance, and financial performance.

It is intended that transparent reporting of geotechnical mining aspects can be achieved without creating additional burden. The reason being is that the mines already have the information at their disposal – it does not require specialised preparation.

The proposition for voluntary disclosure, and the reporting framework that outlines it, aims to facilitate access to technical information[56] in such a way that does not compromise the mining operation.

6.9.3.2 Existing elements amenable to adaptation

The following existing elements amenable to adaptation:

- The **Geoscience Act, 1993** guides the identification of data eligible for sharing.

[56] Relevant technical data and performance relating to rock engineering, geomechanics, and geotechnical engineering aspects

- The **Global Industry Standard on tailings Management (GISTM)** demonstrates equivalent principles and requirements for ensuring ongoing engineering integrity of a built feature,
- The **Eurocode 7** for the format of reports and their relationships to each other,
- The drive for **frequent, independent, expert review** is taken from the Bingham Canyon lessons learnt (Ross, 2017),
- The **SAMREC Table 1** informs the topics of reporting to be extrapolated for rock-related counterparts, and
- Annual company integrated reporting provides the platform and portal.

It is emphasised that the purpose of the reporting framework is to create value and facilitate risk management by understanding the performance [of the rock mass and the rock engineering design] to mining as it devleopes over time.
The objective is not to establish long term plans and goals for new things to come – rather, it looks back and says '*what did the design and model estimate would happen, and what did actually happen*' in terms of rock-related aspects.

It is proposed the uptake of the reporting framework be carried out over a transitionary period of approximately 3-5 years, before being adopted formally – if suitable.

6.10 Value creation

It is envisioned that the value creation will be facilitated through:

- Advancement of risk management using societal[57] amplification – as illustrated in Figure 6-1. During social amplification, Renn (1992) describes that:
    - *Signals from physical events are transformed into communication signals and forwarded to amplification stations. These stations process the information and respond to the messages by sending out new information or acting upon the content of the received message.*
    - *Individuals may form or change their opinions on an issue or demand changes with regard to risk management practices.*
    - *Stations may use the incoming information to promote structural and institutional innovations that would help to cope with the respective hazard.*
    - *All these societal actions trigger secondary and tertiary impacts (e.g. institutional changes)*
    - *Finally, the amplification process evokes new societal and technological changes, which in turn start a new cycle of amplification.*
- In the current context 'societal' is intended to refer to the professional community and collective, more so that the lay person.
- The improved communication of risk, via guided interactions through the three levels of conflict in risk debates[58] toward rationalised discourse - as illustrated in Figure 6-2.
- the implication of performability, as illustrated in Figure 6-3. Performance engineering is intended to allow for dependability as well as sustainability and its related factors (e.g. safety, survivability, quality, reliability, and maintainability).

The demonstration of value creation will be achieved through:

- Reputable reporting of the nation's mining skill, competence, and capacity, at an appropriately granular level of detail,
- Demonstration of the alignment and integration of statutory elements for maximum benefit, as well as
- The transparent reporting of evidenced performance of the mining excavations in relation to the data quality and quantity available.

[57] Renn (1992) uses the phrase 'social' amplification. The candidate has modified the phrase to 'societal' amplification to express the involvement of learned bodies, interested agencies etc., more so than the lay person of an unrelated community

[58] Renn (1992) explains that:
On the first level, debates focus on technical issues such as engineered safety or probability estimates.
The second levels refers to institutional performance, with focus on the ability of the risk management roles to monitor and control risks effectively.
The third level places the risk issue in a larger context of world views.

Then from these cumulatively, mining operations will be able to participate in many value creation cycles – as illustrated in Figure 6-4.

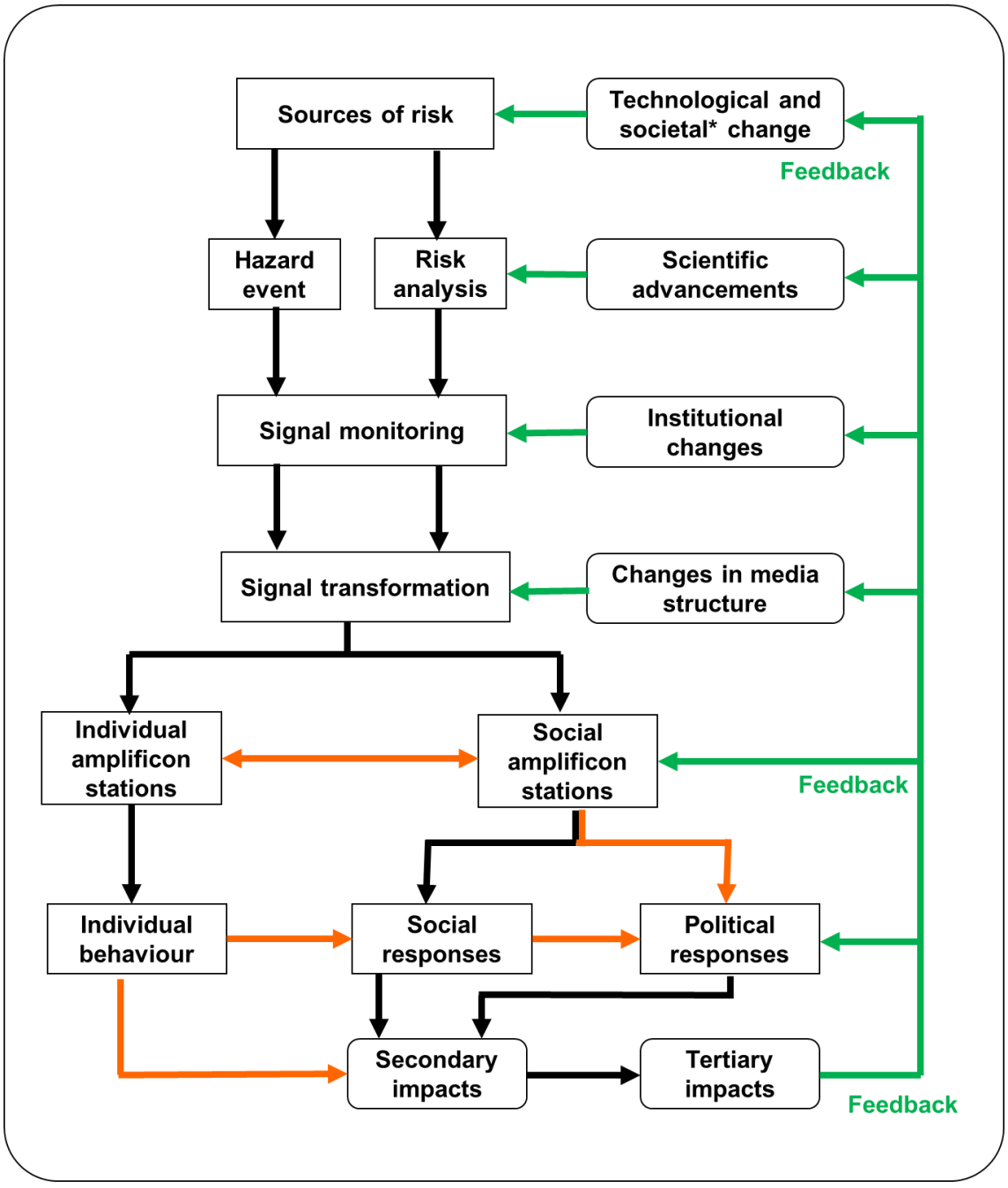


Figure 6-1: Risk communication in the concept of societal amplification (adapted from Renn, 1992)

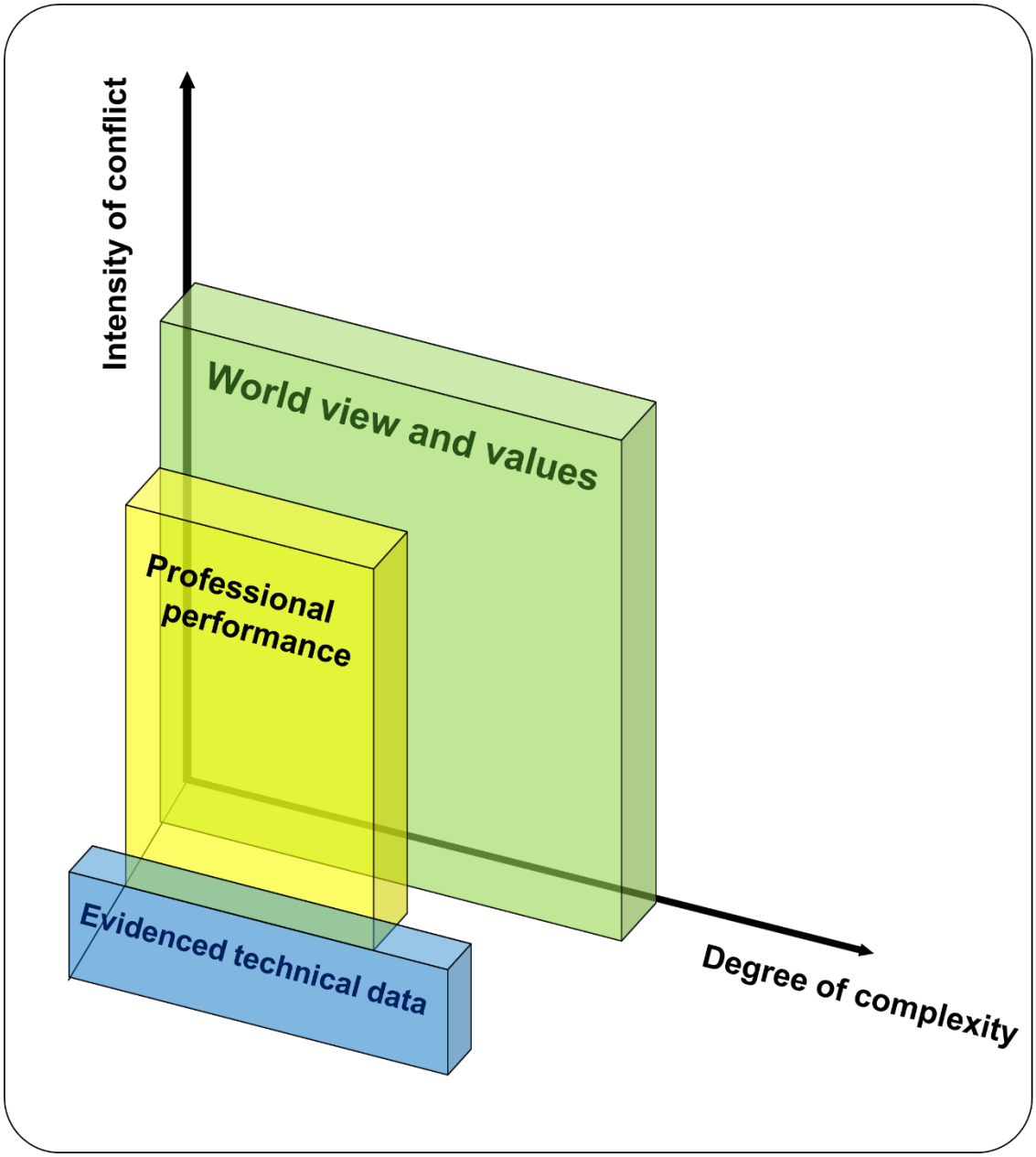


Figure 6-2: The three levels of conflict in risk debates (Renn, 1992)

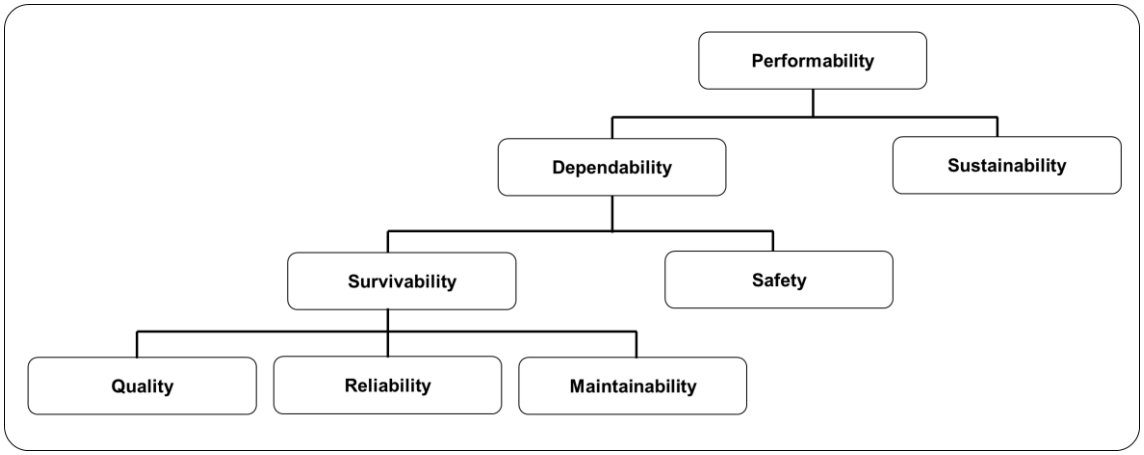


Figure 6-3: Implication of performability (Misra, 2008)

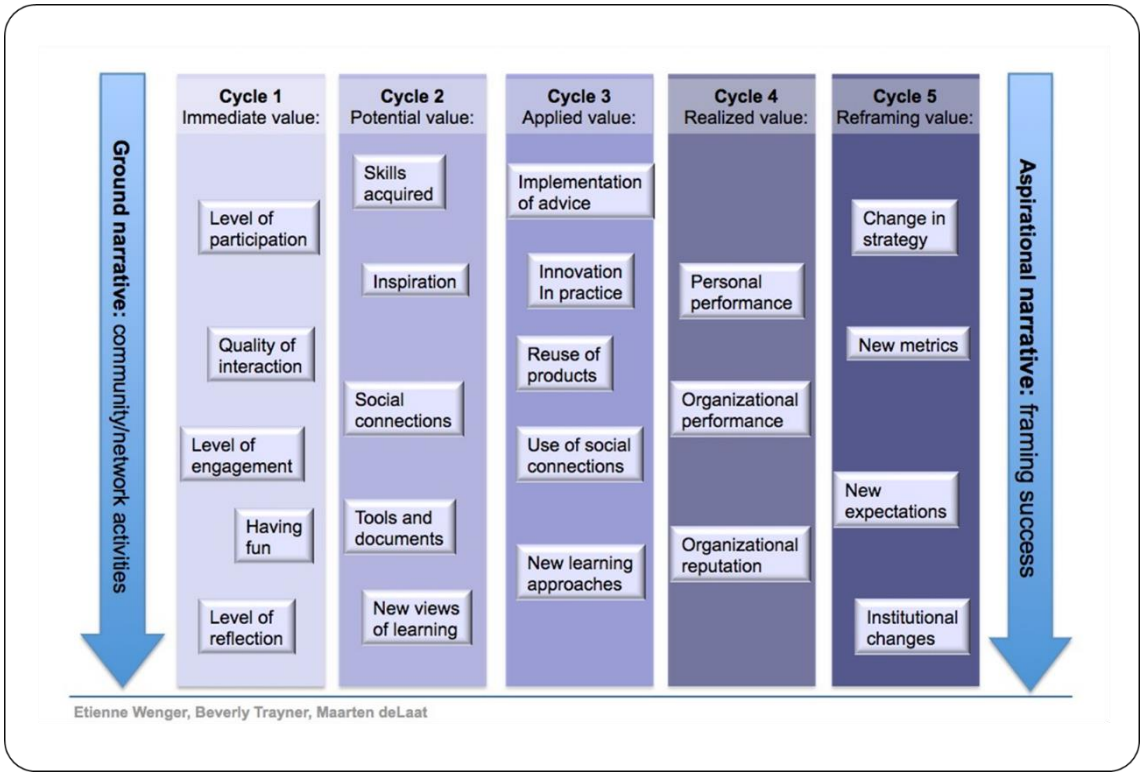


Figure 6-4: Examples of indicators within value creation cycles (Mackness, 2012)

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The research carried out for the study differs somewhat to the approach that has become more popular in recent years.

The research does not make use of an individual case study at a mine, under sponsorship of the owner of the mine, to demonstrate the application of a computational software toward the intended design of a mining excavation.

In contrast, the study undertook to evaluate various assets, concepts, trends, tools, and those paradigms dependant on rock engineering, geomechanics, geotechnical engineering within the subject of mining engineering.

The study was an ambitious undertaking and not all of the objectives could be achieved – due to insufficient access to specific types of geotechnical data. However, several definite contributions to knowledge have been demonstrated.

The candidate considers it unlikely that an advancement in understanding so profound and universally applicable will be realised in the near future, as to resolve all matters of geotechnical engineering objectivity, uncertainty and variability. Therefore, we continue to apply ourselves to managing and mastering incremental element. The proposed voluntary disclosure represents one such increment in the interpretive breakthrough.

The proposition is not motivated from a point of moral ideology, but rather as a national imperative.

It is envisioned that:

- The ongoing competency and future capacity of rock engineering professionals;
- The improved granularity in technical reporting to improve investor perception and confidence;
- The more cohesive, evidenced record of mining geotechnical features and performance;
- The improved risk management and holistic, informed decision-making across all stages of strategic, operational, and tactical functioning

will be to the benefit of all stakeholders.

Progression of debate has shown that empirical knowledge is subjective and therefore not entirely reliable. As much as the preoccupation with ‘disruptive technologies’ and mechanisation exist, empirical methods are still heavily relied on in hard-rock mining.

Failure of rock is likely to involve several different mechanisms, however traditional methods often

- Focus on a single method only;
- Do not purposely consider the role of scale-effect;
- Do not purposely consider the effects of time; and
- Focus very much on the characterisation of in situ rock, with lesser attention to the rock mass as it is affected by mining.

The physics that underpin rock engineering are sufficiently understood (e.g. the behaviour of solids, the mechanism of kinematics etc.) and it does not seem to be these aspects that create phenomenal circumstances in mining. Rather, it is our ***application*** of understanding that appears to be tentative. Therefore, the candidate motivates for the voluntary disclosure of data – within context, reason, and limitation – as well as the reporting of design specifications and their performance achieved in reality.

Through these, the conclusions of the research are:

1) The compilation of an extensive geotechnical database was not possible because it is not supported by the disclosure of historical information by mining companies in South Africa.
2) The use of prescriptive frameworks on the quality and quantity of data needed to satisfy studies over the life of the mine is impractical given the amount of variables to be considered.
3) The complexity of the statutory framework has resulted in the recognition that some of the items intended toward ensuring safety in mining do not meet the necessary criteria for their intended function.
4) Capitalisation and funding differs between companies - therefore creating different risk management environments that are not all equal.
5) The risk assessment and management paradigms of mining companies in South Africa are not known in any meaningful amount of detail.
6) It is perceived that failure of the geotechnical design is possible through the accumulation of incremental and unfavourable elements. It is also perceived that a global failure is not the only means to realising a state of force majeure.
7) There is an express need for improved information management systems by research organisations serving the South African mining industry.

7.2 Recommendations

Pertinent recommendations for the next steps and for further research are formulated hereunder.

It is acknowledged that mining companies in South Africa are already required to report extensively on various issues – including Mineral Resource and Mineral Reserve, production, environmental and social governance, and financial performance.

It is intended that transparent reporting of geotechnical mining aspects can be achieved without creating additional burden.

1) The reporting framework devised during the research should be presented to the mining fraternity, through a presentation to the Southern African Institute for Mining and Metallurgy as well as the Council for Geoscience.

   An initial schema should be composed for those organisations willing to participate in a trial thereof. The initial schema should be run for approximately 3 years, with evaluation carried out in a public platform each year. Refinements to the schema should be implemented during years 4 and 5, such that after year 5 – the type, format, layout, presentation, and dissemination of data should be sufficiently established.

2) The Guidelines for the preparation of Mandatory Codes of Practice relating to rock-related accidents:
   a) Should be revised, through collaborative consultation and tripartite participation, to reflect the advances in the industry over the last ten or so years and to provide a more appropriate reporting structure, then
   b) The Guidelines should be gazetted.

   In this regard, a draft proposal has been initiated for submission to the Minister of the Department of Minerals and Energy and/or the Chief Inspector of Mines, as appropriate. The proposal intends to make provision for limited involvement of fourth year mining engineering students from Wits University to facilitate an introduction and exposure to industry activity.

3) Plans for engagements with relevant representatives of the DMRE and the Department of Statistics South Africa have been initiated. The engagements serve to explore the ideology and methodology regarding the reporting of fatalities in the mining industry. It is emphasised that the matter must be

addressed with due tact and delicacy, given that perceived changes to the reporting may unsettle users of the information.

4) Plans for engagements with relevant representatives of the research organisations serving the South African mining industry (MHSC, SIMRAC, CSIR, Minerals Council etc) are being formulated. The engagements serve to identify if any plans are in place toward the implementation of an improved information management systems to facilitate improved knowledge transfer to a larger base of recipients.

5) Similarly, the engagements intend to make provision for limited involvement of fourth year mining engineering students from Wits University to facilitate an introduction and exposure to industry activity.

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9 ANNEXURES

9.1 Annexure A: Sources of Data

Annexure A-1: Themes, topics and disciplines investigated during research

Table 9-1: Overview of themes, topics, and disciplines investigated (grouped broadly, and then listed alphabetically, for ease of context)

Relating to the field	Relating to the lab	Relating to instability	Relating to emergency	Relating to spatial
characteristics, description, field tests, heterogenous, homogenous, igneous, metamorphic, observation, rocks, sedimentary, soil, strength	brittle, ductile, heterogenous, homogenous, rocks, soil, specimen, test	design, dynamic, failure, break, envelope, failure, fall of ground, fracture, instability, latent residual, monitor, optimise, rehabilitate, remediate, rockburst, rockfall, seismic, slip, slough, stability, time-dependent	emergency, evacuate, trigger, controlled, monitoring, warning system	GIS (Geographic Information System), transform
Relating to data handling	**Relating to computation**	**Relating to change**	**Relating to technology**	**Relating to paradigm**
database, estimate, order of magnitude, confidence interval, metrology, population [data], regression, sampling, statistics, variability	back-analysis, big data', empirical, analytical , discretisation, experimental, modelling, numerical, probability, software	adaptation, evolution, improvement, innovation, progression	4IR, algorithm, augmented, automated, autonomous, digital, digital twin, innovation, machine learning, photogrammetric, real-time, relay, remote, simulated, virtual	benchmark, best practice, compliance, conformance, guideline, index / indices, mandatory, must vs ought (legal), phenomenon, prescribed, suggested
Relating to 'less than ideal'	**Relating to risk aspects**	**Relating to communication**	**Relating to flexibility**	**Relating to opinions**
context, error, flaw, judgement, mis-calculation, mistake, over/under estimation, rules of thumb, use, misuse and abuse	ambiguity, assessment, bayes, consequence, context, hazard, Monte Carlo, policy, probability, tolerance, uncertainty	context, exclusions, extrapolate, imply, indicate, infer, limitations, state, warrantees	co-dependent, dependent, inter-dependent, optionality, reliability, robustness, validate, verify	competent person, context, discourse, expert, informed, judgement, perception, policy, relevance

Annexure A-2: Journals

Table 9-2: Journal publications identified and used (listed alphabetically, for ease of continuity)

Journal	Journal (continued)
ACRN Oxford Journal of Finance and Risk Perspectives	International Journal of Physical Modelling in Geotechnics
Acta Geotechnica	International Journal of Risk Assessment and Management
African Journal Archive	International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts
African mining monitor	International Journal of Surface Mining Reclamation and Environment
Analytical and Numerical Methods in Mining Engineering	International Journal of the JCRM (Japanese Committee for Rock Mechanics)
Applied Earth Science	International society for rock mechanics (ISRM)
ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering	Jamba: Journal of Disaster Risk Studies
Australia mining report	Journal of ASTM International (JAI) (American Society for Testing and Materials, ASTM)
Australian Geomechanics Journal	Journal of Environmental Hydrology
Australian Institutions of Mining and Metallurgy	Journal of Geo-engineering Sciences
Benchmarking: An International Journal	Journal of Geotechnical and Geoenvironmental Engineering (American Society of Civil Engineers)
Big Data Mining and Analytics	Journal of Geotechnical Engineering
Bulletin of Engineering Geology and the Environment - The official journal of the IAEG	Journal of Governance Risk Management Compliance and Sustainability
Canada mining report	Journal of Hydrogeology and Hydrologic Engineering
Canadian Geotechnical Journal	Journal of Hydrologic Engineering
Canadian Geotechnical Society Rock Mechanics Division (RMD)	Journal of Hydrology
Canadian Institute of Mining	Journal of Integrated Disaster Risk Management
Canadian Journal of Earth Sciences	Journal of International Crisis and Risk Communication Research
Canadian Mining Journal	Journal of Mining and Environment
Computers and Geotechnics	Journal of Mining and Metallurgy. Section A: Mining
Data Mining and Knowledge Discovery	Journal of Mining and Metallurgy. Section B: Metallurgy
Electronic Journal of Geotechnical Engineering	Journal of Mining and Strata Control Engineering
Electronic Transactions on Numerical Analysis	Journal of Mining Institute
Engineering Geology	Journal of Mining Science
Environmental Geotechnics	Journal of Mining Science and Technology
Environmental Geotechnics	Journal of Operational Risk
ESAIM: Mathematical Modelling and Numerical Analysis	Journal of Risk
Explosives Engineering - official Journal of the Institute of Explosives Engineers	Journal of Risk Analysis and Crisis Response (JRACR)
Geodinamica Acta	Journal of Risk and Financial Management
GeoHazards	Journal of Risk and Insurance

Journal	Journal (continued)
Geological Abstracts	Journal of Risk and Uncertainty
Geological Field Trips and Maps	Journal of Risk Model Validation
Geological Journal	Journal of Risk Research
Geology Today	Journal of Rock Mechanics and Geotechnical Engineering
Geomatics, Natural Hazards and Risk	Journal of Sustainable Mining
Geomechanics and Tunnelling	Journal of the Chemical, Metallurgical and Mining Society of South Africa
Geophysical Journal International	Journal of the Southern African Institute of Mining and Metallurgy
Geophysical Prospecting	Law, Probability and Risk
Georisk	Materials Performance and Characterisation (MPC) (American Society for Testing and Materials, ASTM)
Georisk-Assessment and Management of Risk for Engineered Systems and Geohazards	Metals and mining in South Africa
Geoscience Data Journal	Mineral Processing and Extractive Metallurgy: Transactions of the Institute of Mining and Metallurgy
Geostandards and Geoanalytical Research	Mining
Geotechnical and Geological Engineering	Mining engineering
Geotechnical Engineering	Mining Informational and Analytical Bulletin
Geotechnical Research	Mining Machines
Geotechnical Testing Journal (GTJ) (American Society for Testing and Materials, ASTM)	Mining of Mineral Deposits
Geotechnical, Geological and Earthquake Engineering	Mining Quarterly
Geotechnics	Mining Science
Geotechnik	Mining Technology: Transactions of the Institute of Mining and Metallurgy
Geotechnique	Mining, Metallurgy and Exploration
Geotectonics	Mining, metallurgy and exploration
Global metals and mining	Natural Hazards and Earth System Sciences
Groundwater	Probability theory and related fields
GSA Field Guides	Probability, Uncertainty and Quantitative Risk
Handbook of Numerical Analysis	Proceedings of the Institution of Civil Engineers: Geotechnical Engineering
Hydrogeology Journal	Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability
Hydrological Sciences Journal	Quarterly Journal of Engineering Geology and Hydrogeology
Hydrology: Current Research	Risk Analysis
IMA Journal of Numerical Analysis	Risk and Decision Analysis
Innovative Infrastructure Solutions	Risk in Contemporary Economy
Inside Mining	Risk Management
Institution of Mining and Metallurgy. Transactions. Section B: Applied earth sciences	Risks
Interdisciplinary Science Reviews	Rock and Soil Mechanics
International Journal for Numerical and Analytical Methods in Geomechanics	Rock Mechanics and Rock Engineering
International Journal for Numerical Methods in Engineering	Rocks and Minerals

Journal	Journal (continued)
International Journal of Business Continuity and Risk Management	Scientific bulletin. Series D, Mining, mineral processing, non-ferrous metallurgy, geology and environmental engineering
International Journal of Disaster Risk Reduction	Scientific Mining Journal
International Journal of Disaster Risk Science	Soils and Rocks
International Journal of Geoengineering Case Histories by the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE)	South African Institution of Civil Engineering
International Journal of Geotechnical Engineering	Statistical Theory and Related Fields
International Journal of Hydrology Science and Technology	Statistics and Risk Modelling
International Journal of Mining and Geo-Engineering	Stochastic Environmental Research and Risk Assessment
International Journal of Mining and Mineral Engineering	Topics in Mining, Metallurgy and Materials Engineering
International Journal of Mining Science and Technology	Topics in Safety, Risk, Reliability and Quality
International Journal of Mining, Reclamation and Environment	Transactions of the Institution of Mining and Metallurgy. Section A, Mining technology
International Journal of Numerical Analysis and Modelling	Tunnelling Journal
International Journal of Numerical Modelling: Electronic Networks, Devices and Fields	Water SA
	World of Mining - Surface and Underground

Annexure A-3: Conferences and Symposia

Table 9-3: Sample of conferences and conference proceedings used (listed chronology for ease of continuity)

Year	Name
1972	Applications for Computers and Operations Research in the Minerals Industries (APCOM) '72
1973	1st International Kimberlite Conference
1977	2nd International Kimberlite Conference
1982	1st International Mine Water Association Congress (IMWA) 1982, Budapest, Hungary
1982	3rd International Kimberlite Conference
1985	2nd International Mine Water Association Congress (IMWA), 1985, Granada, Spain
1986	4th International Kimberlite Conference
1987	Applications for Computers and Operations Research in the Minerals Industries (APCOM) '87: Mining
1987	Twentieth International Symposium on the Application of Computers and Mathematics in the Mineral Industries
1988	3rd International Mine Water Association Congress (IMWA), 1988, Melbourne, Australia.
1988	Colloquium: Management Techniques in the Mining and Metallurgical Industry
1991	4th International Mine Water Association Congress (IMWA), 1991, Slovenia
1991	5th International Kimberlite Conference
1991	7th International Congress on Rock Mechanics
1993	Human Productivity (1993): SAIMM Colloquium - Improving the Productivity of Human Resources
1994	5th International Mine Water Association Congress (IMWA), 1994, Nottingham, United Kingdom.
1994	International Association of Engineering Geology (IAEG) Congress
1995	6th International Kimberlite Conference
1996	Surface Mining 1996
1997	6th International Mine Water Association Congress (IMWA), 1997, Bled, Slovenia.
1998	International Association of Engineering Geology (IAEG) Congress
1999	Pan American Conference on Soil Mechanics and Geotechnical Engineering
2000	7th International Mine Water Association Congress (IMWA), 2000, Katowice, Poland.
2000	An International Conference on Geotechnical and Geological Engineering (GeoEng 2000)
2000	MassMin 2000
2000	South African Young Geotechnical Engineers Conference. "Geotechnics - Into Africa"
2002	International Association of Engineering Geology (IAEG) Congress
2003	10th Congress Of The International Society For Rock Mechanics : Technology roadmap for rock mechanics
2003	5th Large Open Pit Mining Conference
2003	8th International Kimberlite Conference
2003	8th International Mine Water Association Congress (IMWA), 2003, Johannesburg, South Africa.
2003	Applications for Computers and Operations Research in the Minerals Industries (APCOM) 2003: Danie Krige publications
2003	ISRM 2003: Technology roadmap for future
2003	Mine Closure (2003)
2004	Contributions of Rock Mechanics to the New Century; 3rd ARMS (Asian Rock Mechanics Symposium) 2004; The 2004 ISRM International Symposium

Year	Name
2005	9th International Mine Water Association Congress (IMWA), 2005, Oviedo, Spain.
2005	Base Metals Conference 2005 - Kitwe
2005	Impact of the Human Activity on the Geological Environment; EUROCK 2005; the 2005 ISRM International Symposium
2005	Rock Mechanics for Underground Environment; an ISRM Regional Symposium
2005	Sixth International Symposium on Rockburst and Seismicity in Mining
2005	Third South African Rock Engineering Symposium: 'Best practices in Rock Engineering'
2006	59th Canadian Geotechnical Conference and 7th Joint Canadian Geotechnical Society (CGS) /Canadian National Chapter of the International Association of Hydrogeologists (IAH-CNC) Groundwater Speciality Conference
2006	EUROCK 06 - Multiphysics Coupling and Long Term Behaviour in Rock Mechanics
2006	Geotechnique: Sea to Sky
2006	International Association of Engineering Geology (IAEG) Congress
2006	ISRM International Symposium on *In situ* Rock Stress
2006	The Southern African Institute of Mining and Metallurgy International Symposium on stability of rock slopes in open pit mining and civil engineering situations
2006	Platinum 2006: Second International Platinum Conference
2006	Rise of the Machines - The "State of the Art" in mining mechanisation, automation hydraulic transportation and communications
2006	Rock Mechanics in Underground Construction, the 4th ARMS (Asian Rock Mechanics Symposium), and the 2006 ISRM International Symposium
2006	South African National Institute of Rock Engineering (SANIRE) 2006: Facing the Challenges
2007	4th International Conference on Deep Mining 2007
2007	Base Metals Conference 2007 - Swakopmund
2007	International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering
2007	ISRM 11th International Congress on Rock Mechanics
2008	10th International Mine Water Association Congress (IMWA), 2008, Carlsbad, Czech Republic.
2008	12th International Association for Computer Methods and Advances in Geomechanics conference (IACMAG)
2008	1st South American Symposium on Rock Excavations, an ISRM- Regional Symposium
2008	1st Southern Hemisphere International Rock Mechanics Symposium (SHIRMS 2008), an ISRM- Regional Symposium
2008	42nd U.S. Rock Mechanics Symposium and 2nd U.S.-Canada Rock Mechanics Symposium
2008	5th Asian Rock Mechanics Symposium (ARMS 2008), the 2008 ISRM- International Symposium
2008	6th International Symposium on Ground Support in Mining and Civil Engineering Construction, an ISRM- Regional Symposium
2008	9th International Kimberlite Conference
2008	Ground Support 2008
2008	International Symposium on Conservation of Ancient Sites 2008, an ISRM- Regional Symposium
2008	Narrow Vein 2008
2008	PbZn2008: Lead-Zinc 2008
2008	Platinum 2008: Third International Platinum Conference
2008	Surface Mining 2008
2009	3rd Canada-US Rock Mechanics Symposium and 20th Canadian Rock Mechanics Symposium
2009	Base Metals Conference 2009 - Kasane
2009	EUROCK 2009 - Rock Engineering in Difficult Ground Conditions - Soft Rocks and Karst, an ISRM- Regional Symposium

Year	Name
2009	First International Seminar on Safe and Rapid Development Mining
2009	SAIMM Hard Rock Safety Conference 2009: A Sense of Safety Urgency
2009	Heavy Minerals Conference 2009
2009	Mintek 75 (2009)
2009	Shaft Sinking 2009
2009	Shotcrete 2009
2009	SINOROCK 2009, the 2009 ISRM- International Symposium on Rock Characterisation, Modelling, and Engineering Design Methods
2009	Third International Symposium on Rock Slope Stability (Slope Stability 2009)
2009	World Gold 2009
2010	3rd International Workshop on Rock Mechanics and Geo-Engineering in Volcanic Environments, an ISRM- Specialised Meeting
2010	5th International Conference on Deep Mining 2010
2010	5th International Symposium on *In situ* Rock Stress, an ISRM-Specialised Conference
2010	6th Asian Rock Mechanics Symposium - Advances in Rock Engineering, the 2010 ISRM-International Symposium
2010	Diamonds: Source to Use 2010
2010	Drilling and Blasting 2010
2010	EUROCK 2010 - Rock Mechanics in Civil and Environmental Engineering, an ISRM-Regional Symposium
2010	IAEG Congress 2010: Geologically Active
2010	Platinum 2010: Fourth International Platinum Conference
2011	11th International Mine Water Association Congress (IMWA), 2011, Aachen, Germany.
2011	2nd ISRM International Young Scholars' Symposium on Rock Mechanics
2011	Base Metals Conference 2011 - Phalaborwa
2011	Fourth International Seminar of Strategic vs Tactical Approaches in Mining
2011	International Symposium on Rock Slope Stability in Open Pit Mining and Civil Engineering
2011	ISRM 12th International Congress on Rock Mechanics
2012	10th International Kimberlite Conference
2012	6th International Conference on Deep Mining 2012
2012	ARMS 7 - ISRM Asian Regional Symposium - 7th Asian Rock Mechanics Symposium
2012	EUROCK 2012, the 2012 ISRM International Symposium - Rock Engineering and Technology for Sustainable Underground Construction
2012	Fourth International Conference on Site Characterisation (ISC'4)
2012	ISRM Regional Symposium - II South American Symposium on Rock Excavations
2012	Platinum 2012: Fifth International Platinum Conference
2012	Second Southern Hemisphere International Rock Mechanics Symposium
2013	5th International Seminar on Strategic versus Tactical: Approaches to global competitiveness and sustainability of the global mining industry
2013	Base Metals Conference 2013 - White River
2013	Effective and Sustainable Hydraulic Fracturing - an ISRM Specialised Conference
2013	EUROCK 2013 - The 2013 ISRM International Symposium – Rock Mechanics for Resources, Energy, and Environment
2013	International Symposium on Slope Stability in Open Pit Mining and Civil Engineering
2013	ISRM International Symposium - EUROCK 201
2013	Mine Safe Conference 2013
2013	Mining, Environment and Society Conference: Issues and responses
2013	Professional Development For Women In Engineering

Year	Name
2013	SINOROCK 2013 - Rock Characterisation, Modelling and Engineering Design Methods - an ISRM Specialised Conference
2013	Workshop on Failure in Geomechanics
2014	12th International Mine Water Association Congress (IMWA) 2014: Interdisciplinary Responses to Mine Water Challenges, Xuzhou, China.
2014	1st International Conference on Applied Empirical Design Methods in Mining - an ISRM Specialised Conference
2014	1st International Workshop "From Dependable to Resilient, from Resilient to Antifragile Ambients and Systems"
2014	3rd ISRM International Young Scholars' Symposium on Rock Mechanics
2014	6th South African Rock Engineering Symposium
2014	7th International Conference on Deep Mining 2014
2014	ARMS 8 - The 2014 ISRM International Symposium - 8th Asian Rock Mechanics Symposium
2014	AusRock 2014: 3rd Australasian Ground Control in Mining Conference
2014	Discrete Fracture Network Engineering
2014	EUROCK 2014 - ISRM European Regional Symposium - Rock Engineering and Rock Mechanics: Structures in and on Rock Masses
2014	International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering
2014	Risk Conference 2014
2014	Third Australasian Ground Control in Mining Conference
2014	VI Brazilian Rock Mechanics Symposium - an ISRM Specialised Conference
2014	Young Professionals Conference of the Minerals Industry 2014
2015	9th International Symposium on Field Measurements in Geomechanics
2015	Base Metals Conference 2015 - Livingstone
2015	EUROCK 2015 - the 64th Geomechanics Colloquy
2015	International Seminar on Design Methods in Underground Mining
2015	International Symposium on Slope Stability in Open Pit Mining and Civil Engineering
2015	ISRM 13th International Congress on Rock Mechanics
2015	VIII South American Congress on Rock Mechanics
2015	Workshop on Volcanic Rocks and Soils
2016	7th *In situ* Rock Stress Symposium
2016	Advanced metals Initiative (AmI) Ferrous and Base Metals Development Conference 2016
2016	ARMS 9 - the 9th Asian Rock Mechanics Symposium
2016	Asia Pacific Slope Stability Conference in Mining (APSSIM) 2016
2016	EUROCK 2016 - Rock Mechanics and Rock Engineering: From Past to the Future
2016	First South African Geotechnical Conference
2016	GEOSAFE: 1st International Symposium on Reducing Risks in Site Investigation, Modelling and Construction for Rock Engineering
2016	International Conference on Rock Dynamics (RocDyn) 2
2016	VII Brazilian Rock Mechanics Symposium - an ISRM Specialised Conference
2017	11th International Kimberlite Conference
2017	13th AusIMM Underground Operators' Conference 2017
2017	13th International Mine Water Association Congress (IMWA) 2017: Mine Water and Circular Economy, Rauha/Lappeenranta, Finland.
2017	15th International Conference of International Association for Computer Methods and Advances in Geomechanics (IACMAG)
2017	38th Annual Short Course Grouting Fundamentals and Current Practice
2017	66th Geomechanics Colloquium 2017

Year	Name
2017	7th International Symposium on Geomechanics - an ISRM Specialised Conference
2017	8th International Conference on Deep Mining 2017
2017	EUROCK 2017 - ISRM European Rock Mechanics Symposium
2017	International Conference on Soil Mechanics and Geotechnical Engineering
2017	ISRM International Symposium 'Rock Mechanics for Africa'
2017	Progressive Failure and Long-Term Strength Degradation of Brittle Rocks - an ISRM Specialised Conference
2017	SRM AfriRock - Rock Mechanics for Africa (AfriRock 2017)
2017	VIII International Research and Practice Conference "Innovations in Mining Enterprise Engineering: Geomechanical Tools in Planning, Design and Mining Operations"
2017	YSRM 2017 - the 4th ISRM Young Scholars' Symposium on Rock Mechanics and NDRM 2017 - the 5th International Symposium on New Development in Rock Engineering - an ISRM Specialised Conference
2018	11th International Conference on Geosynthetics - 11ICG
2018	12th International Symposium on Rock Fragmentation by Blasting
2018	12th Regional Rock Mechanics Symposium of Turkey
2018	28th Mine Seismology Seminar
2018	3rd South American Symposium on Rock Excavations - SASORE 2018
2018	4th Australasian Ground Control in Mining Conference - AusRock 2018
2018	ARMS 10 - the 10th Asian Rock Mechanics Symposium
2018	EUROCK 2018 - ISRM European Rock Mechanics Symposium
2018	Fourth International Conference on Block and Sub-level Caving 2018
2018	International Conference on Coupled Processes in Fractured Geological Media: Observation, Modelling, and Application (CouFrac)
2018	International Conference on Earth Science and Geo Science - an ISRM Specialised Conference
2018	International Symposium on Seismic Performance and Design of Slopes - an ISRM Specialised Conference
2018	ISRM Geomechanics Colloquium
2018	RockDyn-3 - 3rd International Conference on Rock Dynamics and Applications - an ISRM Specialised Conference
2018	VIII Brazilian Rock Mechanics Symposium
2018	VIII International Geomechanics Conference
2019	1st International Seminar on Safe and Rapid Development in Mining
2019	3rd International Conference on Information Technology in Geo-Engineering
2019	8th International Symposium in Geomechanics - an ISRM Specialised Conference
2019	9th International Conference on Deep Mining 2019
2019	9th International Conference on Ground Support 2019
2019	Future of Deep Mining 2019
2019	Geotechnical Challenges in Karst
2019	Grouting Fundamentals and Current Practice - 40th Annual Short Course - 1st European Edition
2019	International Conference on Advances in Structural and Geotechnical Engineering (ICASGE) '19
2019	International Conference on Mining Geomechanical Risk
2019	International Workshop on Shotcrete Technology in Underground Construction - an ISRM Specialised Conference
2019	ISRM 14th International Congress on Rock Mechanics
2019	ISRM Advance course in rock grouting
2019	Mining Geotechnical Risk

Year	Name
2019	Shaoxing International Forum on Rock Mechanics and Engineering Geology - an ISRM Specialised Conference
2019	YSRM2019 - the 5th ISRM Young Scholars' Symposium on Rock Mechanics and REIF2019 - International Symposium on Rock Engineering for Innovative Future - an ISRM Specialised Conference
2020	2nd International Conference on Underground Mining Technology
2020	2nd International Conference on Coupled Processes in Fractured Geological Media: Observation, Modelling, and Application (CouFrac2020) - an ISRM Specialised Conference
2020	2nd International Symposium on Seismic Performance and Design of Slopes
2020	4th International Conference on Geotechnical Engineering ICGE'20
2020	EUROCK 2020 - ISRM European Rock Mechanics Symposium
2020	International Conference on Rock Mechanics and Rock Engineering - an ISRM Specialised Conference
2020	MassMin 2020: Eighth International Conference and Exhibition on Mass Mining
2020	TISOLS2020 - Tenth International Symposium on Land Subsidence
2021	3rd International Discrete Fracture Network Engineering Conference
2021	5th International Workshop on Rock Mechanics and Engineering Geology in Volcanic Fields - an ISRM Specialised Conference
2021	9th International Symposium on Geomechanics - an ISRM Specialised Conference
2021	ARMS 11 - 11th Asian Rock Mechanics Symposium, Challenges and Opportunities in Rock Mechanics - an ISRM Regional Symposium
2021	EUROCK 2021 - Mechanics and Rock Engineering from Theory to Practice - the 2021 ISRM International Symposium
2021	RocScience International Conference - The Evolution of Geotech: 25 Years of Innovation
2021	Second International Slope Stability in Mining Conference
2021	Southern African Rare Earths International Conference 2021
2021	XIII ISL - International Symposium on Landslides: Landslides and Sustainable Development - a FedIGS/JTC1 Conference
2022	11th International Symposium on Field Measurements in Geomechanics
2022	16th International Conference of the International Association for Computer Methods and Advances in Geomechanics (IACMAG)
2022	56th U.S. Rock Mechanics/Geomechanics Symposium
2022	5th International Conference on Block and Sub-level Caving
2022	Damage Mechanics Challenge Workshop
2022	EUROCK 2022 - Rock and Fracture Mechanics in Rock Engineering and Mining - an ISRM Regional Symposium
2022	IEEE Asia-Pacific Conference on Image Processing, Electronics and Computers
2022	LARMS 2022 - Challenges in rock mechanics: towards a sustainable development of infrastructure - the 2022 ISRM International Symposium
2022	RaSiM10 - Rockbursts and Seismicity in Mines
2022	RocDyn-4: 4th International Conference on Rock Dynamics - an ISRM Specialised Conference
2022	SBMR2022 - 9th Brazilian Rock Mechanics Symposium - an ISRM Specialised Conference
2023	10th European Conference on Numerical Methods in Geotechnical Engineering (organised by the European Regional Technical Committee ERTC7 under the umbrella of the International Society for Soil Mechanics and Geotechnical Engineering, ISSMGE).
2023	49th Annual Conference on Explosives and Blasting Technique - Advancing the Science and Art of Explosives
2023	Future of Mining Americas (FOM Americas)
2023	Global Gold Convention (GGC)
2023	Global Mining Summit
2023	Indian Near Surface Geophysics Conference and Exhibition (INSGC and Exhibition)

Year	Name
2023	International Conference on Ground Control in Mining
2023	Conference on High-Performance Mining (HPM)
2023	International Conference on Machine Learning, Cloud Computing and Intelligent Mining
2023	International Conference on Mining Material and Metallurgical Engineering
2023	International Future Mining Conference
2023	International Mining and Resources Conference (IMARC) 2023
2023	International Mining and Resources Conference and Expo (IMARC)
2023	Life of Mine Conference
2023	Mining 4.0 - Roadmap for The Future
2023	NSW Mining HSEC (health, safety, environment and community) Conference
2023	Queensland Mining Industry Health and Safety Conference

9.2 Annexure B: Standards and Suggested Methods

9.2.1 Annexure B-1: ISO Standards

9.2.1.1 Geotechnical Standards

Table 9-4: ISO Geotechnical Standards

ISO Geotechnical Standards
(ISO 14688-1:2017) Geotechnical investigation and testing — Identification and classification of soil — Part 1: Identification and description
(ISO 14688-2:2017) Geotechnical investigation and testing — Identification and classification of soil — Part 2: Principles for a classification
(ISO 14689:2017) Geotechnical investigation and testing — Identification, description and classification of rock
(ISO/AWI 16383-1) Geotechnical investigation and testing — Laboratory testing of rock — Part 1: Determination of water content
(ISO 17628:2015) Geotechnical investigation and testing — Geothermal testing — Determination of thermal conductivity of soil and rock using a borehole heat exchanger
(ISO 17892-1:2014) Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content
(ISO 17892-1:2014/Amd 1:2022) Geotechnical investigation and testing — Laboratory testing of soil — Part 1: Determination of water content — Amendment 1
(ISO 17892-2:2014) Geotechnical investigation and testing — Laboratory testing of soil — Part 2: Determination of bulk density
(ISO 17892-3:2015) Geotechnical investigation and testing — Laboratory testing of soil — Part 3: Determination of particle density
(ISO 17892-4:2016) Geotechnical investigation and testing — Laboratory testing of soil — Part 4: Determination of particle sise distribution
(ISO 17892-5:2017) Geotechnical investigation and testing — Laboratory testing of soil — Part 5: Incremental loading oedometer test
(ISO 17892-6:2017) Geotechnical investigation and testing — Laboratory testing of soil — Part 6: Fall cone test
(ISO 17892-7:2017) Geotechnical investigation and testing — Laboratory testing of soil — Part 7: Unconfined compression test
(ISO 17892-8:2018) Geotechnical investigation and testing — Laboratory testing of soil — Part 8: Unconsolidated undrained triaxial test
(ISO 17892-9:2018) Geotechnical investigation and testing — Laboratory testing of soil — Part 9: Consolidated triaxial compression tests on water saturated soils
(ISO 17892-10:2018) Geotechnical investigation and testing — Laboratory testing of soil — Part 10: Direct shear tests
(ISO 17892-11:2019) Geotechnical investigation and testing — Laboratory testing of soil — Part 11: Permeability tests
(ISO 17892-12:2018) Geotechnical investigation and testing — Laboratory testing of soil — Part 12: Determination of liquid and plastic limits
(ISO 17892-12:2018/Amd 1:2021) Geotechnical investigation and testing — Laboratory testing of soil — Part 12: Determination of liquid and plastic limits — Amendment 1
(ISO 17892-12:2018/Amd 2:2022) Geotechnical investigation and testing — Laboratory testing of soil — Part 12: Determination of liquid and plastic limits — Amendment 2
(ISO 18674-1:2015) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 1: General rules
(ISO 18674-2:2016) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 2: Measurement of displacements along a line: Extensometers
(ISO 18674-3:2017) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 3: Measurement of displacements across a line: Inclinometers
(ISO 18674-3:2017/Amd 1:2020) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 3: Measurement of displacements across a line: Inclinometers — Amendment 1
(ISO 18674-4:2020) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 4: Measurement of pore water pressure: Piezometers
(ISO 18674-5:2019) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 5: Stress change measurements by total pressure cells
(ISO/WD 18674-7) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 7: Measurement of strains

ISO Geotechnical Standards
(ISO/DIS 18674-8) Geotechnical investigation and testing — Geotechnical monitoring by field instrumentation — Part 8: Measurement of loads: Load cells
(ISO 22282-1:2012) Geotechnical investigation and testing — Geohydraulic testing — Part 1: General rules
(ISO 22282-2:2012) Geotechnical investigation and testing — Geohydraulic testing — Part 2: Water permeability tests in a borehole using open systems
(ISO 22282-3:2012) Geotechnical investigation and testing — Geohydraulic testing — Part 3: Water pressure tests in rock
(ISO 22282-4:2021) Geotechnical investigation and testing — Geohydraulic testing — Part 4: Pumping tests
(ISO 22282-5:2012) Geotechnical investigation and testing — Geohydraulic testing — Part 5: Infiltrometer tests
(ISO 22282-6:2012) Geotechnical investigation and testing — Geohydraulic testing — Part 6: Water permeability tests in a borehole using closed systems
(ISO 22475-1:2021) Geotechnical investigation and testing — Sampling methods and groundwater measurements — Part 1: Technical principles for the sampling of soil, rock and groundwater
(ISO 22476-1:2012) Geotechnical investigation and testing — Field testing — Part 1: Electrical cone and piezocone penetration test
(ISO 22476-1:2012/Cor 1:2013) Geotechnical investigation and testing — Field testing — Part 1: Electrical cone and piezocone penetration test — Technical Corrigendum 1
(ISO 22476-1) Geotechnical investigation and testing — Field testing — Part 1: Electrical cone and piezocone penetration test
(ISO 22476-2:2005) Geotechnical investigation and testing — Field testing — Part 2: Dynamic probing
(ISO 22476-2:2005/Amd 1:2011) Geotechnical investigation and testing — Field testing — Part 2: Dynamic probing — Amendment 1
(ISO 22476-3:2005) Geotechnical investigation and testing — Field testing — Part 3: Standard penetration test
(ISO 22476-3:2005/Amd 1:2011) Geotechnical investigation and testing — Field testing — Part 3: Standard penetration test — Amendment 1
(ISO 22476-4:2021) Geotechnical investigation and testing — Field testing — Part 4: Prebored pressuremeter test by Ménard procedure
(ISO 22476-5:2012) Geotechnical investigation and testing — Field testing — Part 5: Flexible dilatometer test
(ISO/DIS 22476-5) Geotechnical investigation and testing — Field testing — Part 5: Prebored pressuremeter test
(ISO 22476-6:2018) Geotechnical investigation and testing — Field testing — Part 6: Self-boring pressuremeter test
(ISO 22476-7:2012) Geotechnical investigation and testing — Field testing — Part 7: Borehole jack test
(ISO 22476-8:2018) Geotechnical investigation and testing — Field testing — Part 8: Full displacement pressuremeter test
(ISO 22476-9:2020) Geotechnical investigation and testing — Field testing — Part 9: Field vane test
(ISO 22476-10:2017) Geotechnical investigation and testing — Field testing — Part 10: Weight sounding test
(ISO 22476-11:2017) Geotechnical investigation and testing — Field testing — Part 11: Flat dilatometer test
(ISO 22476-12:2009) Geotechnical investigation and testing — Field testing — Part 12: Mechanical cone penetration test
(ISO 22476-14:2020) Geotechnical investigation and testing — Field testing — Part 14: Borehole dynamic probing
(ISO 22476-15:2016) Geotechnical investigation and testing — Field testing — Part 15: Measuring while drilling
(ISO/CD 22476-16) Geotechnical investigation and testing — Field testing — Part 16: Borehole shear test
(ISO 22477-1:2018) Geotechnical investigation and testing — Testing of geotechnical structures — Part 1: Testing of piles: static compression load testing
(ISO/DIS 22477-2) Geotechnical investigation and testing — Testing of geotechnical structures — Part 2: Testing of piles: Static tension load testing
(ISO 22477-4:2018) Geotechnical investigation and testing — Testing of geotechnical structures — Part 4: Testing of piles: dynamic load testing
(ISO 22477-5:2018) Geotechnical investigation and testing — Testing of geotechnical structures — Part 5: Testing of grouted anchors
(ISO 22477-10:2016) Geotechnical investigation and testing — Testing of geotechnical structures — Part 10: Testing of piles: rapid load testing
(ISO 24057) Geotechnics — Array measurement of microtremors to estimate shear wave velocity profile
(ISO/TS 24283-1:2022) Geotechnical investigation and testing — Qualification criteria and assessment — Part 1: Qualified technician and qualified operator

ISO Geotechnical Standards
(ISO/TS 24283-2:2022) Geotechnical investigation and testing — Qualification criteria and assessment — Part 2: Responsible expert
(ISO/TS 24283-3:2022) Geotechnical investigation and testing — Qualification criteria and assessment — Part 3: Qualified enterprise

9.2.1.2 Drilling Standards

Table 9-5: ISO Drilling Standards

ISO Drilling Standards
(ISO 3551-2:1992) Rotary core diamond drilling equipment — System A — Part 1: Metric units
(ISO 3552-1:1992) Rotary core diamond drilling equipment — System B — Part 2: Inch units

9.2.1.3 Soil Standards

Table 9-6: ISO Soil Standards

ISO Soil Standards
(ISO 17313:2004) Soil quality — Determination of hydraulic conductivity of saturated porous materials using a flexible wall permeameter
(ISO 23992:2022) Soil quality — Framework for detailed recording and monitoring of changes in dynamic soil properties
(ISO 25177:2019) Soil quality — Field soil description
(ISO 28258:2013) Soil quality — Digital exchange of soil-related data
(ISO 28258:2013/Amd 1:2019) Soil quality — Digital exchange of soil-related data — Amendment 1
(ISO 17313:2004) Soil quality — Determination of hydraulic conductivity of saturated porous materials using a flexible wall permeameter
(ISO 23992:2022) Soil quality — Framework for detailed recording and monitoring of changes in dynamic soil properties
(ISO 25177:2019) Soil quality — Field soil description
(ISO 28258:2013) Soil quality — Digital exchange of soil-related data
(ISO 28258:2013/Amd 1:2019) Soil quality — Digital exchange of soil-related data — Amendment 1

9.2.1.4 Standards Relating to Minerals and Mining

Table 9-7: ISO Standards Relating to Minerals and Mining

ISO Standards Relating to Minerals and Mining
(ISO 22932-2:2020) Mining — Vocabulary — Part 2: Geology
(ISO 22932-3:2020) Mining – Vocabulary — Part 3: Rock mechanics
(ISO 22932-5:2020) Mining — Vocabulary — Part 5: Drilling and blasting
(ISO 19434:2017) Mining - Classification of mine accidents
(ISO 4657:2022) Assessment specification of coalbed methane resources
(ISO 18871:2015) Method of determining coalbed methane content
(ISO 18875:2015) Coalbed methane exploration and development — Terms and definitions
(ISO 19426-1:2018) Structures for mine shafts — Part 1: Vocabulary
(ISO 19426-2:2018) Structures for mine shafts — Part 2: Headframe structures
(ISO 19426-3:2018) Structures for mine shafts — Part 3: Sinking stages
(ISO 19426-4:2018) Structures for mine shafts — Part 4: Conveyances

ISO Standards Relating to Minerals and Mining
(ISO 19426-5:2018) Structures for mine shafts — Part 5: Shaft system structures
(ISO 19426-7:2021) Structures for mine shafts — Part 7: Rope guides
(ISO 19434:2017) Mining — Classification of mine accidents
(ISO 19434:2017/Amd 1:2019) Mining — Classification of mine accidents — Amendment 1
(ISO 20305:2020) Mine closure and reclamation — Vocabulary
(ISO 21795-1:2021) Mine closure and reclamation planning — Part 1: Requirements
(ISO 21795-2:2021) Mine closure and reclamation planning — Part 2: Guidance
(ISO 22932-1:2020) Mining — Vocabulary — Part 1: Planning and surveying
(ISO 22932-2:2020) Mining — Vocabulary — Part 2: Geology
(ISO/DIS 22932-3) Mining – Vocabulary — Part 3: Rock mechanics
(ISO/DIS 22932-4) Mining — Vocabulary — Part 4: Prospecting and exploration
(ISO/DIS 22932-5) Mining — Vocabulary — Part 5: Drilling and blasting
(ISO 23664:2021) Traceability of rare earths in the supply chain from mine to separated products
(ISO 23872:2021) Mining structures — Underground structures
(ISO 23875:2021) Mining — Air quality control systems for operator enclosures — Performance requirements and test methods
(ISO 23875:2021/Amd 1:2022) Mining — Air quality control systems for operator enclosures — Performance requirements and test methods — Amendment 1
(ISO/DIS 24419-1) Mine closure and reclamation – Managing mining legacies — Part 1: Requirements and recommendations
(ISO/CD TR 24419-2.2) Mine closure and reclamation – Managing mining legacies — Part 2: Case studies and bibliography

9.2.1.5 Standards Relating to Uncertainty

Table 9-8: ISO Standards Relating to Uncertainty [59,60]

ISO Standards Relating to Uncertainty
(ISO/IEC Guide 98-1:2009) Uncertainty of measurement — Part 1: Introduction to the expression of uncertainty in measurement
(ISO/IEC Guide 98-3:2009) Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement

[59] There are several standards planned, including:
- Uncertainty of measurement — Part 2: Concepts and basic principles
- Uncertainty of measurement — Part 4: Role of measurement uncertainty in conformity assessment
- Uncertainty of measurement — Part 5: Applications of the least-squares method

[60] There are several supplements planned, including:
- Uncertainty of measurement — Part 3, Supplement 2: Models with any number of output quantities
- Uncertainty of measurement — Part 3, Supplement 3: Modelling

9.2.1.6 Standards Relating to Risk

Table 9-9: ISO Standards Relating to Risk

ISO Relating to Risk
(ISO Guide 73:2009) Risk management — Vocabulary
(ISO 31000:2018) Risk management — Guidelines
(ISO/IEC 31010:2019) Risk management — Risk assessment techniques

9.2.1.7 Standards Relating to Statistics

Table 9-10: ISO Standards Relating to Statistics

ISO Standards Relating to Statistics
(ISO 3534-1:2006) Statistics — Vocabulary and symbols — Part 1: General statistical terms and terms used in probability
(ISO 3534-2:2006) Statistics — Vocabulary and symbols — Part 2: Applied statistics
(ISO 3534-3:2013) Statistics — Vocabulary and symbols — Part 3: Design of experiments
(ISO 3534-4:2014) Statistics — Vocabulary and symbols — Part 4: Survey sampling

9.2.1.8 Standards Relating to Quality

Table 9-11: ISO Standards Relating to Quality

ISO Standards Relating to Quality
(ISO 10017:2021) Quality management - Guidance on statistical techniques for ISO 9001:2015
(ISO 9000:2015) Quality management systems - Fundamentals and vocabulary
(ISO/IEC Guide 68:2002) Arrangements for the recognition and acceptance of conformity assessment results
(ISO 690:2021) Information and documentation — Guidelines for bibliographic references and citations to information resources

9.2.1.9 Artificial Intelligence and Information Technology

Table 9-12: ISO Standards for Artificial Intelligence and Information Technology

ISO Standards for Artificial Intelligence and Information Technology
(ISO/IEC 20546:2019) Information technology - Big data - Overview and vocabulary
(ISO/IEC TR 20547-1:2020) Information technology - Big data reference architecture - Part 1: Framework and application process
(ISO/IEC TR 20547-2:2018) Information technology - Big data reference architecture - Part 2: Use cases and derived requirements
(ISO/IEC 20547-3:2020) Information technology - Big data reference architecture - Part 3: Reference architecture
(ISO 12620:2019) Management of terminology resources - Data category specifications
(ISO 16642:2017) Computer applications in terminology - Terminological markup framework

ISO Standards for Artificial Intelligence and Information Technology
(ISO 26162:2012) Systems to manage terminology, knowledge and content — Design, implementation and maintenance of terminology management systems
(ISO 26162-1:2019) Management of terminology resources - Terminology databases - Part 1: Design
(ISO 26162-2:2019) Management of terminology resources - Terminology databases - Part 2_Software
(ISO 704:2009) Terminology work - Principles and methods
(ISO 860:2007) Terminology work - Harmonisation of concepts and terms
(ISO/IEC TR 20547-5:2018) Information technology - Big data reference architecture - Part 5: Standards roadmap
(ISO/IEC TR 24028:2020) Information technology - Artificial intelligence - Overview of trustworthiness in artificial intelligence
(ISO/IEC TR 24029-1:2021) Artificial Intelligence
(ISO/IEC TR 24030:2021) Information technology - Artificial intelligence

9.2.2 Annexure B-2: ISRM Suggested Methods

Table 9-13: ISRM Suggested Methods

ISRM Suggested Methods
ISRM SM for Determining Shear Strength (1974)
ISRM SM for Monitoring Rock Movements Using Inclinometers and Tiltmeters (1977)
ISRM SM for Determining Hardness and Abrasiveness of Rocks (1978)
ISRM SM for Determining Tensile Strength of Rock Materials (1978)
ISRM SM for Determining the Strength of Rock Materials in Triaxial Compression (1978)
ISRM SM for Monitoring Rock Movements Using Borehole Extensometers (1978)
ISRM SM for Petrographic Description of Rocks (1978)
ISRM SM for Quantitative Description of Discontinuities in Rock Masses (1978)
ISRM SM for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials (1979)
ISRM SM for Geophysical Logging of Boreholes (1981)
ISRM SM for Surface Monitoring of Movements Across Discontinuities (1984)
ISRM SM for Determining Point Load Strength (1985)
ISRM SM for Deformability Determination Using a Flexible Dilatometer (1987)
ISRM SM for Rock Stress Determination (1987)
ISRM SM for Determining the Fracture Toughness of Rock (1988)
ISRM SM for Seismic Testing Within and Between Boreholes (1988)
ISRM SM for Laboratory Testing of Argillaceous Swelling Rock (1989)
ISRM SM for Large Scale Sampling and Triaxial Testing of Jointed Rock (1989)
ISRM SM for Blast Vibration Monitoring (1992)
ISRM SM for Rapid Field Identification of Swelling and Slaking Rocks (1994)
ISRM SM for Deformability Determination Using a Stiff Dilatometer (1996)
ISRM SM for Determining the Indentation Hardness Index of Rock Materials (1998)
ISRM SM for Laboratory Testing of Swelling Rocks (1999)
ISRM SM for the Complete Stress-Strain Curve for Intact Rock in Uniaxial Compression (1999)
ISRM SM for In situ stress measurements - Part 1: Strategy for Rock Stress Estimation (2003)
ISRM SM for In situ stress measurements - Part 2: Overcoming Methods (2003)
ISRM SM for In situ stress measurements - Part 3: Hydraulic Fracturing (HF) and/or Hydraulic Testing of Pre-existing Fractures (HTPF)n (2003)
ISRM SM for In situ stress measurements - Part 4: Quality Control of Rock Stress Estimation (2003)
ISRM SM for Land Geophysics in Rock Engineering (2004)
ISRM SM for Borehole Geophysics in Rock Engineering (2006)
ISRM SM for Rockbolt Testing (1974)
ISRM SM for Determining In Situ Deformability of Rock (1979)
ISRM SM for Pressure Monitoring Using Hydraulic Cells (1980)
ISRM SM for Rock Anchorage Testing (1985)
ISRM SM for In Situ Microseismic Monitoring of the Fracturing Process in Rock Masses (2016)
ISRM SM for Determining the Basic Friction Angle of Planar Rock Surfaces by Means of Tilt Tests (2018)
ISRM SM for Determining Deformation and Failure Characteristics of Rocks Subjected to True Triaxial Compression (2019)
ISRM SM for In Situ Acoustic Emission Monitoring of the Fracturing Process in Rock Masses (2019)

Table 9-14: ISRM Reports

ISRM Reports
ISRM Report on List of Symbols (1970)
ISRM Report on Recommendations on Site Investigation Techniques (1975)
ISRM Report on Terminology (pp. 1-43) (1975)
ISRM Report on Terminology (pp. 44-83) (1975)
ISRM Report on Basic Geotechnical Description of Rock Masses (1980)
ISRM Report on Report on Teaching of Rock Mechanics (1981)
ISRM Report on Characterisation of Swelling Rock (1983)
ISRM Report on Report on ISRM Fields of Activities (1986)
ISRM Report on Suggested Improvement on Schmidt Rebound Hardness ISRM Suggested Method (1993)
ISRM Report on Comments and Recommendations on Design and Analysis Procedures for Structures in Argillaceous Swelling Rock (1994)
ISRM Report on Commission on Rock Grouting (pp. 1-22) (1996)
ISRM Report on Commission on Rock Grouting (pp. 23-45) (1996)
ISRM Report on Supporting Paper on Determination of In Situ Deformation Modulus (1997)

9.2.3 Annexure B-3: ASTM International (formerly American Society for Testing and Materials) Standard Test Methods, Work Items, Manuals

9.2.3.1 Standard Test Methods

Table 9-15: ASTM International Standard Test Methods

ASTM International Standard Test Methods
ASTM D2113-14 Standard Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
ASTM D2936-08 Standard Test Method for Direct Tensile Strength of Intact Rock Core Specimens
ASTM D3967-08 Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens
ASTM D4553-08 Standard Test Method for Determining In Situ Creep Characteristics of Rock
ASTM D4554-12 Standard Test Method for In Situ Determination of Direct Shear Strength of Rock Discontinuities
ASTM D4611-08 Standard Test Method for Specific Heat of Rock and Soil
ASTM D4879-08 Standard Guide for Geotechnical Mapping of Large Underground Openings in Rock
ASTM D4992-14e1 Standard Practice for Evaluation of Rock to be Used for Erosion Control
ASTM D5079-08 Standard Practices for Preserving and Transporting Rock Core Samples
ASTM D5121-15 Standard Practice for Preparation of Rock Slabs for Durability Testing
ASTM D5255-15 Standard Practice for Certification of Personnel Engaged in the Testing of Soil and Rock
ASTM D5434-12 Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock
ASTM D5731-08 Standard Test Method for Determination of the Point Load Strength Index of Rock and Application to Rock Strength Classifications
ASTM D5873-14 Standard Test Method for Determination of Rock Hardness by Rebound Hammer Method [61]
ASTM D5878-08 Standard Guides for Using Rock-Mass Classification Systems for Engineering Purposes
ASTM D6032-08 Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core
ASTM D6473-15 Standard Test Method For Specific Gravity And Absorption of Rock For Erosion Control
ASTM D653-14 Standard Terminology Relating to Soil, Rock, and Contained Fluids
ASTM D6711-15 Standard Practice for Specifying Rock to Fill Gabions, Revet Mattresses, and Gabion Mattresses
ASTM D7012 Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperature
ASTM D7099-04(2010) Standard Terminology Relating to Frozen Soil and Rock

[61] ASTM D5873-14 Standard Test Method for Determination of Rock Hardness by Rebound Hammer Method was withdrawn on or about 10 January 2023, however it is included in Table 9-15 because it is likely and anticipated that the test method will have been used and/or described in the literature, data and reports used in the research.

9.2.3.2 Work Items

Table 9-16: ASTM International Work Items

ASTM International Work Items
WK14112 New Guide for Guide for The Determination of Water (Moisture) Content of Soil and Rock
WK24243 New Practice for Handling, Transportation, and Storage of Frozen Soil and Rock Samples
WK38102 Revision of D2936 - 08 Standard Test Method for Direct Tensile Strength of Intact Rock Core Specimens
WK50304 Revision of D5079 - 08 Standard Practices for Preserving and Transporting Rock Core Samples
WK14112 New Guide for Guide for The Determination of Water (Moisture) Content of Soil and Rock

9.2.3.3 Manuals

Table 9-17: ASTM International Manuals

ASTM International Manuals
MNL11-EB Manual on Drilling, Sampling, and Analysis of Coal, Compiled by ASTM Subcommittees D05.18 and D05.23
MNL19-EB Manual on the Building of Materials Databases
MNL20-2ND-EB Corrosion Tests and Standards: Application and Interpretation-Second Edition
MNL20-2ND-SUP-EB Supplement to Corrosion Tests and Standards: Application and Interpretation, 2nd Edition
MNL22-2ND-EB Business Performance Excellence through Total Quality Management—2nd Edition
MNL30-EB Relating Consumer, Descriptive, and Laboratory Data to Better Understand Consumer Responses
MNL32-5TH-EB Manual on Test Sieving Methods: Guidelines for Establishing Sieve Analysis Procedures
MNL54-EB Preparing and Delivering Technical Presentations
MNL63-EB Just-About-Right (JAR) Scales: Design, Usage, Benefits, and Risks
MNL65-EB Application of ASTM E2691 Standard Practice for Job Productivity Measurement
MNL70-EB Quality Control of Soil Compaction Using ASTM Standards
MNL7-9TH-EB Presentation of Data and Control Chart Analysis, 9th Edition

9.2.3.4 Special Technical Publications

Table 9-18: ASTM International Special Technical Publications

ASTM International Standard Test Methods
392 Instruments and Apparatus for Soil and Rock Mechanics
402 Testing Techniques for Rock Mechanics
429 Determination of Stress in Rock-A State-of-the-Art Report
477 Determination of the In Situ Modulus of Deformation of Rock*
479 Special Procedures for Testing Soil and Rock for Engineering Purposes
483 Sampling of Soil and Rock
554 Field Testing and Instrumentation of Rock
745 Fracture Mechanics for Ceramics, Rocks, and Concrete*
869 Measurements of Rock Properties at Elevated Pressures and Temperatures*

ASTM International Standard Test Methods
977 Advanced Triaxial Testing of Soil and Rock*
984 Rock Classification Systems for Engineering
1177 Rock for Erosion Control*
1350 Non-destructive and Automated Testing for Soil and Rock Properties
1358 Field Instrumentation of Soil and Rock

9.2.3.5 Supporting Material

Table 9-19: ASTM International 10.1.6.5 Supporting Material

ASTM International 10.1.6.5 Supporting Material
D5489 Core Symbol Chart
D7012 Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperature (Blueprints)
D220001 Standard Reference Photographs

9.3 Annexure C: Companies

9.3.1 Annexure C-1: Mining companies active in South Africa

Table 9-20: Companies identified from the Department of Minerals and Energy Register of Operating Mines in South Africa

Company	Company (cont.)
African Diamond AB	Lindleys Mining (Pty) Ltd.
African Nickel Holdings (Pty) Ltd	Lindum Reefs Gold Mining Co. Ltd.
African Rainbow Minerals Ltd.	Lower Orange River Diamonds Pty. Ltd.
African Star Mining (Pty) Ltd.	Meepo Investment Consortium (Pty) Ltd.
African Thunder Platinum Ltd	Messina Platinum Mines Ltd.
Alexkor Ltd.	Metmin (Pty) Limited
Andrada Mining Ltd.	Minerals Technologies Inc.
Anglo American Platinum Ltd.	Miranda Mineral Holdings Ltd.
Aquila Resources Pty Ltd.	Mkhombi Mining (Pty) Ltd
Assmang Pty. Ltd.	Namakwa Diamonds Ltd.
Assore Ltd.	Namibian Minerals Corp.
Atlatsa Resources Corp.	Nautical Petroleum plc
Aurora Empowerment Systems (Proprietary) Ltd.	New African Mining Ag
Barplats Investments Ltd.	New Kleinfontein Mining Co Ltd.
Barrick	Nigel Gold Mining Co. (Pty) Ltd
Bauba Resources Ltd.	Northam Platinum Holdings Ltd.
Bayer (Pty) Ltd	Northwest Diamond Co. Pty
BCKP Ltd.	Oakbay Resources and Energy Ltd.
Belmont Mining Ltd.	Orion Minerals Ltd.
BHP Billiton	Pala Investments Ltd.
BlueRock Diamonds PLC	Palabora Copper Pty. Ltd.
Blyvoor Gold (Pty) Ltd.	Pan African Resources PLC
Botswana Diamonds PLC	Petra Diamonds Ltd.
Bracken Mines Ltd.	Platfields Ltd.
Brasilca Mining Corp.	Platinum Australia Ltd.
Bushveld Minerals Ltd.	Platinum Group Metals Ltd.
Canadian Gold South Africa (Pty) Ltd	Prismatica Diamonds (Pty) Ltd
Cancun Trading Pty Ltd	Private Interest
Cape Resources Plc	Rainbow Rare Earths Ltd.
Centurion Gold Holdings Inc.	Realm Resources Ltd.
China African Precious Metals (Pty) Ltd.	Rio Tinto
Chrometco Ltd.	Rooiberg Tin Ltd
Clover Alloys (SA) Pty. Ltd.	Royal Bafokeng Platinum Ltd.
De Beers Consolidated Mines Ltd.	Royal Bafokeng Resources Holdings Pty. Ltd.
De Beers SA	Samadi (Douglas) Exploration
Diamco	Samancor Chrome Holdings (Pty)
Diamcor Mining Inc.	Samancor Chrome Ltd.
Diamix plc (Nyota Minerals)	Sedibelo Resources Limited
DiamondCorp Plc	Shirley Hayes Ipk (Pty) Ltd.

Company	Company (cont.)
DiamondTech, Inc.	Sibanye Stillwater Ltd.
DRDGOLD Ltd.	Siyanda Resources Pty Ltd.
Eastern Platinum Ltd.	South Roodepoort Main Reefs
Ekapa Mining (Pty) Ltd.	South32 Ltd.
Etruscan Diamonds Pty. Ltd.	Southern African Tantalum Mining (Pty) Ltd
Ferrox Holdings Ltd.	Southstone Minerals Ltd.
Forward Africa Mining Pty. Ltd.	Spearhead Capital Limited
Frontier Diamonds Ltd.	Steenkampskraal Thorium Ltd
Frontier Mining Ltd.	Stilfontein Gold Mining Co. Ltd.
Frontier Rare Earths Ltd.	Superior Mining International Corp.
Glencore PLC	Superkolong Consortium
Glenover Phosphate (Pty) Ltd.	Superkolong Pty Ltd
Global Diamond Resources Inc.	Sylvania Platinum Ltd.
Global Diamond Resources Plc	Tata Steel Ltd.
Golconda Gold Ltd.	Taung Gold International Ltd.
Gold Fields Ltd.	Terris Chrome Ltd
Gold One International Ltd.	Thabex Ltd.
Goldplat PLC	Tharisa PLC
Greenhurst Mining and Exploration (Pty) Ltd	Theta Gold Mines Ltd.
Guangxi Dameng Manganese Industry Group Co. Ltd.	Trans Hex Group Ltd.
Guangxi N and H Metallurgy Development Co., Ltd.	United Manganese of Kalahari (Pty) Ltd.
Harmony Gold Mining Co. Ltd.	Uranium One Africa Ltd.
HolGoun Investment Holdings	Vale
Impala Platinum Holdings Ltd.	Valencia Ventures Inc.
Ivanhoe Mines Ltd.	Vanadium Resources Ltd.
Jubilee Metals Group PLC	Vantage Goldfields Ltd.
Jupiter Mines Ltd.	Vedanta Ltd.
Kalagadi Manganese Pty. Ltd.	Village Main Reef Ltd.
Kaldora Resources Ltd	Wesizwe Platinum Ltd.
Kimberley Consolidated Mining Ltd.	West Wits Mining Ltd.
KMG Diamond Resources plc	Western Uranium Pty Ltd
Kudumane Manganese Resources (Pty) Ltd.	White Rivers Exploration Pty Limited
Kumba Iron Ore Ltd.	Xstrata
Lakebush Pty Ltd	Zaaiplaats Mining Ltd.
	Zijin Mining Group Co. Ltd.

9.3.2 Annexure C-2: Mining companies listed on the JSE

Table 9-21: Example showing the names and selected information of companies listed on the JSE [62]

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
African Rainbow Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ARI	South Africa
Anglo American Platinum Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	AMS	South Africa
AngloGold Ashanti Limited	Ordinary Shares	Gold	Common Equity	ANG	South Africa
BHP Group Limited	LTD Ordinary Shares	Diversified Metals and Mining	Common Equity	BHG	Australia
DRDGOLD Limited	Ordinary Shares	Gold	Common Equity	DRD	South Africa
Europa Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EUZ	Australia
Gold Fields Limited	Ordinary Shares	Gold	Common Equity	GFI	South Africa
Harmony Gold Mining Company Limited	Ordinary Shares	Gold	Common Equity	HAR	South Africa
Impala Platinum Holdings Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	IMP	South Africa
Kumba Iron Ore Limited	Ordinary Shares	Steel	Common Equity	KIO	South Africa
Northam Platinum Holdings Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	NPH	South Africa
Orion Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ORN	Australia
Sibanye Stillwater Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	SSW	South Africa
South32 Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	S32	Australia
Southern Palladium Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	SDL	Australia
Wesizwe Platinum Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	WEZ	South Africa

[62] S&P Global MI's (2018) Global Industry Classification Standard (GICS) for 'Metals and Mining' is defined as "*Companies engaged in the diversified production or extraction of metals and minerals not classified elsewhere. Including, but not limited to, nonferrous metal mining (except bauxite) salt and borate mining, phosphate rock mining, and diversified mining operations. Excludes iron ore mining, classified in the Steel Sub-Industry, bauxite mining, classified in the Aluminium Sub-Industry, and coal mining, classified in either the Steel or Coal & Consumable Fuels Sub-Industries"*

9.3.3 Annexure C-3: Mining Companies on the ASX

Table 9-22: Example showing the names and selected information of companies listed on the ASX

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
29Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	29M	Australia
5E Advanced Materials Inc.	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	5EA	USA
ABx Group Limited	Ordinary Shares	Aluminium	Common Equity	ABX	Australia
Accelerate Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AX8	Australia
ACDC Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ADC	Australia
ActivEX Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AIV	Australia
Adavale Resources Limited	Npv Dfd 07/09/23 (ex-Rights)	Diversified Metals and Mining	Common Equity	ADDN	Australia
Adavale Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ADD	Australia
Adelong Gold Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ADG	Australia
Admiralty Resources NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	ADY	Australia
Adriatic Metals PLC	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	ADT	United Kingdom
Aeon Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AML	Australia
Aeris Resources Limited	Ordinary Shares	Copper	Common Equity	AIS	Australia
African Gold Limited	Ordinary Shares	Gold	Common Equity	A1G	Australia
Agrimin Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AMN	Australia
Aguia Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AGR	Australia
AIC Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	A1M	Australia
Alara Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AUQ	Australia
Albion Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ALB	Australia
Alchemy Resources Limited	Ordinary Shares	Gold	Common Equity	ALY	Australia
Alderan Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AL8	Australia
Aldoro Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ARN	Australia
Alicanto Minerals Limited	Ordinary Shares	Gold	Common Equity	AQI	Australia
Alice Queen Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AQX	Australia
Alkane Resources Limited	Ordinary Shares	Gold	Common Equity	ALK	Australia
Alliance Nickel Limited	Ordinary Shares	Gold	Common Equity	AXN	Australia
Allkem Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AKE	Australia
Allup Silica Limited	Share Capital	Diversified Metals and Mining	Common Equity	APS	Australia
Almonty Industries Inc.	Chess Depositary Interest Common Shares	Diversified Metals and Mining	Depositary Receipt	AII	Canada
Altamin Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AZI	Australia
Altech Batteries Limited	Npv Dfd 11/08/23(ex-Rights)	Aluminium	Common Equity	ATCN	Australia
Altech Batteries Limited	Ordinary Shares	Aluminium	Common Equity	ATC	Australia
Alto Metals Limited	Ordinary Shares	Gold	Common Equity	AME	Australia
Alumina Limited	Ordinary Shares	Aluminium	Common Equity	AWC	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Alvo Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ALV	Australia
Amani Gold Limited	Ordinary Shares	Gold	Common Equity	ANL	Australia
Amani Gold Limited	Warrants (15/01/2024)	Gold	Common Equity	ANLOA	Australia
American Rare Earths Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ARR	Australia
American West Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AW1	Australia
Anax Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ANX	Australia
Andromeda Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ADN	Australia
Anson Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ASN	Australia
Antilles Gold Limited	Ordinary Shares	Gold	Common Equity	AAU	Australia
Antipa Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AZY	Australia
Apollo Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AON	Australia
Arafura Rare Earths Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ARU	Australia
Arcadia Minerals Limited	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	AM7	United Kingdom
Archer Materials Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AXE	Australia
Ardea Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ARL	Australia
Ardiden Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ADV	Australia
Argent Minerals Limited	OPTION 30/11/24 AUD0.04	Diversified Metals and Mining	Depositary Receipt	ARDO	Australia
Argent Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ARD	Australia
Argonaut Resources NL	Ordinary Shares	Gold	Common Equity	ARE	Australia
Argosy Minerals Limited	Common Shares	Diversified Metals and Mining	Common Equity	AGY	Australia
Arizona Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AZL	Australia
Ark Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AHK	Australia
Armada Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AMM	Australia
Arrow Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AMD	Australia
Artemis Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ARV	Australia
Aruma Resources Limited	Ordinary Shares	Gold	Common Equity	AAJ	Australia
Askari Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AS2	Australia
Asra Minerals Limited	Ordinary Shares	Gold	Common Equity	ASR	Australia
Aston Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ASO	Australia
Astral Resources NL	Ordinary Shares	Gold	Common Equity	AAR	Australia
Astron Corporation Limited	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	ATR	Hong Kong
Astute Metals NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	ASE	Australia
Athena Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AHN	Australia
Atlantic Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	A11	Australia
Audalia Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ACP	Australia
Augustus Minerals Ltd	Common Shares	Diversified Metals and Mining	Common Equity	AUG	Australia
AuKing Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AKN	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Aurelia Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AMI	Australia
Auric Mining Limited	Ordinary Shares	Gold	Common Equity	AWJ	Australia
Auris Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AUR	Australia
Aurora Energy Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	1AE	Australia
Aurum Resources Limited	Ordinary Shares	Gold	Common Equity	AUE	Australia
Aurumin Limited	Ordinary Shares	Gold	Common Equity	AUN	Australia
Ausgold Limited	Ordinary Shares	Gold	Common Equity	AUC	Australia
Ausmon Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AOA	Australia
AusQuest Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AQD	Australia
Austin Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AYT	Australia
Austral Gold Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	AGD	Australia
Austral Resources Australia Ltd	Ordinary Shares	Copper	Common Equity	AR1	Australia
Australasian Metals Limited	Ordinary Shares	Gold	Common Equity	A8G	Australia
Australia United Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AYM	Australia
Australian Critical Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ACM	Australia
Australian Gold and Copper Limited	Share Capital	Gold	Common Equity	AGC	Australia
Australian Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AUZ	Australia
Australian Potash Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	APC	Australia
Australian Rare Earths Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AR3	Australia
Australian Silica Quartz Group Ltd.	Ordinary Shares	Diversified Metals and Mining	Common Equity	ASQ	Australia
Australian Strategic Materials Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	ASM	Australia
Australian Vanadium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AVL	Australia
Auteco Minerals Limited	Ordinary Shares	Gold	Common Equity	AUT	Australia
Avenira Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AEV	Australia
Avira Resources Limited	Ordinary Shares	Gold	Common Equity	AVW	Australia
AVZ Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AVZ	Australia
Azure Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AZS	Australia
Balkan Mining and Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BMM	Australia
Ballymore Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BMR	Australia
Barton Gold Holdings Limited	Ordinary Shares	Gold	Common Equity	BGD	Australia
Base Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BSE	Australia
Bastion Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BMO	Australia
Battery Age Minerals Ltd	New Ordinary Shares	Diversified Metals and Mining	Common Equity	BM8	Australia
Battery Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BAT	Australia
BBX Minerals Limited	Ordinary Shares	Gold	Common Equity	BBX	Australia
Beacon Minerals Limited	Ordinary Shares	Gold	Common Equity	BCN	Australia
Belararox Limited	Share Capital	Diversified Metals and Mining	Common Equity	BRX	Australia
Bellavista Resources Limited	Share Capital	Diversified Metals and Mining	Common Equity	BVR	Australia
Bellevue Gold Limited	Ordinary Shares	Gold	Common Equity	BGL	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Benz Mining Corp.	NPV (CDI 1:1)	Diversified Metals and Mining	Depositary Receipt	BNZ	Canada
Besra Gold Inc.	Chess Depositary Interest Common Shares	Gold	Depositary Receipt	BEZ	Canada
BHP Group Limited	LTD Ordinary Shares	Diversified Metals and Mining	Common Equity	BHP	Australia
Bindi Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BIM	Australia
Black Canyon Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BCA	Australia
Black Cat Syndicate Limited	Ordinary Shares	Gold	Common Equity	BC8	Australia
Black Dragon Gold Corp.	Chess Depositary Interest Common Shares	Gold	Depositary Receipt	BDG	Canada
Black Rock Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BKT	Australia
Blackstone Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BSX	Australia
BMG Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BMG	Australia
Boab Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BML	Australia
Boadicea Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	BOA	Australia
Boart Longyear Group Ltd.	Npv Dfd 05/10/21(ex- Split)	Diversified Metals and Mining	Common Equity	N.A.	Canada
Boart Longyear Group Ltd.	Ordinary Shares	Diversified Metals and Mining	Common Equity	BLY	Canada
Bougainville Copper Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BOC	Papua New Guinea
BPM Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BPM	Australia
Brightstar Resources Limited	Ordinary Shares	Gold	Common Equity	BTR	Australia
Bryah Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BYH	Australia
Bubalus Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BUS	Australia
Bulletin Resources Limited	Ordinary Shares	Gold	Common Equity	BNR	Australia
Burgundy Diamond Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BDM	Australia
Burley Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	BUR	Australia
Buxton Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	BUX	Australia
C29 Metals Limited	Share Capital	Diversified Metals and Mining	Common Equity	C29	Australia
Calidus Resources Limited	Ordinary Shares	Gold	Common Equity	CAI	Australia
Cannindah Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CAE	Australia
Canterbury Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CBY	Australia
Canyon Resources Limited	Ordinary Shares	Gold	Common Equity	CAY	Australia
Capral Limited	Ordinary Shares	Aluminium	Common Equity	CAA	Australia
Caprice Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CRS	Australia
Capricorn Metals Ltd	Ordinary Shares	Gold	Common Equity	CMM	Australia
Caravel Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CVV	Australia
Carawine Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CWX	Australia
Carbine Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CRB	Australia
Carnaby Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CNB	Australia
Carnavale Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CAV	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Caspin Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CPN	Australia
Cassius Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CMD	Australia
Castile Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CST	Australia
Castillo Copper Limited	Ordinary Shares	Copper	Common Equity	CCZ	Australia
Castle Minerals Limited	Ordinary Shares	Gold	Common Equity	CDT	Australia
Catalina Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	CTN	Australia
Catalyst Metals Limited	Ordinary Shares	Gold	Common Equity	CYL	Australia
Cavalier Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	CVR	Australia
Cazaly Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CAZ	Australia
Celsius Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CLA	Australia
Centaurus Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CTM	Australia
Centrex Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CXM	Australia
Chalice Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CHN	Australia
Challenger Gold Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CEL	Australia
Charger Metals NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	CHR	Australia
Chesser Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CHZ	Australia
Chilwa Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CHW	Australia
CI Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CII	Australia
Citigold Corporation Limited	Ordinary Shares	Gold	Common Equity	CTO	Australia
Clara Resources Australia Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	C7A	Australia
Classic Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CLZ	Australia
Cobalt Blue Holdings Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	COB	Australia
Cobre Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CBE	Australia
Coda Minerals Limited	Share Capital	Diversified Metals and Mining	Common Equity	COD	Australia
Codrus Minerals Limited	Ordinary Shares	Gold	Common Equity	CDR	Australia
Cohiba Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CHK	Australia
Comet Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CRL	Australia
Conico Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	CNJ	Australia
Constellation Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CR1	Australia
Coolabah Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CBH	Australia
Cooper Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CPM	Australia
Copper Search Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CUS	Australia
Copper Strike Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CSE	Australia
Coppermoly Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	COY	Australia
Corazon Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CZN	Australia
Core Lithium Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	CXO	Australia
Corella Resources Limited	Common Stock	Diversified Metals and Mining	Common Equity	GGL	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Corella Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	CR9	Australia
Cosmo Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CMO	Australia
Cosmos Exploration Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	C1X	Australia
Cradle Resources Limited	Ordinary shares	Diversified Metals and Mining	Common Equity	CXX	Australia
Critical Minerals Group Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CMG	Australia
Critical Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CRR	Australia
CuFe Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	CUF	Australia
Cullen Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CUL	Australia
Culpeo Minerals Limited	Ordinary Shares	Copper	Common Equity	CPO	Australia
Cyclone Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	CLE	Australia
Cygnus Metals Limited	Ordinary Shares	Gold	Common Equity	CY5	Australia
Cyprium Metals Limited	Ordinary Shares	Copper	Common Equity	CYM	Australia
Dacian Gold Limited	Ordinary Shares	Gold	Common Equity	DCN	Australia
Dalaroo Metals Ltd	Common Stock	Diversified Metals and Mining	Common Equity	DAL	Australia
Dart Mining NL	Ordinary Shares	Gold	Common Equity	DTM	Australia
Dateline Resources Limited	Ordinary Shares	Gold	Common Equity	DTR	Australia
DDH1 Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DDH	Australia
De Grey Mining Limited	Ordinary Shares	Gold	Common Equity	DEG	Australia
Delta Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DLI	Australia
Desert Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DM1	Australia
DeSoto Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DES	Australia
Develop Global Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DVP	Australia
DevEx Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DEV	Australia
DGR Global Limited	Ordinary Shares	Gold	Common Equity	DGR	Australia
Diablo Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DBO	Australia
Diatreme Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DRX	Australia
Discovery Alaska Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DAF	Australia
DiscovEx Resources Limited	Ordinary Shares	Gold	Common Equity	DCX	Australia
DMC Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DMM	Australia
Dome Gold Mines Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	DME	Australia
Dragon Mountain Gold Limited	Ordinary Shares	Gold	Common Equity	DMG	Australia
Dreadnought Resources Limited	Ordinary Shares	Gold	Common Equity	DRE	Australia
Duketon Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DKM	Australia
Dundas Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DUN	Australia
DY6 Metals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	DY6	Australia
Dynamic Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	DYM	Australia
E79 Gold Mines Limited	Ordinary Shares	Gold	Common Equity	E79	Australia
Eagle Mountain Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EM2	Australia
Eastern Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EMS	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
EcoGraf Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EGR	Australia
Element 25 Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	E25	Australia
Elementos Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ELT	Australia
Emerald Resources NL	Ordinary Shares	Gold	Common Equity	EMR	Australia
eMetals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EMT	Australia
Emmerson Resources Limited	Ordinary Shares	Gold	Common Equity	ERM	Australia
Empire Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ERL	Australia
Emu NL	Contributing Shares	Diversified Metals and Mining	Common Equity	EMUCA	Australia
Emu NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	EMU	Australia
Encounter Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ENR	Australia
Enegex Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ENX	Australia
Energy Transition Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	ETM	Australia
Enova Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ENV	Australia
ENRG Elements Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EEL	Australia
Enterprise Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ENT	Australia
EQ Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EQR	Australia
Equus Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EQE	Australia
Errawarra Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	ERW	Australia
Essential Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ESS	Australia
Estrella Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ESR	Australia
Euro Manganese Inc.	Chess Depositary Interest Common Shares	Diversified Metals and Mining	Depositary Receipt	EMN	Canada
European Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EUR	Australia
European Metals Holdings Limited	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	EMH	BVI
EV Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EVR	Australia
Evergreen Lithium Limited	Share Capital	Diversified Metals and Mining	Common Equity	EG1	Australia
Evion Group NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	EVG	Australia
Evolution Energy Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	EV1	Australia
Evolution Mining Limited	Ordinary Shares	Gold	Common Equity	EVN	Australia
Falcon Metals Limited	Share Capital	Gold	Common Equity	FAL	Australia
Far East Gold Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FEG	Australia
Felix Gold Limited	Ordinary Shares	Gold	Common Equity	FXG	Australia
Fertoz Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FTZ	Australia
Fin Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FIN	Australia
Firefinch Limited	Ordinary Shares	Gold	Common Equity	FFX	Australia
Firetail Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FTL	Australia
First Au Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FAU	Australia
Flynn Gold Limited	Ordinary Shares	Gold	Common Equity	FG1	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Focus Minerals Limited	Ordinary Shares	Gold	Common Equity	FML	Australia
Forrestania Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FRS	Australia
Frontier Energy Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FHE	Australia
Future Battery Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FBM	Australia
Future Metals NL	Ordinary Shares	Precious Metals and Gemstones	Common Equity	FME	Australia
FYI Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	FYI	Australia
Galan Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GLN	Australia
Galena Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	G1A	Australia
Galileo Mining Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	GAL	Australia
Gascoyne Resources Limited	Ordinary Shares	Gold	Common Equity	GCY	Australia
Gateway Mining Limited	Ordinary Shares	Gold	Common Equity	GML	Australia
GBM Resources Limited	Ordinary Shares	Gold	Common Equity	GBZ	Australia
GCX Metals Limited	Ordinary Shares	Gold	Common Equity	GCX	Australia
Genesis Minerals Limited	Ordinary Shares	Gold	Common Equity	GMD	Australia
Genesis Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GES	Australia
Geopacific Resources Limited	Ordinary Shares	Gold	Common Equity	GPR	Australia
Gibb River Diamonds Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GIB	Australia
Gladiator Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GLA	Australia
Global Lithium Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GL1	Australia
Globe Metals and Mining Limited	PV DFD 07/09/23(EX-RIGHTS)	Diversified Metals and Mining	Common Equity	GBEN	Australia
Globe Metals and Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GBE	Australia
Godolphin Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GRL	Australia
Gold 50 Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	G50	Australia
Gold Mountain Limited	Ordinary Shares	Gold	Common Equity	GMN	Australia
Gold Road Resources Limited	Ordinary Shares	Gold	Common Equity	GOR	Australia
Golden Cross Resources Limited	NPV DFD 01/07/22 (EX-SPLIT)	Gold	Common Equity	GCRDB	Australia
Golden Cross Resources Limited	Ordinary Shares	Gold	Common Equity	GCR	Australia
Golden Deeps Limited	NPV DFD 24/01/24	Diversified Metals and Mining	Common Equity	GEDDA	Australia
Golden Deeps Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GED	Australia
Golden Mile Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	G88	Australia
Golden Rim Resources Ltd	Ordinary Shares	Gold	Common Equity	GMR	Australia
Golden State Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GSM	Australia
GR Engineering Services Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GNG	Australia
Great Boulder Resources Limited	Ordinary Shares	Gold	Common Equity	GBR	Australia
Great Northern Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GNM	Australia
Great Southern Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GSN	Australia
Great Western Exploration Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GTE	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Green Critical Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GCM	Australia
Green Technology Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GT1	Australia
Greenstone Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GSR	Australia
GreenTech Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	GRE	Australia
Greenwing Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	GW1	Australia
Group 6 Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	G6M	Australia
GTI Energy Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	GTR	Australia
Gullewa Limited	Ordinary Shares	Gold	Common Equity	GUL	Australia
GWR Group Limited	Ordinary Shares	Gold	Common Equity	GWR	Australia
Hamelin Gold Limited	Ordinary Shares	Gold	Common Equity	HMG	Australia
Hammer Metals Limited	Ordinary Shares	Gold	Common Equity	HMX	Australia
Hannans Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HNR	Australia
Haranga Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HAR	Australia
Hastings Technology Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HAS	Australia
Havilah Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HAV	Australia
Hawthorn Resources Limited	New Ordinary Shares	Gold	Common Equity	HAW	Australia
Heavy Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HVY	Australia
Heavy Rare Earths Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HRE	Australia
Helix Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HLX	Australia
Hexagon Energy Materials Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HXG	Australia
High-Tech Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HTM	Australia
Hillgrove Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HGO	Australia
Horizon Gold Limited	Ordinary Shares	Gold	Common Equity	HRN	Australia
Horizon Minerals Limited	Ordinary Shares	Gold	Common Equity	HRZ	Australia
Horseshoe Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	HOR	Australia
Hot Chili Limited	Ordinary Shares	Copper	Common Equity	HCH	Australia
Iceni Gold Limited	Ordinary Shares	Gold	Common Equity	ICL	Australia
IGO Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	IGO	Australia
Iltani Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ILT	Australia
Iluka Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ILU	Australia
Image Resources NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	IMA	Australia
Imdex Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	IMD	Australia
Impact Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	IPT	Australia
Inca Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ICG	Australia
Indiana Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	IDA	Australia
Industrial Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	IND	Australia
Infinity Lithium Corporation Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	INF	Australia
Infinity Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	IMI	Australia
Investigator Resources Limited	OPTION 08/03/25 AUD0.063	Diversified Metals and Mining	Common Equity	IVRO	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Investigator Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	IVR	Australia
ioneer Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	INR	Australia
Ionic Rare Earths Limited	Ordinary Shares	Gold	Common Equity	IXR	Australia
IperionX Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	IPX	Australia
IRIS Metals Limited	Ordinary Shares	Gold	Common Equity	IR1	Australia
Ironbark Zinc Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	IBG	Australia
iTech Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	ITM	Australia
Javelin Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	JAV	Australia
Jervois Global Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	JRV	Australia
Jindalee Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	JRL	Australia
Jupiter Mines Limited	New Common Shares	Diversified Metals and Mining	Common Equity	JMS	Australia
Kairos Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KAI	Australia
Kaiser Reef Limited	Ordinary Shares	Gold	Common Equity	KAU	Australia
Kalamazoo Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KZR	Australia
Kalgoorlie Gold Mining Limited	Ordinary Shares	Gold	Common Equity	KAL	Australia
KGL Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KGL	Australia
Killi Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KLI	Australia
Kin Mining NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	KIN	Australia
Kincora Copper Limited	Chess Depositary Interest Common Shares	Diversified Metals and Mining	Depositary Receipt	KCC	Canada
King River Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KRR	Australia
Kingfisher Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KFM	Australia
Kingsgate Consolidated Limited	Ordinary Shares	Gold	Common Equity	KCN	Australia
Kingsland Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	KNG	Australia
Kingsrose Mining Limited	Ordinary Shares	Gold	Common Equity	KRM	Australia
Kingston Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KSN	Australia
Koba Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KOB	Australia
Koonenberry Gold Limited	Ordinary Shares	Gold	Common Equity	KNB	Australia
Korab Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KOR	Australia
Kore Potash plc	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	KP2	United Kingdom
Krakatoa Resources Limited	Ordinary Shares	Gold	Common Equity	KTA	Australia
Kula Gold Limited	Ordinary Shares	Gold	Common Equity	KGD	Australia
Kuniko Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	KNI	Australia
Labyrinth Resources Limited	Ordinary Shares	Gold	Common Equity	LRL	Australia
Lachlan Star Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LSA	Australia
Lake Resources NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	LKE	Australia
Lanthanein Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LNR	Australia
Larvotto Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LRV	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Latin Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LRS	Australia
Latrobe Magnesium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LMG	Australia
LCL Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LCL	Australia
Leeuwin Metals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	LM1	Australia
Lefroy Exploration Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LEX	BVI
Legacy Minerals Holdings Limited	Share Capital	Diversified Metals and Mining	Common Equity	LGM	Australia
Legend Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LEG	Australia
Leo Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LLL	Australia
Lepidico Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LPD	Australia
Lightning Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	L1M	Australia
Lincoln Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LML	Australia
Lindian Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LIN	Australia
Lion One Metals Limited	Chess Depositary Interest Common Shares	Gold	Depositary Receipt	LLO	Canada
Liontown Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LTR	Australia
Lithium Australia Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LIT	Australia
Lithium Australia Limited	NPV PPD (1.01C PAID - 4.99C	Diversified Metals and Mining	Common Equity	LITCF	Australia
Lithium Energy Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LEL	Australia
Lithium Plus Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	LPM	Australia
Lithium Power International Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LPI	Australia
Locksley Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LKY	Australia
Lode Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	LDR	Australia
Lodestar Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LSR	Australia
Lord Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LRD	Australia
Lotus Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LOT	Australia
Lotus Resources Limited	NPV	Diversified Metals and Mining	Common Equity	N.A.	Australia
Loyal Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LLI	Australia
Lucapa Diamond Company Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	LOM	Australia
Lunnon Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LM8	Australia
Lycaon Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LYN	Australia
Lykos Metals Limited	Share Capital	Diversified Metals and Mining	Common Equity	LYK	Australia
Lynas Rare Earths Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	LYC	Australia
M3 Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	M3M	Australia
Macarthur Minerals Limited	Common Shares	Diversified Metals and Mining	Common Equity	MFE	Australia
Macarthur Minerals Limited	NPV (AUS QUOTED)	Diversified Metals and Mining	Common Equity	MIO	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Macmahon Holdings Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MAH	Australia
Magmatic Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MAG	Australia
Magnetic Resources NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	MAU	Australia
Magnetic Resources NL	Contributing Shares	Diversified Metals and Mining	Common Equity	MAUCA	Australia
Magnis Energy Technologies Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MNS	Australia
Magnum Mining and Exploration Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MGU	Australia
Magontec Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MGL	Australia
Mako Gold Limited	Ordinary Shares	Gold	Common Equity	MKG	Australia
Mamba Exploration Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	M24	Australia
Mandrake Resources Limited	Ordinary Shares	Gold	Common Equity	MAN	Australia
Manhattan Corporation Limited	Ordinary Shares	Gold	Common Equity	MHC	Australia
Mantle Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MTL	Australia
Manuka Resources Limited	New Ordinary Shares	Precious Metals and Gemstones	Common Equity	MKR	Australia
Many Peaks Gold Limited	Share Capital	Diversified Metals and Mining	Common Equity	MPG	Australia
Maronan Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MMA	Australia
Marquee Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MQR	Australia
Marvel Gold Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MVL	Australia
Matador Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MZZ	Australia
Matsa Resources Limited	Ordinary Shares	Gold	Common Equity	MAT	Australia
Maximus Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MXR	Australia
Mayur Resources Ltd	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	MRL	Singapore
Medallion Metals Limited	Ordinary Shares	Gold	Common Equity	MM8	Australia
Meeka Metals Limited	Ordinary Shares	Gold	Common Equity	MEK	Australia
Megado Minerals Limited	Ordinary Shares	Gold	Common Equity	MEG	Australia
Metal Bank Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MBK	Australia
Metal Bank Limited	Option Dfd 30/11/22(ex-Split)	Diversified Metals and Mining	Common Equity	MBKDB	Australia
Metal Hawk Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MHK	Australia
Metalicity Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MCT	Australia
Metallica Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MLM	Australia
Metals Australia Ltd	Ordinary Shares	Gold	Common Equity	MLS	Australia
Metals X Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MLX	Australia
MetalsGrove Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MGA	Australia
MetalsTech Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MTC	Australia
Metarock Group Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MYE	Australia
Meteoric Resources NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	MEI	Australia
Metro Mining Limited	Ordinary Shares	Aluminium	Common Equity	MMI	Australia
Midas Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MM1	Australia
Middle Island Resources Limited	Ordinary Shares	Gold	Common Equity	MDI	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Minbos Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MNB	Australia
Mindax Limited	Ordinary Shares	Gold	Common Equity	MDX	Australia
Mineral Commodities Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	MRC	Australia
Mineral Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MIN	Australia
Minerals 260 Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MI6	Australia
MinRex Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MRR	Australia
Miramar Resources Limited	Ordinary Shares	Gold	Common Equity	M2R	Australia
Mitchell Services Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MSV	Australia
Mithril Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MTH	Australia
Mitre Mining Corporation Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MMC	Australia
MLG Oz Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MLG	Australia
Moab Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MOM	Australia
Moho Resources Limited	Ordinary Shares	Gold	Common Equity	MOH	Australia
Mont Royal Resources Limited	Ordinary Shares	Gold	Common Equity	MRZ	Australia
Morella Corporation Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	1MC	Australia
Mount Burgess Mining N.L.	Ordinary Shares	Diversified Metals and Mining	Common Equity	MTB	Australia
Mount Ridley Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MRD	Australia
MRG Metals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	MRQ	Australia
Mt Malcolm Mines NL	Ordinary Shares	Gold	Common Equity	M2M	Australia
MTM Critical Metals Limited	Share Capital	Diversified Metals and Mining	Common Equity	MTM	Australia
Musgrave Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	MGV	Australia
Nagambie Resources Limited	Ordinary Shares	Gold	Common Equity	NAG	Australia
Narryer Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NYM	Australia
Native Mineral Resources Holdings Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NMR	Australia
Navarre Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NML	Australia
Nelson Resources Limited	Ordinary Shares	Gold	Common Equity	NES	Australia
Neometals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	NMT	Australia
New Talisman Gold Mines Limited	Ordinary Shares	Gold	Common Equity	NTL	New Zealand
New World Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NWC	Australia
Newcrest Mining Limited	Ordinary Shares	Gold	Common Equity	NCM	Australia
Newfield Resources Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	NWF	Australia
NewPeak Metals Limited	Ordinary Shares	Gold	Common Equity	NPM	Australia
NewPeak Metals Limited	NPV DFD 19/07/23(EX-OPTION)	Gold	Common Equity	NPMO	Australia
Nex Metals Explorations Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NME	Australia
Nexus Minerals Limited	Ordinary Shares	Gold	Common Equity	NXM	Australia
NGX Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NGX	Australia
Nickel Industries Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NIC	Australia
NickelSearch Limited	New Ordinary Shares	Diversified Metals and Mining	Common Equity	NIS	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
NickelX Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NKL	Australia
NICO Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NC1	Australia
Nimy Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NIM	Australia
Nordic Nickel Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NNL	Australia
Norfolk Metals Limited	Share Capital	Diversified Metals and Mining	Common Equity	NFL	Australia
Noronex Limited	Ordinary Shares	Copper	Common Equity	NRX	Australia
North Stawell Minerals Limited	Common Shares	Gold	Common Equity	NSM	Australia
Northern Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NTU	Australia
Northern Star Resources Limited	Ordinary Shares	Gold	Common Equity	NST	Australia
Norwest Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NWM	Australia
Nova Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	NVA	Australia
NT Minerals Limited	Ordinary Shares	Copper	Common Equity	NTM	Australia
Oakajee Corporation Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	OKJ	Australia
OAR Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	OAR	Australia
Oceana Lithium Limited	Ordinary SHares	Diversified Metals and Mining	Common Equity	OCN	Australia
Octava Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	OCT	Australia
OD6 Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	OD6	Australia
Odessa Minerals Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	ODE	Australia
Odin Metals Limited	Ordinary Shares	Gold	Common Equity	ODM	Australia
Odyssey Gold Limited	Ordinary Shares	Gold	Common Equity	ODY	Australia
Okapi Resources Limited	Ordinary Shares	Gold	Common Equity	OKR	Australia
Olympio Metals Limited	Ordinary Shares	Gold	Common Equity	OLY	Australia
OM Holdings Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	OMH	Bermuda
Omnia Metals Group Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	OM1	Australia
Ookami Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	OOK	Australia
Ora Banda Mining Limited	Ordinary Shares	Gold	Common Equity	OBM	Australia
Ora Gold Limited	Ordinary Shares	Gold	Common Equity	OAU	Australia
Orange Minerals NL	Ordinary shares	Diversified Metals and Mining	Common Equity	OMX	Australia
OreCorp Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ORR	Australia
Orion Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ORM	Australia
Orion Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ORN	Australia
Osmond Resources Limited	Share Capital	Diversified Metals and Mining	Common Equity	OSM	Australia
OzAurum Resources Limited	Ordinary Shares	Gold	Common Equity	OZM	Australia
Ozz Resources Limited	Share Capital	Gold	Common Equity	OZZ	Australia
Pacgold Limited	Ordinary Shares	Gold	Common Equity	PGO	Australia
Pacific Nickel Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PNM	Australia
Pan Asia Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PAM	Singapore
Panoramic Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PAN	Australia
Pantera Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PFE	Australia
Panther Metals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	PNT	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Pantoro Limited	Ordinary Shares	Gold	Common Equity	PNR	Australia
Parabellum Resources Limited	Share Capital	Diversified Metals and Mining	Common Equity	PBL	Australia
Patagonia Lithium Limited	Share Capital	Diversified Metals and Mining	Common Equity	PL3	Australia
Paterson Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	PSL	Australia
Patriot Battery Metals Inc.	CDI ORD NPV 10:1	Diversified Metals and Mining	Depositary Receipt	PMT	Canada
Patriot Lithium Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PAT	Australia
Peak Minerals Limited	Ordinary Shares	Gold	Common Equity	PUA	Australia
Peak Rare Earths Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PEK	Australia
Peako Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PKO	Australia
Peel Mining Limited	Ordinary Shares	Copper	Common Equity	PEX	Australia
Peregrine Gold Limited	Ordinary Shares	Gold	Common Equity	PGD	Australia
Perenti Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PRN	Australia
Perpetual Resources Limited	Ordinary Shares	Gold	Common Equity	PEC	Australia
Perseus Mining Limited	Ordinary Shares	Gold	Common Equity	PRU	Australia
Petratherm Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PTR	Australia
PhosCo Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	PHO	Australia
Piedmont Lithium Inc.	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	PLL	USA
Pilbara Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PLS	Australia
Pinnacle Minerals Limited	Share Capital	Diversified Metals and Mining	Common Equity	PIM	Australia
Pivotal Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PVT	Australia
Platina Resources Limited	Ordinary Shares.	Precious Metals and Gemstones	Common Equity	PGM	Australia
PNX Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PNX	Australia
Podium Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	POD	Australia
PolarX Limited	Npv Dfd 08/09/23 (ex-Rights)	Diversified Metals and Mining	Common Equity	PXXN	Australia
PolarX Limited	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Common Equity	PXX	Australia
Polymetals Resources Ltd	Ordinary Shares	Gold	Common Equity	POL	Australia
Poseidon Nickel Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	POS	Australia
Power Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PNN	Australia
Predictive Discovery Limited	Ordinary Shares	Gold	Common Equity	PDI	Australia
Prodigy Gold NL	Ordinary Shares	Gold	Common Equity	PRX	Australia
Prospech Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PRS	Australia
Prospect Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PSC	Australia
Protean Energy Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	POW	Australia
Province Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PRL	Australia
PT Aneka Tambang Tbk	Chess Depositary Interest Series B Common Shares	Gold	Depositary Receipt	ATM	Indonesia
Pure Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PR1	Australia
Pursuit Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	PUR	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
PVW Resources Limited	Ordinary Shares	Gold	Common Equity	PVW	Australia
QEM Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	QEM	Australia
QMines Limited	Share Capital	Diversified Metals and Mining	Common Equity	QML	Australia
Quantum Graphite Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	QGL	Australia
Queensland Pacific Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	QPM	Australia
QX Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	QXR	Australia
R3D Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	R3D	Australia
Ragnar Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RAG	Australia
Ragusa Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RAS	Australia
Raiden Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RDN	Australia
Ramelius Resources Limited	Ordinary Shares	Gold	Common Equity	RMS	Australia
Rand Mining Limited	Ordinary Shares	Gold	Common Equity	RND	Australia
RareX Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	REE	Australia
RBR Group Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RBR	Australia
Reach Resources Limited	Ordinary Shares	Gold	Common Equity	RR1	Australia
Recharge Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	REC	Australia
Red 5 Limited	Ordinary Shares	Gold	Common Equity	RED	Australia
Red Metal Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RDM	Australia
Red Mountain Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RMX	Australia
Red River Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RVR	Australia
Redcastle Resources Limited	Ordinary Shares	Gold	Common Equity	RC1	Australia
Redstone Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RDS	Australia
Reedy Lagoon Corporation Limited	Npv Dfd 29/08/23(ex-Rights)	Diversified Metals and Mining	Common Equity	RLCN	Australia
Reedy Lagoon Corporation Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RLC	Australia
Regener8 Resources NL	Ordinary Shares	Gold	Common Equity	R8R	Australia
Regis Resources Limited	Ordinary Shares	Gold	Common Equity	RRL	Australia
Renascor Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RNU	Australia
Renegade Exploration Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RNX	Australia
Resolute Mining Limited	Ordinary Shares	Gold	Common Equity	RSG	Australia
Resolute Mining Limited	NPV DFD 07/11/07(EX-RIGHTS)	Gold	Common Equity	N.A.	Australia
Resolution Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RML	Australia
Resource Base Limited	Ordinary Shares	Gold	Common Equity	RBX	Australia
Resource Mining Corporation Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RMI	Australia
Resources and Energy Group Limited	Ordinary Shares	Gold	Common Equity	REZ	Australia
Revolver Resources Holdings Ltd	Ordinary Shares	Copper	Common Equity	RRR	Australia
Rex Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RXM	Australia
Richmond Vanadium Technology Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RVT	Australia
Riedel Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RIE	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Rimfire Pacific Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RIM	Australia
Rincon Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RCR	Australia
Rio Tinto Group	LTD Ordinary Shares	Diversified Metals and Mining	Common Equity	RIO	United Kingdom
Riversgold Limited	Ordinary Shares	Gold	Common Equity	RGL	Australia
Ronin Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	RON	Australia
Rox Resources Limited	Ordinary Shares	Gold	Common Equity	RXL	Australia
RTG Mining Inc.	Chess Depositary Interest Common Shares	Gold	Depositary Receipt	RTG	BVI
Rubix Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RB6	Australia
Rumble Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	RTR	Australia
S2 Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	S2R	Australia
Sabre Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SBR	Australia
Sandfire Resources Limited	Ordinary Shares	Copper	Common Equity	SFR	Australia
Santa Fe Minerals Limited	Ordinary Shares	Gold	Common Equity	SFM	Australia
Santana Minerals Limited	Ordinary Shares	Gold	Common Equity	SMI	Australia
Sarama Resources Ltd	Chess Depositary Interest Common Shares	Gold	Depositary Receipt	SRR	Canada
Sarytogan Graphite Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SGA	Australia
Saturn Metals Limited	Ordinary Shares	Gold	Common Equity	STN	Australia
Savannah Goldfields Limited	Ordinary Shares	Gold	Common Equity	SVG	Australia
Sayona Mining Limited	NPV DFD 29/07/22(EX-OPTION)	Diversified Metals and Mining	Common Equity	SYANE	Australia
Sayona Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SYA	Australia
Scorpion Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SCN	Australia
SensOre Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	S3N	Australia
Sheffield Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SFX	Australia
SI6 Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SI6	Australia
Sierra Nevada Gold Inc.	Chess Depositary Interest Share Capital	Diversified Metals and Mining	Depositary Receipt	SNX	USA
Sierra Nevada Gold Inc.	Npv Dfd 23/08/23(ex-Rights)	Diversified Metals and Mining	Common Equity	SNXN	USA
Sierra Rutile Holdings Limited	New Ordinary Shares	Diversified Metals and Mining	Common Equity	SRX	Australia
Sihayo Gold Limited	Ordinary Shares	Gold	Common Equity	SIH	Australia
Silver Lake Resources Limited	Ordinary Shares	Gold	Common Equity	SLR	Australia
Silver Mines Limited	Ordinary Shares	Silver	Common Equity	SVL	Australia
Sipa Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SRI	Australia
Siren Gold Limited	Ordinary Shares	Gold	Common Equity	SNG	Australia
Sky Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SKY	Australia
Solis Minerals Ltd.	Chess Depositary Interest Common Shares	Diversified Metals and Mining	Depositary Receipt	SLM	Canada
Solstice Minerals Limited	Ordinary Shares	Gold	Common Equity	SLS	Australia
South Harz Potash Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SHP	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
South32 Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	S32	Australia
South-East Queensland Exploration Limited	NPV	Diversified Metals and Mining	Common Equity	SQX	Australia
Southern Cross Gold Ltd	Ordinary Shares	Gold	Common Equity	SXG	Australia
Southern Gold Limited	Ordinary Shares	Gold	Common Equity	SAU	Australia
Southern Hemisphere Mining Limited	Common Shares.	Diversified Metals and Mining	Common Equity	SUH	Australia
Southern Palladium Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	SPD	Australia
Sovereign Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SVM	Australia
SSR Mining Inc.	NPV CDI 1:1	Gold	Depositary Receipt	SSR	Canada
St Barbara Limited	Ordinary Shares	Gold	Common Equity	SBM	Australia
St George Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SGQ	Australia
Star Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SMS	Australia
Stavely Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SVY	Australia
Stelar Metals Limited	Share Capital	Diversified Metals and Mining	Common Equity	SLB	Australia
Stellar Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SRZ	Australia
Strandline Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	STA	Australia
Strata Investment Holdings Plc	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	SRT	United Kingdom
Strategic Energy Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SER	Australia
Strickland Metals Limited	Ordinary Shares	Gold	Common Equity	STK	Australia
Sultan Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SLZ	Australia
Summit Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SUM	Australia
Summit Minerals Limited	Npv Dfd 30/0/25(ex-Option)	Diversified Metals and Mining	Common Equity	N.A.	Australia
Sunrise Energy Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SRL	Australia
Sunshine Metal Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SHN	Australia
Sunstone Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	STM	Australia
Superior Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SPQ	Australia
Surefire Resources NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	SRN	Australia
Syrah Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	SYR	Australia
Taiton Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	T88	Australia
Talga Group Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	TLG	Australia
Talisman Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TLM	Australia
Tambourah Metals Limited	Share Capital	Diversified Metals and Mining	Common Equity	TMB	Australia
Tanami Gold NL	Ordinary Shares	Gold	Common Equity	TAM	Australia
Taruga Minerals Limited	Ordinary Shares	Gold	Common Equity	TAR	Australia
Tasman Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	TAS	Australia
TechGen Metals Ltd	New Ordinary Shares	Diversified Metals and Mining	Common Equity	TG1	Australia
Technology Metals Australia Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TMT	Australia
Tempest Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TEM	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Tempus Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TMR	Australia
Ten Sixty Four Limited	Ordinary Shares	Gold	Common Equity	X64	Australia
Tennant Minerals Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	TMS	Australia
Terrain Minerals Limited	Ordinary Shares	Gold	Common Equity	TMX	Australia
Terramin Australia Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TZN	Australia
Tesoro Gold Ltd	Ordinary Shares	Gold	Common Equity	TSO	Australia
TG Metals Limited	Common Shares	Diversified Metals and Mining	Common Equity	TG6	Australia
Theta Gold Mines Limited	Ordinary Shares	Gold	Common Equity	TGM	Australia
Thomson Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	TMZ	Australia
Thomson Resources Ltd	NPV DFD	Diversified Metals and Mining	Common Equity	TMZN	Australia
Thomson Resources Ltd	OPTION 30/11/22 AUD0.03	Diversified Metals and Mining	Common Equity	TMZO	Australia
Thor Energy Plc	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	THR	United Kingdom
Tian Poh Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TPO	Australia
Tietto Minerals Limited	Ordinary Shares	Gold	Common Equity	TIE	Australia
Titan Minerals Limited	Common Shares	Gold	Common Equity	TTM	Australia
Titanium Sands Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TSL	Australia
Tivan Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TVN	Australia
Todd River Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TRT	Australia
Tombola Gold Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TBA	Australia
Torque Metals Limited	Ordinary Shares	Gold	Common Equity	TOR	Australia
Toubani Resources Inc.	CDI ORD NPV 1:1	Gold	Depositary Receipt	TRE	Canada
Traka Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TKL	Australia
Trek Metals Limited	Chess Depositary Interest Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	TKM	Bermuda
Tribune Resources Limited	Ordinary Shares	Gold	Common Equity	TBR	Australia
Triton Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TON	Australia
Troy Resources Limited	Ordinary Shares	Gold	Common Equity	TRY	Australia
True North Copper Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TNC	Australia
Truscott Mining Corporation Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	TRM	Australia
Tungsten Mining NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	TGN	Australia
Turaco Gold Limited	Ordinary Shares	Gold	Common Equity	TCG	Australia
Unico Silver Limited	Ordinary Shares	Gold	Common Equity	USL	Australia
Uvre Limited	Share Capital	Diversified Metals and Mining	Common Equity	UVA	Australia
Valor Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VAL	Australia
Vanadium Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VR8	Australia
Variscan Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VAR	Australia
Venture Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VMS	Australia
Venus Metals Corporation Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	VMC	Australia
Vertex Minerals Limited	Ordinary Shares	Gold	Common Equity	VTX	Australia
VHM Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VHM	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
ViaGold Rare Earth Resources Holdings Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VIA	Bermuda
Victory Metals Limited	New Ordinary Shares	Gold	Common Equity	VTM	Australia
Viking Mines Limited	Ordinary Shares	Gold	Common Equity	VKA	Australia
Viridis Mining and Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VMM	Australia
Vital Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VML	Australia
Volt Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VRC	Australia
Voltaic Strategic Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VSR	Australia
VRX Silica Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VRX	Australia
Vulcan Energy Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VUL	Australia
Vysarn Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	VYS	Australia
WA Kaolin Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WAK	Australia
WA1 Resources Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	WA1	Australia
Walkabout Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WKT	Australia
Warriedar Resources Limited	Ordinary Shares	Gold	Common Equity	WA8	Australia
West African Resources Limited	Ordinary Shares	Gold	Common Equity	WAF	Australia
West Cobar Metals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WC1	Australia
West Wits Mining Limited	Ordinary Shares	Gold	Common Equity	WWI	Australia
Westar Resources Limited	Ordinary Shares	Gold	Common Equity	WSR	Australia
Western Gold Resources Limited	Ordinary Shares	Gold	Common Equity	WGR	Australia
Western Mines Group Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	WMG	Australia
Western Yilgarn NL	Ordinary Shares	Aluminium	Common Equity	WYX	Australia
Westgold Resources Limited	Ordinary Shares	Gold	Common Equity	WGX	Australia
WestStar Industrial Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WSI	Australia
White Cliff Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WCN	Australia

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
White Rock Minerals Ltd	Ordinary Shares	Diversified Metals and Mining	Common Equity	WRM	Australia
WIA Gold Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WIA	Australia
WIA Gold Limited	NPV DFD 22/08/23(EX-RIGHTS)	Diversified Metals and Mining	Common Equity	WIAN	Australia
Widgie Nickel Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WIN	Australia
Wildcat Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WC8	Australia
Wiluna Mining Corporation Limited	Ordinary Shares	Gold	Common Equity	WMC	Australia
Winsome Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WR1	Australia
Woomera Mining Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	WML	Australia
Xanadu Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	XAM	Australia
Xantippe Resources Limited	Npv Dfd 17/08/23 (ex-Rights)	Diversified Metals and Mining	Common Equity	XTCN	Australia
Xantippe Resources Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	XTC	Australia
Yandal Resources Limited	Ordinary Shares	Gold	Common Equity	YRL	Australia
Yari Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	YAR	Australia
Zenith Minerals Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ZNC	Australia
Zeotech Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	ZEO	Australia
Zimplats Holdings Limited	Ordinary Shares	Precious Metals and Gemstones	Common Equity	ZIM	United Kingdom
Zinc of Ireland NL	Ordinary Shares	Diversified Metals and Mining	Common Equity	ZMI	Australia
Zuleika Gold Limited	Ordinary Shares	Gold	Common Equity	ZAG	Australia

9.3.4 Annexure C-4: Mining Companies on the TSX

Table 9-23: Example showing the names and selected information of companies listed on the TSX

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp- oration
Aclara Resources Inc.	Class A Ordinary Shares	Diversified Metals and Mining	Common Equity	ARA	Canada
Agnico Eagle Mines Limited	Common Shares	Gold	Common Equity	AEM	Canada
Alamos Gold Inc.	Class A common stock, no par value.	Gold	Common Equity	AGI	Canada
Allkem Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	AKE	Australia
Almaden Minerals Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	AMM	Canada
Almonty Industries Inc.	Common Shares	Diversified Metals and Mining	Common Equity	AII	Canada
Alta Copper Corp.	Common Shares	Copper	Common Equity	ATCU	Canada
Altius Minerals Corporation	Common Shares	Diversified Metals and Mining	Common Equity	ALS	Canada
Americas Gold and Silver Corporation	Common Shares	Diversified Metals and Mining	Common Equity	USA	Canada
Amerigo Resources Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	ARG	Canada
Argonaut Gold Inc.	Common Shares	Gold	Common Equity	AR	Canada
Aris Mining Corporation	Common Voting Shares	Gold	Common Equity	ARIS	Canada
Arizona Metals Corp.	New Common Shares	Diversified Metals and Mining	Common Equity	AMC	Canada
Arizona Sonoran Copper Company Inc.	Common Shares	Copper	Common Equity	ASCU	Canada
Ascendant Resources Inc.	Common Shares	Diversified Metals and Mining	Common Equity	ASND	Canada
Ascot Resources Ltd.	Common Shares	Gold	Common Equity	AOT	Canada
Augusta Gold Corp.	Common Stock	Diversified Metals and Mining	Common Equity	G	USA
Aura Minerals Inc.	Common Shares	Gold	Common Equity	ORA	BVI
Avalon Advanced Materials Inc.	Common Shares	Diversified Metals and Mining	Common Equity	AVL	Canada
Avino Silver and Gold Mines Ltd.	Common Shares	Precious Metals and Gemstones	Common Equity	ASM	Canada
Aya Gold and Silver Inc.	Common Shares	Silver	Common Equity	AYA	Canada
B2Gold Corp.	Common Shares	Gold	Common Equity	BTO	Canada
Barrick Gold Corporation	Common Shares.	Gold	Common Equity	ABX	Canada
Belo Sun Mining Corp	Common Shares	Gold	Common Equity	BSX	Canada
Calibre Mining Corp.	Common Shares	Gold	Common Equity	CXB	Canada
Canagold Resources Ltd.	Common Shares	Gold	Common Equity	CCM	Canada

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp- oration
Capstone Copper Corp.	New Common Shares	Copper	Common Equity	CS	Canada
Centamin plc	Ordinary Shares	Gold	Common Equity	CEE	United Kingdom
Centerra Gold Inc.	Common Shares	Gold	Common Equity	CG	Canada
China Gold International Resources Corp. Ltd.	Common Shares.	Gold	Common Equity	CGG	Canada
Condor Gold Plc	Ordinary Shares	Gold	Common Equity	COG	United Kingdom
Discovery Silver Corp.	Common Shares	Silver	Common Equity	DSV	Canada
Dundee Precious Metals Inc.	Common Shares	Gold	Common Equity	DPM	Canada
Dynacor Group Inc.	Common Shares	Gold	Common Equity	DNG	Canada
Eastern Platinum Limited	Common Shares	Precious Metals and Gemstones	Common Equity	ELR	Canada
Eldorado Gold Corporation	Voting Common Shares.	Gold	Common Equity	ELD	Canada
Eloro Resources Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	ELO	Canada
Endeavour Mining plc	Voting Shares	Gold	Common Equity	EDV	United Kingdom
Endeavour Silver Corp.	Common Shares	Silver	Common Equity	EDR	Canada
Entrée Resources Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	ETG	Canada
Equinox Gold Corp.	New Common Shares	Gold	Common Equity	EQX	Canada
Erdene Resource Development Corporation	Common Shares	Diversified Metals and Mining	Common Equity	ERD	Canada
Ero Copper Corp.	Common Shares	Copper	Common Equity	ERO	Canada
Euro Sun Mining Inc.	Common Shares	Diversified Metals and Mining	Common Equity	ESM	Canada
Euromax Resources Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	EOX	Canada
Excellon Resources Inc.	Common Shares	Silver	Common Equity	EXN	Canada
Excelsior Mining Corp.	Common Shares	Diversified Metals and Mining	Common Equity	MIN	Canada
Faraday Copper Corp.	New Common Shares	Copper	Common Equity	FDY	Canada
Filo Corp.	Common Shares	Diversified Metals and Mining	Common Equity	FIL	Canada
First Majestic Silver Corp.	Common Shares	Silver	Common Equity	FR	Canada
First Mining Gold Corp.	New Common Shares	Gold	Common Equity	FF	Canada
First Quantum Minerals Ltd.	Common Shares	Copper	Common Equity	FM	Canada
Foraco International SA	Ordinary Shares	Diversified Metals and Mining	Common Equity	FAR	France
Foran Mining Corporation	Common Shares	Diversified Metals and Mining	Common Equity	FOM	Canada
Fortuna Silver Mines Inc.	Common Shares	Silver	Common Equity	FVI	Canada
Fortune Minerals Limited	Common Shares	Diversified Metals and Mining	Common Equity	FT	Canada

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp- oration
Franco-Nevada Corporation	Common stock, no par value.	Gold	Common Equity	FNV	Canada
Freegold Ventures Limited	Common Shares	Gold	Common Equity	FVL	Canada
Fury Gold Mines Limited	Common Shares	Gold	Common Equity	FURY	Canada
Galiano Gold Inc.	Common Shares	Gold	Common Equity	GAU	Canada
Gatos Silver, Inc.	Common Stock	Silver	Common Equity	GATO	USA
Generation Mining Limited	Common Shares	Precious Metals and Gemstones	Common Equity	GENM	Canada
Global Atomic Corporation	Common Shares	Diversified Metals and Mining	Common Equity	GLO	Canada
Globex Mining Enterprises Inc.	Common Shares	Diversified Metals and Mining	Common Equity	GMX	Canada
GoGold Resources Inc.	Common Shares	Silver	Common Equity	GGD	Canada
Gold Mountain Mining Corp.	Common Shares	Gold	Common Equity	GMTN	Canada
Gold Springs Resource Corp.	Common Shares	Gold	Common Equity	GRC	Canada
Golden Minerals Company	Common Stock	Precious Metals and Gemstones	Common Equity	AUMN	USA
Goldgroup Mining Inc.	Common Shares	Gold	Common Equity	GGA	Canada
GoldMining Inc.	Common Shares	Gold	Common Equity	GOLD	Canada
Horizonte Minerals Plc	Ordinary Shares	Diversified Metals and Mining	Common Equity	HZM	United Kingdom
Hudbay Minerals Inc.	Common Shares	Diversified Metals and Mining	Common Equity	HBM	Canada
i-80 Gold Corp.	Common Shares	Gold	Common Equity	IAU	Canada
IAMGOLD Corporation	Common Shares.	Gold	Common Equity	IMG	Canada
Imperial Metals Corporation	Common Shares	Copper	Common Equity	III	Canada
International Tower Hill Mines Ltd.	Common Shares	Gold	Common Equity	ITH	Canada
Ivanhoe Electric Inc.	Common Stock	Diversified Metals and Mining	Common Equity	IE	USA
Ivanhoe Mines Ltd.	Class A Common Shares	Diversified Metals and Mining	Common Equity	IVN	Canada
Jaguar Mining Inc.	Common Shares	Gold	Common Equity	JAG	Canada
K92 Mining Inc.	Common Shares	Gold	Common Equity	KNT	Canada
Karora Resources Inc.	Common Shares	Gold	Common Equity	KRR	Canada
Kinross Gold Corporation	Common Shares	Gold	Common Equity	K	Canada
Largo Inc.	Common Shares	Diversified Metals and Mining	Common Equity	LGO	Canada
Liberty Gold Corp.	Common Stock	Gold	Common Equity	LGD	Canada
Lithium Americas Corp.	Common Shares	Diversified Metals and Mining	Common Equity	LAC	Canada
Lithium Royalty Corp.	Common Shares	Diversified Metals and Mining	Common Equity	LIRC	Canada
Loncor Gold Inc.	Common Shares	Gold	Common Equity	LN	Canada
Lucara Diamond Corp.	Common Shares	Precious Metals and Gemstones	Common Equity	LUC	Canada
Lundin Gold Inc.	Common Shares	Gold	Common Equity	LUG	Canada

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp- oration
Lundin Mining Corporation	Common Shares	Copper	Common Equity	LUN	Canada
MAG Silver Corp.	Common Shares	Silver	Common Equity	MAG	Canada
Major Drilling Group International Inc.	Common Shares	Diversified Metals and Mining	Common Equity	MDI	Canada
Mandalay Resources Corporation	Common Shares	Gold	Common Equity	MND	Canada
Marathon Gold Corporation	Common Shares	Gold	Common Equity	MOZ	Canada
Marimaca Copper Corp.	Common Shares	Copper	Common Equity	MARI	Canada
Mawson Gold Limited	Common Shares.	Gold	Common Equity	MAW	Canada
McEwen Mining Inc.	Common Stock	Gold	Common Equity	MUX	USA
Meridian Mining UK Societas	Common Shares	Diversified Metals and Mining	Common Equity	MNO	United Kingdom
Minco Silver Corporation	Common Shares	Silver	Common Equity	MSV	Canada
Mineros S.A.	Ordinary Shares	Gold	Common Equity	MSA	Colombia
Monarch Mining Corporation	Common Shares	Gold	Common Equity	GBAR	Canada
Moneta Gold Inc.	Common Shares	Gold	Common Equity	ME	Canada
Mountain Province Diamonds Inc.	Common Shares	Precious Metals and Gemstones	Common Equity	MPVD	Canada
Nevada Copper Corp.	Common Stock	Copper	Common Equity	NCU	Canada
New Gold Inc.	Common Shares	Gold	Common Equity	NGD	Canada
New Pacific Metals Corp.	Common Shares.	Silver	Common Equity	NUAG	Canada
Newcrest Mining Limited	Ordinary Shares	Gold	Common Equity	NCM	Australia
Newmont Corporation	Common Shares	Gold	Common Equity	NGT	USA
NextSource Materials Inc.	Common Stock	Diversified Metals and Mining	Common Equity	NEXT	Canada
Nickel Creek Platinum Corp.	Common Shares	Diversified Metals and Mining	Common Equity	NCP	Canada
Nighthawk Gold Corp.	Common Shares	Gold	Common Equity	NHK	Canada
NioCorp Developments Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	NB	Canada
Northcliff Resources Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	NCF	Canada
Northern Dynasty Minerals Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	NDM	Canada
NovaGold Resources Inc.	Common Shares	Gold	Common Equity	NG	Canada
Novo Resources Corp.	Common Shares	Gold	Common Equity	NVO	Canada
OceanaGold Corporation	Ordinary Shares	Gold	Common Equity	OGC	Canada
Orbit Garant Drilling Inc.	Common Shares	Diversified Metals and Mining	Common Equity	OGD	Canada
Orea Mining Corp.	Common Shares	Gold	Common Equity	OREA	Canada
Orezone Gold Corporation	Common Shares	Gold	Common Equity	ORE	Canada
Orla Mining Ltd.	Common Shares	Gold	Common Equity	OLA	Canada

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp- oration
Orvana Minerals Corp.	Common Shares	Gold	Common Equity	ORV	Canada
Osisko Gold Royalties Ltd	Common Shares.	Gold	Common Equity	OR	Canada
Osisko Mining Inc.	Common Shares	Gold	Common Equity	OSK	Canada
Pan American Silver Corp.	Common Shares	Silver	Common Equity	PAAS	Canada
Perpetua Resources Corp.	Common Shares	Gold	Common Equity	PPTA	Canada
Perseus Mining Limited	Ordinary Shares	Gold	Common Equity	PRU	Australia
Platinum Group Metals Ltd.	Common Shares	Precious Metals and Gemstones	Common Equity	PTM	Canada
PolyMet Mining Corp.	Common Shares	Diversified Metals and Mining	Common Equity	POM	Canada
Probe Gold Inc.	Common Shares	Gold	Common Equity	PRB	Canada
Queen's Road Capital Investment Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	QRC	Cayman Islands
RTG Mining Inc.	Common Shares	Gold	Common Equity	RTG	BVI
Rupert Resources Ltd.	Common Shares	Gold	Common Equity	RUP	Canada
Sabre Gold Mines Corp.	Common Shares	Gold	Common Equity	SGLD	Canada
San Gold Corporation	Common Shares	Gold	Common Equity	N.A.	Canada
Sandstorm Gold Ltd.	Common Shares.	Gold	Common Equity	SSL	Canada
Scandium International Mining Corp.	Common Shares	Diversified Metals and Mining	Common Equity	SCY	Canada
Seabridge Gold Inc.	Common Shares	Gold	Common Equity	SEA	Canada
Serabi Gold plc	Ordinary Shares	Gold	Common Equity	SBI	United Kingdom
Sherritt International Corporation	Restricted Voting Shares	Diversified Metals and Mining	Common Equity	S	Canada
Sierra Metals Inc.	Common Shares	Diversified Metals and Mining	Common Equity	SMT	Canada
Signal Gold Inc.	Common Shares	Gold	Common Equity	SGNL	Canada
Silver Bear Resources Plc	Common Shares	Silver	Common Equity	SBR	United Kingdom
Silver Bull Resources, Inc.	Common Stock	Diversified Metals and Mining	Common Equity	SVB	USA
Silvercorp Metals Inc.	Common Shares.	Silver	Common Equity	SVM	Canada
SilverCrest Metals Inc.	Common Shares	Silver	Common Equity	SIL	Canada
Skeena Resources Limited	Common Shares	Gold	Common Equity	SKE	Canada
Solaris Resources Inc.	Common Shares	Diversified Metals and Mining	Common Equity	SLS	Canada
SolGold Plc	Ordinary Shares	Copper	Common Equity	SOLG	United Kingdom
Solitario Resources Corp.	Common Stock	Diversified Metals and Mining	Common Equity	SLR	USA
SSR Mining Inc.	Common Shares	Gold	Common Equity	SSRM	Canada
St. Augustine Gold and Copper Limited	Common Shares	Gold	Common Equity	SAU	BVI
Star Diamond Corporation	Common Shares	Precious Metals and Gemstones	Common Equity	DIAM	Canada
Starcore International Mines Ltd.	Common Shares	Gold	Common Equity	SAM	Canada

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp- oration
Steppe Gold Ltd.	Common Shares	Precious Metals and Gemstones	Common Equity	STGO	Canada
Sulliden Mining Capital Inc.	Common Shares	Precious Metals and Gemstones	Common Equity	SMC	Canada
Talisker Resources Ltd.	Common Shares	Diversified Metals and Mining	Common Equity	TSK	Canada
Talon Metals Corp.	Common Shares	Diversified Metals and Mining	Common Equity	TLO	BVI
Taseko Mines Limited	Common Shares.	Copper	Common Equity	TKO	Canada
Teck Resources Limited	Class B Subordinated Voting Shares	Diversified Metals and Mining	Common Equity	TECK.B	Canada
Teck Resources Limited	Class A Common Shares	Diversified Metals and Mining	Common Equity	TECK.A	Canada
Titan Mining Corporation	Common Shares	Diversified Metals and Mining	Common Equity	TI	Canada
Torex Gold Resources Inc.	Common Shares	Gold	Common Equity	TXG	Canada
Treasury Metals Inc.	Common Shares	Gold	Common Equity	TML	Canada
Trilogy Metals Inc.	Common Shares	Diversified Metals and Mining	Common Equity	TMQ	Canada
Triple Flag Precious Metals Corp.	Common Shares	Gold	Common Equity	TFPM	Canada
Troilus Gold Corp.	Common Shares	Gold	Common Equity	TLG	Canada
TRX Gold Corporation	Common Shares	Gold	Common Equity	TNX	Canada
Victoria Gold Corp.	Common Shares	Gold	Common Equity	VGCX	Canada
Vista Gold Corp.	Common Shares	Gold	Common Equity	VGZ	Canada
Vox Royalty Corp.	Common Shares	Precious Metals and Gemstones	Common Equity	VOXR	Canada
Wallbridge Mining Company Limited	Common Shares	Diversified Metals and Mining	Common Equity	WM	Canada
Wesdome Gold Mines Ltd.	Common Shares	Gold	Common Equity	WDO	Canada
Western Copper and Gold Corporation	Common Shares	Diversified Metals and Mining	Common Equity	WRN	Canada
Wheaton Precious Metals Corp.	Common Shares	Gold	Common Equity	WPM	Canada
Xanadu Mines Limited	Ordinary Shares	Diversified Metals and Mining	Common Equity	XAM	Australia
Xtra-Gold Resources Corp.	Common Stock	Gold	Common Equity	XTG	BVI
Yorbeau Resources Inc.	Class A Common Shares	Gold	Common Equity	YRB	Canada

9.3.5 Annexure C-5: Mining Companies on the NYSE

Table 9-24: Example showing the names and selected information of companies listed listed on the NYSE

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Agnico Eagle Mines Limited	Common Shares	Gold	Common Equity	AEM	Canada
Alamos Gold Inc.	Class A common stock, no par value.	Gold	Common Equity	AGI	Canada
AngloGold Ashanti Limited	American Depositary Receipts Ordinary Shares	Gold	Depositary Receipt	AU	South Africa
Apex Mining Co., Inc.	Common Shares	Gold	Common Equity	APXNF	Philippines
Barrick Gold Corporation	Common Shares.	Gold	Common Equity	GOLD	Canada
BHP Group Limited	American Depositary Receipts LTD Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	BHP	Australia
Centerra Gold Inc.	Common Shares	Gold	Common Equity	CGAU	Canada
Coeur Mining, Inc.	Common Stock	Gold	Common Equity	CDE	USA
Compañía de Minas Buenaventura S.A.A.	American Depositary Receipts Common Shares	Gold	Depositary Receipt	BVN	Peru
Compass Minerals International, Inc.	Common Stock	Diversified Metals and Mining	Common Equity	CMP	USA
DRDGOLD Limited	American Depositary Receipts Ordinary Shares	Gold	Depositary Receipt	DRD	South Africa
Eldorado Gold Corporation	Voting Common Shares.	Gold	Common Equity	EGO	Canada
Endeavour Silver Corp.	Common Shares	Silver	Common Equity	EXK	Canada
Ero Copper Corp.	Common Shares	Copper	Common Equity	ERO	Canada
First Majestic Silver Corp.	Common Shares	Silver	Common Equity	AG	Canada
Fortuna Silver Mines Inc.	Common Shares	Silver	Common Equity	FSM	Canada
Franco-Nevada Corporation	Common stock, no par value.	Gold	Common Equity	FNV	Canada
Freeport-McMoRan Inc.	Class B Common Stock	Copper	Common Equity	FCX	USA
Gatos Silver, Inc.	Common Stock	Silver	Common Equity	GATO	USA
Gold Fields Limited	American Depositary Receipts Ordinary Shares	Gold	Depositary Receipt	GFI	South Africa
Harmony Gold Mining Company Limited	American Depositary Receipts Ordinary Shares	Gold	Depositary Receipt	HMY	South Africa

Issuer Name	Description	Industry Classification	Equity Type	Ticker	Country of Incorp-oration
Hecla Mining Company	Common Stock	Silver	Common Equity	HL	USA
Hecla Mining Company	PFD CV SER B	Silver	Preferred Security	HL.PR B	USA
Hudbay Minerals Inc.	Common Shares	Diversified Metals and Mining	Common Equity	HBM	Canada
IAMGOLD Corporation	Common Shares.	Gold	Common Equity	IAG	Canada
Kinross Gold Corporation	Common Shares	Gold	Common Equity	KGC	Canada
Lithium Americas Corp.	Common Shares	Diversified Metals and Mining	Common Equity	LAC	Canada
Materion Corporation	Common Stock	Diversified Metals and Mining	Common Equity	MTRN	USA
McEwen Mining Inc.	Common Stock	Gold	Common Equity	MUX	USA
Metals Acquisition Limited	Ordinary Shares	Copper	Common Equity	MTAL	United Kingdom
MP Materials Corp.	Class A Common Stock	Diversified Metals and Mining	Common Equity	MP	USA
Newmont Corporation	Common Shares	Gold	Common Equity	NEM	USA
Nexa Resources S.A.	Common Shares	Diversified Metals and Mining	Common Equity	NEXA	Luxembourg
Nouveau Monde Graphite Inc.	Common Shares	Diversified Metals and Mining	Common Equity	NMG	Canada
Osisko Development Corp.	Common Shares	Gold	Common Equity	ODV	Canada
Osisko Gold Royalties Ltd	Common Shares.	Gold	Common Equity	OR	Canada
Pan American Silver Corp.	Common Shares	Silver	Common Equity	PAAS	Canada
Rio Tinto Group	American Depositary Receipts PLC Ordinary Shares	Diversified Metals and Mining	Depositary Receipt	RIO	United Kingdom
Sandstorm Gold Ltd.	Common Shares.	Gold	Common Equity	SAND	Canada
Seabridge Gold Inc.	Common Shares	Gold	Common Equity	SA	Canada
Sibanye Stillwater Limited	SPON ADR EACH REP 4 ORD SHS	Precious Metals and Gemstones	Depositary Receipt	SBSW	South Africa
Skeena Resources Limited	Common Shares	Gold	Common Equity	SKE	Canada
Southern Copper Corporation	Common Stock	Copper	Common Equity	SCCO	USA
Teck Resources Limited	Class B Subordinated Voting Shares	Diversified Metals and Mining	Common Equity	TECK	Canada
Triple Flag Precious Metals Corp.	Common Shares	Gold	Common Equity	TFPM	Canada
Western Atlas Resources Inc.	Common shares	Gold	Common Equity	N.A.	Canada
Wheaton Precious Metals Corp.	Common Shares	Gold	Common Equity	WPM	Canada

9.3.6 Annexure C-6: Hard Rock Mining Operations in South Africa

Table 9-25: List of hard rock mining operations in South Africa

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Afplats (Pty) Ltd-Leeuwkop Mine		Impala Platinum Holdings Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Underground
Afrimat Demaneng Mine (Pty) Ltd		Afrimat (Pty) Ltd	Manganese Ore; Iron Ore	Northern Cape	Opencast
Akanani	Central, Northern, P1, P2, Southern Priority Area, SPA	Sibanye Stillwater Ltd.	Platinum	Limpopo	
Amandelbult Production Services		Anglo Platinum Ltd	PGM	Limpopo	Opencast
Amari Manganese (Pty) Ltd		ENRC Management (Pty) Ltd	Manganese Ore	Northern Cape	Underground
Anglo Platinum - Dishaba Mine		Anglo Platinum Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Opencast; Underground
Anglo Platinum - Tumela Mine		Anglo Platinum Ltd	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sodium Sulphate; Sulphur	Limpopo	Opencast; Underground
Aquila Steel (South Africa) (Pty) Ltd		Aquila Resources Ltd	Iron Ore	Limpopo	Opencast
Armgold/Orkney	Orkney, Vaal Reefs Shafts 1 to 7, Welkom	China African Precious Metals (Pty) Ltd.	Gold	North-West	
Assen Iron Ore		Manngwe Mining (Pty) Ltd	Iron Ore	North-West	Opencast
Assmang (Pty) Ltd - Beeshoek	Beeshoek	African Rainbow Minerals/Assore	Iron Ore	Northern Cape	Opencast
Assmang (Pty) Ltd - Manganese Mines		African Rainbow Minerals Ltd / Assore Ltd	Manganese Ore	Northern Cape	Underground
Assmang Ltd - Manganese Mines		African Rainbow Minerals Ltd / Assore Ltd	Manganese Ore	Northern Cape	Opencast
Aurico Gold Reclamation (Pty) Ltd		Aurico Gold Reclamation (Pty) Ltd	Gold	North-West	Surface
Autumn Skies Mine		Autumn Skies Resources And Logistics (Pty) Ltd	Iron Ore; Iron Bp Manganese	Northern Cape	Opencast
Bafokeng Rasimone Platinum Mine		Royal Bafokeng Platinum	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Opencast; Underground
Bakubung	BPM, Frischgewaagd, Ledig Frischgewaagd, Mimosa 81 JQ, MR, Pilanesberg, Project 2, Zandrivierspoort 210 JP	Wesizwe Platinum Ltd.	Platinum	North-West	
Bakubung Minerals (Pty) Ltd		Wesizwe Platinum Ltd	PGM	North-West	Underground

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Barberton	11-block, Agnes, Amira, Betty, BGMO, Bluejackets, Western Cross, Thomas, ZK, Zwartkoppie, Zwartkoppies Deep	Pan African Resources Plc	Gold	Mpumalanga	
Barbrook	Barberton, Brown, Clifford Scott, Daylight, French Bob, Maid O' Mist, Spring Hills, Taylors, Victory	Vantage Goldfields Ltd.	Gold	Mpumalanga	
Barbrook Mines Limited		Eastern Goldfields Sa (Pty) Ltd	Gold; Silver	Mpumalanga	Underground
Barplats Mines Ltd		Eastern Platinum Ltd	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Underground
Bathopele Mine		Sibanye Platinum Rustenburg	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Underground
Bauba A Hlabirwa Mining Investments (Pty) Ltd		Bauba Platinum	Chrome Ore	Mpumalanga	Opencast
Beatrix Mining Operations		Sibanye - Stillwater	Gold; Silver	Free State	Underground
Beeshoek	Beeshoek Village Pit, Beesthoek, BF, BN, Bruce Pit, East Pit, GF, HF/HB, HH Ext, HL, King Pit, ML3/93, NC 223 MRC, Olyn Fontein, Olynfontein, Oppikoppie, Village, Village Pit, West Pit	Assmang Pty. Ltd.	Iron Ore	Northern Cape	
Black Chrome	Mooihoek	Chrometco Ltd.	Chromite	Limpopo	
Black Mountain	Big Syncline, BMM, Broken Hill, Deeps, Swartberg, Zinc International	Vedanta Ltd.	Lead	Northern Cape	
Black Mountain Mining (Pty) Ltd		Vedanta Resources Plc	Lead Metal Ic; Silver; Iron Ore; Copper; Lead Concentrate; Zinc Concentrate; Zinc Metal Ic	Northern Cape	Underground
Black Mountain Mining (Pty) Ltd - Gamsberg Project	Gamsberg (manual entry)	Vedanta Resources Plc	Zinc Metal Ic; Copper; Lead Metal Ic	Northern Cape	Opencast
Blue Ridge	BB-TBM, Blaauwbank, Blue Sky North, Fonte Verde, Millennium, Sperrylite	Sibanye Stillwater Ltd.	Platinum	Limpopo	
Blue Ridge Platinum Mine		Sibanye Platinum Mine	PGM; Gold; Cobalt Metal Ic;	Mpumalanga	Underground

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
			Copper; Nickel; Sulphur		
Blyvooruitzicht Gold Mine		Harvard - Liquidators	Gold; Silver	Gauteng	Underground
Bokang Mine		Afgem Ltd	Diamonds Kimberlite	Northern Cape	Underground
Bokoni Platinum Mines (Pty) Limited		Atlatsa Resources Corporation	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Underground
Booysendal		Northam Platinum Ltd	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	Mpumalanga	Opencast
Booysendal North	BNM, BNU, Buttonshope 51JT, Der Brochen 7JT, Draaikraal 48JT, Hebron 5JT, Kliprivier 73JT, Merensky, North UG2, Pietersburg, Sheeprun 50JT, Uysedoorns 47JT	Northam Platinum Holdings Ltd.	Platinum	Limpopo	
Booysendal South	Buttonshope, Draaikraal, Everest, Klipriver, Sheeprun	Northam Platinum Holdings Ltd.	Platinum	Mpumalanga	
Boshoek	Boekenhoutfontein, Bultfontein	Sa Chrome Jv	Chromite	North-West	
Boshoek		Glencore Merafe Venture	Chrome Ore	North-West	Opencast
Boskop Mine		Dvd Quality Engineering (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Bosveld Mines		Gnt Mining (Pty) Ltd	Gold; Silver	Kwa-Zulu Natal	Underground
Buffelsfontein Gold Mining		Heaven Sent Gold Processing	Gold; Silver	North-West	Underground
Burnstone	Area 1, Area 2, Balfour, Kimberley Reef, Southgold	Sibanye Stillwater Ltd.	Gold	Mpumalanga	
Burnstone Gold Mine		South Gold Exploration (Pty) Ltd	Gold; Silver	Mpumalanga	Underground
China African Precious Metals (Pty) Ltd		Peng Xing Shanghai and Bek Holdings (Pty) Ltd	Gold; Silver	North-West	Underground
Consolidated Modderfontein Mines Ltd		Aurora Empowerment System (Pty) Ltd	Gold; Silver	Gauteng	Underground
Cullinan Diamond Mine		Petra Diamonds	Diamonds Kimberlite	Gauteng	Underground
De Beers - The Oaks Mine		De Beers Consolidated Mines	Diamonds Kimberlite	Limpopo	Opencast
De Beers - Venetia Mine		De Beers Consolidated Mines Ltd	Diamonds Kimberlite	Limpopo	Opencast; Surface
De Beers - Voorspoed		De Beers Consolidated Mines	Diamonds Kimberlite	Free State	Underground
De Groote Boom Chrome Mine		De Groote Boom Minerals (Pty) Ltd	Chrome Ore	Mpumalanga	Opencast
De Grooteboom		Sa Chrome Jv	Chromite	Limpopo	
De Wildt	Schietfontein, Zikaatsnek, Zilkaatsnek	Glencore PLC	Platinum	North-West	
Demaneng		Afrimat Ltd.	Iron Ore	Northern Cape	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Destiny Springs Investment 11 (Pty) Ltd		Afarak Group	Chrome Ore	Limpopo	Opencast
Dilokong		Asa Metals (Pty) Ltd	Chromite	Limpopo	
Dilokong Chrome Mine (Pty) Ltd		Asa Metals (Pty) Ltd	Chrome Ore	Mpumalanga	Underground
Diro Manganese (Pty) Ltd - Demaneng		Diro Iron Ore (Pty) Ltd	Manganese Ore; Iron Ore	Northern Cape	Opencast
Dominion	Aflease, Dominion Reefs, Inner Basin Reefs, Klerksdorp, Ottosdal, Rietkuil Syncline, Shiva Gold, Shiva Uranium, Shiva Uranium mine	Oakbay Resources And Energy Ltd.	Gold	North-West	
Doornkop	Doornkop 1A, Doornkop Main Reef, Doornkop South Reef, Kimberley Reef, Main Reef, Randfontein, South Reef	Harmony Gold Mining Co. Ltd.	Gold	Gauteng	
Dwarsrivier Chrome Mine		Assore Ltd	Chrome Ore	Mpumalanga	Opencast; Surface; Underground
East Manganese		Sitatunga	Manganese Ore	Northern Cape	Opencast
East Rand	Cons Modder, Cons Modder Black Reef, Consolidated Modderfontein, East Daggafontein, Gedex, Golden Reefs, Grootvlei, Modder Crusher, Ndlovu Shaft, New State Areas, Nigel, Skukuza, Snake Road, Springs Dagga	Gold One International Ltd.	Gold	Gauteng	
East Rand (Pty) Mines Ltd		Ergo Mining Operations (Pty) Ltd	Gold; Silver	Gauteng	Underground
East Rand Metals Beneficiation (Pty) Ltd		Worldwide Mineral Strategists (Pty) Ltd	Gold; Silver	Gauteng	Surface
Eastern Chrome Mines		Samancor Chrome Ltd	Chrome Ore	Mpumalanga	Underground
Eastern Platinum Pty (Ltd)		Sibanye-Stillwater	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Surface
Eersteling	Franca, Zandrivier	Unnamed Owner	Gold	Limpopo	
Ekapa Minerals (Pty) Ltd T/Z Kimberley Ekapa Mining (Kem)		Ekapa Minerals (Pty) Ltd T/Z Kimberley Ekapa Mining (Kem)	Diamonds Kimberlite	Northern Cape	Underground
Eland	Eland East, Eland Platinum, Elandsfontein, Elandsfontein 440 JQ, Hoekfontein 432 JQ, Kukama,	Northam Platinum Holdings Ltd.	Platinum	North-West	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
	Madibeng, Mululamisi, Nyala				
Eland Platinum Mine (Pty) Ltd		Northam Platinum	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Opencast
Elandsfontein		Metmin (Pty) Limited	Manganese	North-West	
Elandslaagte	Balmoral, Leicester, Russel pipes	Cape Resources Plc	Diamonds	Northern Cape	
Elandslaagte Diamand (Pty) Ltd		Elandslaagte Diamand (Pty) Ltd	Diamonds Kimberlite	Northern Cape	Opencast
Eleazar Gold Mine		Pcd	Gold	North-West	Opencast
Emang Mmogo Mining Resources		Bangala Trust	Manganese Ore	Northern Cape	Opencast
Ergo Mining (Pty) Ltd		Drd Gold Ltd	Gold; Silver	Gauteng	Surface
Erpm Extension	ERPM Extension 1, ERPM Extension 2, Extension 1, Extension 2, Rooikraal, Rooikraal/Withok, Sallies, Van Dyk, Withok	Drdgold Ltd.	Gold	Gauteng	
Evander	107/2010, Evander 6 Shaft, Evander No.6 Shaft, Kimberley Reef, Mining Right No. 107/2010, Six Shaft, Twistdraai	Taung Gold International Ltd.	Gold	Mpumalanga	
Evander 5 Shaft		Pan African Resources	Gold; Silver	Mpumalanga	Underground
Evander 7 Shaft		Pan African Resources	Gold; Silver	Mpumalanga	Underground
Evander 8 Shaft		Pan African Resources	Gold; Silver	Mpumalanga	Underground
Everest	Booysendal South, Chieftains Plains, Everest North, Everest South, Hoogland, Sterkfontein, Walhalla	Northam Platinum Holdings Ltd.	Platinum	Mpumalanga	
Everest Platinum Mine		Aquarius Platinum South Africa (Pty) Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Mpumalanga	Opencast; Surface; Underground
Ezulwini Mining Co (Pty) Ltd		Sibanye Gold Ltd	Gold; Silver; Uranium	Gauteng	Underground
Fairview Gold Mines		Barberton Mines (Pty) Ltd	Gold; Silver	Mpumalanga	Underground
Ferreira Estate and Invest Co - Slot 8		Central Rand Gold Sa (Pty) Ltd	Gold; Silver	Gauteng	Surface; Underground
Findcor Diamonds		Trade First 2073 Cc	Diamonds Kimberlite	Free State	Underground
Finsch Mine		Finsch Diamond Mine (Pty) Ltd	Diamonds Kimberlite	Northern Cape	Underground
Fonte Verde		Unnamed Owner	Platinum	Mpumalanga	
Frank Smith Mine		Ssc Joyspring Mining (Pty) Ltd	Diamonds Kimberlite	Northern Cape	Underground
Free State Saaiplaas		Unnamed Owner	Gold	Free State	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Freegold Operations		Harmony Gold Mining Company Ltd	Gold; Silver	Free State	Underground
Freestate Operations (Masimong Unisel and Phoenix)		Harmony Gold Mining Company Ltd	Gold; Silver	Free State	Underground
Galaxy Gold Reefs (Pty) Ltd - (Previously Agnes Gold Mining)	Previously Agnes Gold Mine	Galane Gold	Gold; Silver	Mpumalanga	Underground
Gamsberg	Gamsberg East, Gamsberg North, Gamsburg, Zinc International, Zinc-International	Vedanta Ltd.	Zinc	Northern Cape	
Garatau	De Kom, De Kom 252KT, Garatouw, Garatouw 282, Garatouw 282KT, Genorah Farms, Hoepakrantz 291KT, Maandagshoek 254KT	Zijin Mining Group Co. Ltd.	Platinum	Limpopo	
Gatelopele Investments and Mining Cc		Gatelopele Investments and Mining Cc	Manganese Ore	Northern Cape	Opencast
General Nice Development Sa (Pty) Ltd		Distant Star Trading 544 Cc	Manganese Ore	North-West	Opencast
Gloria Mine		Assmang Ltd	Manganese Ore	Northern Cape	Underground
Glosam Manganese		Wepex Trading (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Goldplat Recovery (Pty) Ltd		Goldplat Plc	Gold; Silver	Gauteng	Surface
Grasvally	Grass Valley, Zoetveld 294KR	Forward Africa Mining Pty. Ltd.	Chromite	Limpopo	
Gravelotte Mines Ltd		Gravelotte Mines Ltd	Gold; Silver	Gauteng	Underground
Great Noligwa	Anglo 593, ATIC, Crystalkop 69, Doornkom West 446, Fish, GN, Hoekplaats 598, Hypermine, Mispah 274, Moab Khotsong, Modderfontein 440, MW30/5/1/2/2/16 MR, Pretoriuskraal 53, SV4, Vaal River, Viljoenskroon, Zaaiplaats 190, Zuiping, Zuiping 394	Harmony Gold Mining Co. Ltd.	Gold	Free State	
Grootvlei Proprietary Mines Ltd		Aurora Empowerment System (Pty) Ltd	Gold; Silver	Gauteng	Underground
Helam	Fissure Mines	Lindleys Mining (Pty) Ltd.	Diamonds	North-West	
Helam Mining (Pty) Ltd		Petra Diamonds	Diamonds Kimberlite	North-West	Underground
Helena		Sa Chrome Jv	Chromite	Limpopo	
Helena Mine		Clencore	Chrome Ore	Mpumalanga	Surface; Underground
Helpebietjie Mine		Soliter Myn Ondernemings	Iron Ore	Northern Cape	Opencast

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Hernic	Bokfontein, Bokone, De Kroon, Maroelabult, Morula	Terris Chrome Ltd	Chromite	North-West	
Hernic Ferrochome (Pty) Ltd		Hernic Ferrochrome (Pty) Ltd	Chrome Ore	North-West	Opencast; Underground
Hoedspruit		Sibanye Stillwater Ltd.	Platinum	North-West	
Horizon Chrome Mine		Glencore Merafe Venture	Chrome Ore	North-West	Surface; Underground
Hotazel	C Zone, Central Block, HMM, M Zone, Mamatwan, Metalloys, N Zone, Samancor Manganese, South Africa Manganese, Wessels, X Zone	South32 Ltd.	Manganese	Northern Cape	
Hotazel Manganese Mines - Hotazel		Samancor Manganese (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Hotazel Manganese Mines (Pty) Ltd - Mamatwan Mine		Samancor Manganese (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Hotazel Manganese Mines (Pty) Ltd - Wessels Mine		Samancor Manganese (Pty) Ltd	Manganese Ore	Northern Cape	Underground
Impala	Bafokeng North, Big 5, Boschkoppie, Build-up Shafts, Impala Rustenburg, Old Men, Phakamisa, Royal Bafokeng JV Merensky	Impala Platinum Holdings Ltd.	Platinum	North-West	
Impala Platinum Chrome (Pty) Ltd		Impala Platinum Chrome (Pty) Ltd	Chrome Ore	North-West	Opencast
Impala Platinum Ltd		Impala Platinum Holdings Ltd	PGM; Gold; Silver; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Ammonium Sulphate; Sulphur	North-West	Underground
Indaba Digging Industry Cc		Indaba Digging Industry Cc	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Gauteng	Surface
International Ferro Metals (Sa) - Mine		International Ferro Metals Ltd	Chrome Ore	North-West	Underground
Ivanplats Limited (Pty) Ltd		Ivanhoe	PGM	Limpopo	Opencast
Japie Rus Minerale (Pty) Ltd		H2h Holdings (Pty) Ltd	Iron Ore	Northern Cape	Opencast
Jeanette	A-Reef, Bandon 345, Basal Reef, Big Pebble Conglomerate, B-Reef, Buitendachshoop 122, Damplaats 361, Katbosch 358, Khaki Shale, LeClusa 70, Leeuwbosch 285, Mining Right No.	Taung Gold International Ltd.	Gold	Free State	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
	33/2017, MPTRO 144/2013, Portion RE, Weltevreden 59				
Joel	Bambanani, Beatrix, Eland, Freddies, Freegold, Geduld, HJ Joel, Joel 1, Joel 2, Joel North, Joel South, Kudu, Matjha, Nyala, Phakisa, Sable, St Helena, Taung, Tshepong, West, Western Holding	Harmony Gold Mining Co. Ltd.	Gold	Free State	
K2012077655 (Pty) Ltd		H2h Holdings (Pty) Ltd	Iron Ore	Northern Cape	Opencast
Kadgame Mine		Kadgame Mining (Pty) Ltd / Bj Swart	Manganese Ore	Northern Cape	Opencast
Kalagadi		Kalagadi Manganese Pty. Ltd.	Manganese	Northern Cape	
Kalagadi Umtu Mine		Kalagadi Manganese (Pty) Ltd	Manganese Ore	Northern Cape	Opencast; Underground
Kalahari Gold Ridge Mine		Harmony Gold Mining Company Ltd	Gold; Silver	North-West	Opencast
Kalgold	A Zone, A-Zone, D Zone, D-Zone, First Wesgold, Kalahari Goldridge, Madibe, Pillar, Spanover Border, Waterpit, Watertank pit, Watertank-A, West Rand Consolidated, Windmill	Harmony Gold Mining Co. Ltd.	Gold	North-West	
Kalplats	Crater, Crux, Crux Gap, Kalahari, Kalahari Platinum, Kalplats extended, Kaplats, Mira, Orion, Serpens, Sirius, Stella, Vela	Pala Investments Ltd.	Platinum	North-West	
Kareevlei	K1, K2, K3, K4, K5, Kareeboompan, Kareevlei Wes, Klipvlei, KV Main, KV1, KV2, KV3, KV4, KV5, Pipe K5, Skietfontein, Westhoek	Bluerock Diamonds PLC	Diamonds	Northern Cape	
Kegakilwe Trading (Pty) Ltd		Willem Swart	Diamonds Alluvial; Diamonds Any	Limpopo	Opencast
Khumani	BKM Mine, Bruce, King, McCarthy, Mokaning	Assmang Pty. Ltd.	Iron Ore	Northern Cape	
Khumani Iron Ore Mine		Assmang Ltd	Iron Ore	Northern Cape	Opencast
Khuseleka Mine		Sibanye Stillwater	PGM; Gold; Chrome Ore;	North-West	Underground

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
			Cobalt Metal Ic; Copper; Nickel; Sodium Sulphate; Sulphur		
Kimberley	Bultfontein, Dutoitspan, Joint Shaft, KEM JV, Wesselton	Ekapa Mining (Pty) Ltd.	Diamonds	Northern Cape	
Kimberley Underground Mines Jv		Petra Diamonds Sa	Diamonds Kimberlite	Northern Cape	Underground
Klipfontein Manganese Mine		Aquarella Mining	Manganese Ore	Western Cape	Opencast
Klipfontein/Waterval		Sa Chrome Jv	Chromite	North-West	
Klipspringer Mine		Mwana Africa	Diamonds Kimberlite	Limpopo	Opencast; Underground
Koffiefontein Diamond Mine		Blue Diamond Mines (Pty) Ltd	Diamonds Kimberlite	Free State	Surface; Underground
Kolomela	Heuningkranz, Kalahari, Kapstevel, Kapstevel North, Kapstevel South, Klipbankfontein, KSS, Leeuwfontein, Ploegfontein, Sishen South, Welgevonden, Welgevonden South, Wolhaarkop	Kumba Iron Ore Ltd.	Iron Ore	Northern Cape	
Kolomela (Sishen South) Mine		Kumba Iron Ore Ltd	Iron Ore	Northern Cape	Opencast
Kookfontein	UG1, UG2	Bauba Resources Ltd.	Chromite	North-West	
Kookfontein Mine		Bauba Recources Limited	PGM; Gold; Copper; Nickel	North-West	Opencast
Kopanang	Altona, CR, De Pont Landing, Vaal River, VR	Heaven-Sent Gold Group Company Ltd.	Gold	Free State	
Kopanang Gold Mining Co (Pty) Ltd		Village Main Reef (Pty) Ltd	Gold; Silver	Free State	Opencast
Kophia Diamante - Blaauwboschfontein		Kophia Diamante	Diamonds Kimberlite	Free State	Opencast
Kpm (Aquarius)	Gemex, KPM, KPM Waterval, Kroondal	Sibanye Stillwater Ltd.	Platinum	North-West	
Kroondal	Ackerman, Bambanani, K6, Klipfontein, Kopaneng, Kroondal PSA 1, Kwezi, P and SA1, Simunye	Sibanye Stillwater Ltd.	Platinum	North-West	
Kroondal		Glencore PLC	Chromite	North-West	
Kroondal Gemini		Glencore PLC	Chromite	North-West	
Kroondal Mine		Sibanye Platinum	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Opencast; Underground
Kruidfontein	Merensky, Merensky Reef, UG2, UG2FW/PG, UG2P/L	Sedibelo Resources Limited	Platinum	North-West	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Kudumane		Kudumane Manganese Resources (Pty) Ltd.	Manganese	Northern Cape	
Kudumane Manganese Resources		Kmr	Manganese Ore	Northern Cape	Opencast
Kusasalethu	Buffelsdoorn, Deelkraal, Elandskraal, Elandsrand	Harmony Gold Mining Co. Ltd.	Gold	Gauteng	
Kusasalethu		Harmony Gold Mining Company Ltd	Gold; Silver	North-West	Underground
Lace Diamond Mines (Pty) Ltd		Lace Diamond Mines (Pty) Ltd	Diamonds Kimberlite	Free State	Opencast
Lanxess Chrome Mining (Pty) Ltd		Lanxess Chrome Mining (Pty) Ltd	Chrome Ore	North-West	Underground
Leeudoorn	Kloof 7 shaft, Kloof Division, Libanon	Sibanye Stillwater Ltd.	Gold	Gauteng	
Leeuwkop	Afplats, BizAfrica, Imbasa North, Inkosi, Kareepoort, Leeuwkop 402JQ, Wolwekraal, Wolwekraal/Kareepoort	Impala Platinum Holdings Ltd.	Platinum	North-West	
Lehating Mining (Pty) Ltd		Lehating Mining (Pty) Ltd	Manganese Metal	Northern Cape	Opencast
Lesego	Dal Josephat, Eerste Regt, Government Ground, Koppieskraal, Olifantspoort, Phosiri, Spelonk	Heaven-Sent Capital Management Group Co., Ltd.	Platinum	Limpopo	
Libanon	Kloof 8 shaft, Kloof 9 shaft, Kloof Division, Leeudoorn, Venterspost, Venterspost North, Venterspost South	Sibanye Stillwater Ltd.	Gold	Gauteng	
Liger	Leeuwkop, Tigerpoort	Platfields Ltd.	Platinum	Limpopo	
Lime-Chem Resources (Pty) Ltd		Lime-Chem Resources (Pty) Ltd	Iron Ore	Northern Cape	Opencast
Limpopo-Dwaalkop	Dwaalkop, Limpopo, Limpopo II Platinum Project, Rooibokbulk 121 KS	Sibanye Stillwater Ltd.	Platinum	Limpopo	
Lomoteng		Guangxi N and H Metallurgy Development Co., Ltd.	Manganese	Northern Cape	
Lomoteng Mine		Huatian Sa Mining and Investment (Pty) Ltd	Iron Ore; Manganese Ore	Northern Cape	Opencast
M Nel Boerdery		Marius Nel	Diamonds Alluvial; Diamonds Any	North-West	Opencast
Magareng		Glencore PLC	Chromite	Limpopo	
Magareng Mine		Glencore	Chrome Ore	Mpumalanga	Opencast; Underground

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Makgomo Chrome (Pty) Ltd		50% Makgomo Community Trust	Chrome Ore	Mpumalanga	Opencast
Makonjwaan Imperial Mining Co (Pty) L		Eastern Goldfields Sa (Pty) Ltd	Gold; Silver	Mpumalanga	Opencast
Mamatwan Manganese (Pty) Ltd		Erg Management (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Manganese Minerals (Pty) Ltd		New Venture Minng Resources (Pty) Ltd	Manganese Alloys; Manganese Ore; Manganese Metal	North-West	Opencast
Manganex Mine (Pty) Ltd		Shaktir Dash	Manganese Ore	North-West	Opencast
Mapochs		Private Interest	Vanadium	Limpopo	
Maranda Mining Co (Pty) Ltd		Metorex Ltd	Zinc Metal Ic	Limpopo	Underground
Mareesburg 8 JT	Eastern Limb, Eastern Limb Projects, Mareesburg, UG2 Reef	Eastern Platinum Ltd.	Platinum	Limpopo	
Mareesburg Jv		Eastern Platinum Ltd	PGM	Mpumalanga	Surface
Marico Chrome Mine		Marico Chrome Corporation (In Provisional Liquidation)	Chrome Ore	North-West	Opencast
Marikana	Kafferskraal, Kroondal, Marikana PSA, Morex, P and SA2, PSA 2, Spruitfontein	Sibanye Stillwater Ltd.	Platinum	North-West	
Marikana East	Kroondal Mine extension	Glencore PLC	Chromite	North-West	
Marikana Platinum Mine (Old Aqp)		Sibanye Platinum	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Opencast
Marikana West		Glencore PLC	Chromite	North-West	
Marula	Buffelshock, Cla, Clapham, Clapham Shaft, Driekop, Driekop Shaft, Forest Hill, Hackney, Macalacaskop-Turfspruit, Makgomo, New Driekop, Platexco, Trojan, Turfspruit, Winaarshoek, Winnaarshoek	Impala Platinum Holdings Ltd.	Platinum	Limpopo	
Marula Platinum Mine (Pty) Ltd		Impala Holdings Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Underground
Maseve	Elandsfontein, Frischgewaagd, Koedoesfontein, Mimosa, Onderstepoort, Project 1 Merensky, Project 3 Merensky, War Springs, WBC, WBJV, WBJV Project 1, Western Bushveld Joint Venture	Royal Bafokeng Platinum Ltd.	Platinum	North-West	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Maseve Mine		Royal Bafokeng Platinum	PGM; Gold; Cobalt Metal Ic; Copper; Nickel	North-West	Underground
Mashwening Mine		Wide Investments 100 (Pty) Ltd	Manganese Ore; Manganese Metal	Northern Cape	Opencast
Mecklenburg Mine		Chromex Mining (Pty) Ltd	Chrome Ore	Mpumalanga	Opencast
Megamine	Big Pebble Marker Reef, Houtpoort, Houtpoort Channel, Houtpoort Secondary Kimberley (UK9A), Houtpoort Secondary Reef, Houtpoort Southern Extension, Main Reef, Spaarwater, Sub Nigel, Sub-Nigel 1, Sub-Nigel 2, Sub-Nigel 3, Vlakfontein, Vlakfontein Black Reef, Vlakfontein Kimberley (UK9A) Reef, West Vlakfontein, Wit Nigel, Wit Nigel 7 Shaft	Gold One International Ltd.	Gold	Gauteng	
Messina Platinum Mines Ltd		Sibanye-Stillwater	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Underground
Metmin	Rydale	Metmin (Pty) Limited	Manganese	North-West	
Metmin (Pty) Ltd		Obnosis (Pty) Ltd	Manganese Ore	North-West	Opencast
Middelvlei		Pamodzi Gold West Rand (Pty) Ltd	Gold; Silver	Gauteng	Surface
Mintails Group Of Companies		Mintails Mining Sa (Pty) Ltd	Gold; Silver	Gauteng	Surface
Moab and Great Noligwa Operations		Harmony Gold Mining Co Ltd	Gold; Silver; Uranium	North-West	Underground
Moab Khotsong	Crystalkop 69, Doornkom West 446, GN, GNM, Great Noligwa, Hoekplaats 598, Kop Paydam, Kopanang Pay Dam, KPD, Mispah, Mispah TSF, MK, Moab 279, Moab MOD, Modderfontein 440, Nufcor, Pretoriuskraal 53, Vaal River, Viljoenskroon, Zaaiplaats, Zaaiplaats 190, Zuiping 394	Harmony Gold Mining Co. Ltd.	Gold	Free State	
Modder East	Benoni, BPLZ, Channel Facies, Kleinfontein, Modder North, New Kleinfontein,	Gold One International Ltd.	Gold	Gauteng	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
	Turnbridge, UC Prospecting, UK5A, UK9A				
Modikwa	Onverwacht Hill	African Rainbow Minerals Ltd.	Platinum	Limpopo	
Modikwa Platinum Mine		Arm / Anglo Platinum Joint Venture	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Underground
Mogalakwena	Baobab, Boikgantsho, Sandsloot, Tweefontein Hill, Tweefontein North, Zwartfontein, Zwartfontein South	Anglo American Platinum Ltd.	Platinum	Limpopo	
Mogalakwena Platinum Mine		Anglo American Corporation	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Opencast
Mogothlo Mining (Pty) Ltd		Munell (Pty) Ltd	Iron Ore	Northern Cape	Opencast
Mokala		Glencore PLC	Manganese	Northern Cape	
Mokala Manganese Mine		Ntsimbinhle Pty Ltd / Blue Falcon	Manganese Ore	Northern Cape	Opencast
Mokopane	Groenfontein, Zaaiplaats	Andrada Mining Ltd.	Tin	Limpopo	
Mokopane Vanadium	AB Zone, Bellevue, Brits, LP95PR, MML, Mokopane, PQ, P-Q, Schoonoord, Vliegekraal, Vogelstruisfontein, Vriesland	Bushveld Minerals Ltd.	Vanadium	Limpopo	
Moonlight	De Loskop, Good Hope, Gouda Fontein, Gouda Fontein 76 LR, Julietta, Julietta 112 LR, Karnelmelkfontein, LP30/5/1/2/2/201, Moonlight 111 LR, Turqouise Moon, Zone D	Private Interest	Iron Ore	Limpopo	
Morokwa Mine		National Manganese Mines	Manganese Ore	Northern Cape	Opencast
Mototolo	Der Brochen, Helena, Mareesburg	Anglo American Platinum Ltd.	Platinum	Limpopo	
Mototolo Mine		Rustenburg Platinum Mines	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Mpumalanga	Underground
Motsitle Mining - Vlakfontein Mine		Motsitle Mining - Vlakfontein Site (Pty) Ltd	Chrome Ore	North-West	Opencast
Mphahlele's Location	Mphahlele, Mphatlele, M'Phatlele, M'Platlele, Scheiding 407 KS Portion 2	Sedibelo Resources Limited	Platinum	Limpopo	
Nama Copper Resources (Pty) Ltd		Rappa Holdings (Pty) Ltd	Copper	Northern Cape	Underground

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Nchwaning/Gloria	Black Rock, Gloria, Graben, Koppie, Nchwaning, Nchwaning 1, Nchwaning 3, Nchwaning II	Assmang Pty. Ltd.	Manganese	Northern Cape	
New Consort Gold Mine		Barberton Mines (Pty) Ltd	Gold; Silver	Mpumalanga	Underground
New Kleinfontein-Modder East Operations		Gold One	Gold; Silver	Gauteng	Underground
New Venture Mining Chrome Mine		New Venture Mining Investment Holdings (Pty) Ltd	Chrome Ore	North-West	Opencast
Newberry Recovery Works Cc		Newberry Recovery Works Cc	Gold; Silver	Gauteng	Surface
Newlands Diamond Mine		Kophia Diamonds (Pty) Ltd	Diamonds Kimberlite	Northern Cape	Underground
Nigel Gold Mining Co (Pty) Ltd		Aurora Empowerment System (Pty) Ltd	Gold; Silver	Gauteng	Opencast; Underground
Nkomati	MMZ, Nico JV, PCMZ, River of Cows, Slaaihoek, Uitkomst	African Rainbow Minerals Ltd.	Nickel	Mpumalanga	
Nkomati Mine		African Rainbow Minerals and Norilsk Nicke	Nickel; Gold; Silver; PGM; Chrome Ore; Cobalt Metal Ic; Copper;	Mpumalanga	Underground
Nkwe Platinum Mine		Zijin Mining Group Co. Limited	PGM; Gold; Silver; Cobalt Metal Ic; Copper; Nickel	Limpopo	Opencast
Nonnenwerth	Altona, Aurora, Aurora 397, Aurora 397LR, Cracouw, Cracouw 391 LR, HACRA, Harriets Wish, Harriets Wish 393 LR, La Pucella, Lapon, LaPucella, Non Plus Ultra, Non Plus Ultra 683LR, Nonnewerth, Northern Limb Iron	Ironveld PLC	Iron Ore	Limpopo	
Nooitgedacht Chrome Mine		Acacia Recources (Pty) Ltd	Chrome Ore	Limpopo	Opencast
Northam Platinum - Zondereinde		Northam Platinum Ltd	PGM; Gold; Silver; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Underground
Northwest Province	Doornhoek, Northern Node, Oersonskraal, South East Node	Namakwa Diamonds Ltd.	Diamonds	North-West	
Oribi	Basal, Elsburg, Ventersdorp, VS5	White Rivers Exploration Pty Limited	Gold	North-West	
Oryx	Beatrix 4, Beatrix West, Beisa, Doornrivier, Kalkoenkrans Reef	Sibanye Stillwater Ltd.	Gold	Free State	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Palabora Mining Co Ltd		Palabora Mining Co Ltd	Copper; Gold; Silver; PGM; Iron Ore; Nickel; Sulphur; Vermiculite	Limpopo	Opencast; Underground
Pandora	E3, East 4, Eastern Platinum, Hartebeestpoort B, Harties West, Pandora JV, Roodekopjes, Saffy, Uitvalgrond	Sibanye Stillwater Ltd.	Platinum	North-West	
Pensfontein Mine		Rahida Investment (Pty) Ltd	Manganese Ore; Manganese Metal	Northern Cape	Opencast
Pering	East Project, West Expansion	Unnamed Owner	Zinc	North-West	
Pering Mine		Pering Base Metals (Pty) Ltd	Zinc Metal Ic	North-West	Opencast
Phakisa	B Reef, Freddies 4, Free Gold, Free State Geduld 4, Freegold, Matjhabeng (Nyala), Phakisa Shaft, Tshepong, Tshepong South	Harmony Gold Mining Co. Ltd.	Gold	Free State	
Phoenix	Daggafontein Footprint, Gedex Footprint, Modder Crusher Footprint, New State Areas Footprint, Springs Mines Footprint, Sub-Nigel Footprint, Sub-Nigel Other Footprint Channel	Gold One International Ltd.	Gold	Gauteng	
Pilanesberg	Bakhoutrantje, East Pit, Groenfontein, Magazynskraal, Palmietfontein, Rooderand, Ruighoek, Sedibelo, Sedibelo West, Tuschenkomst, Tuschenkomst 135JP, Vogelstruisnek, West Pit, Wilgespruit, Witkleifontein	Sedibelo Resources Limited	Platinum	North-West	
Pilanesberg Platinum Mines (Pty) Ltd		Sedibelo Platinum Mines Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Opencast
Platcro Minerals		Chemstof (Pty) Ltd	Chrome Ore	North-West	Opencast
Platinum Mile	Amplats, Plat Mile, PlatMile, RPM Tails	Sibanye Stillwater Ltd.	Platinum	North-West	
Pmg Mining - Bishop		Pmg Mining (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Prieska	+105 Level, +105 Level Crown Pillar, Annex, Ayoba, Bartotrax, Copperton, Deep Hypogene, Deep Sulphide,	Orion Minerals Ltd.	Copper	Northern Cape	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
	Doonies Pan, Dwyka, Hutchings Shaft, K1, K3, K6, Kielder, Marydale, NW Hinge, NW Trough, PC, PCZM, PK1, PK3, PK6, Prieska Deep Sulphide, Repli, SE, Shallow supergene, Vardocube, Vardocube Deep Sulphide, Witkop				
Primrose Gold Mine		Aurora Empowerment System (Pty) Ltd	Gold; Silver	Gauteng	Underground
Protea Mines (Pty) Ltd		Protea Mines (Pty) Ltd	Gold; Silver	Gauteng	Underground
Rakhoma Mining Resources Pty Ltd		Vanchem Vanadium Products Pty Ltd	Iron Ore; Iron Bp Manganese	Limpopo	Opencast
Rand Uranium (Pty) Ltd		Sibanye Gold Ltd	Gold; Silver; Uranium	Gauteng	Underground
Randfontein Operations		Harmony Gold Mining Company Ltd	Gold; Silver	Gauteng	Underground
Rhovan	Block 9, Leeupen, Pit 1, Pit 2, Pit 3, Pit 4 West, Pit 6, Pit 6 West, Pit7	Glencore PLC	Vanadium	North-West	
Rhythm Of The Nation Trading		Rhythm Of The Nation Trading	Gold	North-West	Opencast
Richmond		Sa Chrome Jv	Chromite	Limpopo	
Ringside Trading 520 (Pty) Ltd		Pacific Bullion (Pty) Ltd	Iron Ore; Manganese Ore	Northern Cape	Opencast
Rooderand		Platinum Australia Ltd.	Platinum	North-West	
Rooderand	LG5, LG6, LG7, M404, M505, MG2, MG3, MG4, MG4A, MG4B	Chrometco Ltd.	Chromite	North-West	
Rooderand Chrome Mine - Pilanesberg Mining Co		Chrometco Ltd	Chrome Ore	North-West	Opencast; Surface
Rooinekke		Lime-Chem Resources (Proprietary) Limited	Iron Ore	Northern Cape	
Rovic Diamonds		Kleinkor Sewentien (Pty) Ltd	Diamonds Kimberlite	Free State	Underground
Ruighoek	Batlhako mine	Minerals Technologies Inc.	Chromite	North-West	
Ruighoek Chrome Mine		Batlhako Mining Limited	Chrome Ore	North-West	Opencast; Underground
Rustenburg	Bathopele, Khomanani, Khuseleka, Paardekraal, Rustenburg East, Siphumelele, Siphumelele 1, Siphumelele 2, Siphumelele 3, Thembelani, Thembelani Deeps, Western Limb Tailings Retreatment	Sibanye Stillwater Ltd.	Platinum	North-West	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Rustenburg		Clover Alloys (Sa) Pty. Ltd.	Chromite	North-West	
Salene Manganese		Thari Resources (Pty) Ltd	Manganese Ore; Manganese Alloys; Iron Ore	Northern Cape	Opencast
Samancor Eastern	Doornbosch mine, Groothoek mine, Jagdlust Cr mine, Steelport mine, Tubatse Division, Tweefontein mine	Samancor Chrome Holdings (Pty)	Chromite	Limpopo	
Samancor Western	Buffelsfontein East Cr mine, Millsell mine, Mooinooi Cr mine, Ruighoek Cr mine	Samancor Chrome Holdings (Pty)	Chromite	North-West	
Sebilo Resources (Pty) Ltd		Tawana Investment Holdings (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Sedibelo	Pilanesberg	Sedibelo Resources Limited	Platinum	North-West	
Sedibeng		Tata Steel Ltd.	Iron Ore	Northern Cape	
Sedibeng Iron Ore		Imr - Metallurgical Resources Ag	Iron Ore	Northern Cape	Opencast
Sedibeng JV	Bellsbank, Dancarl, Messina, ML 1/1995, ML 12/94, Sedibeng	Frontier Diamonds Ltd.	Diamonds	Free State	
Sefateng Chrome Mine		Sefateng Chrome Mine	Chrome Ore	Limpopo	Opencast
Shaft Sinkers (Pty) Ltd		Shaft Sinkers (Pty) Ltd	Gold; Silver	Free State	Opencast
Sheba Gold Mines		Barberton Mines (Pty) Ltd	Gold; Silver	Mpumalanga	Underground
Sibanye Gold - Kloof Gold Mine Division		Sibanye Gold Ltd	Gold; Silver	Gauteng	Underground
Sibanye Gold Ltd - Driefontein Division		Sibanye Gold Ltd	Gold; Silver	Gauteng	Underground
Simolotse	Ardo, Bellsbank (Bokang), Du Plessis, Loxton, Rex	Meepo Investment Consortium (Pty) Ltd.	Diamonds	Northern Cape	
Simolotse Mine		Afgem Ltd	Diamonds Kimberlite	Northern Cape	Underground
Siphumelele 1 Mine		Sibanye Platinum Rustenburg	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Underground
Sishen	Dingleton, DMS, Jig, Kalahari, Kumba Iron, SEP, Shishen, Sishen C, Sishen Expansion Project, Sishen Farm, Welgevonde	Kumba Iron Ore Ltd.	Iron Ore	Northern Cape	
Sishen Iron Ore Mine		Kumba Iron Ore	Iron Ore	Northern Cape	Opencast
Siyanda Bakgatla Platinum Mine		Siyanda Resources	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Surface
Sky Chrome Mining (Pty) Ltd		International Ferro Metals Ltd	Chrome Ore	North-West	Opencast

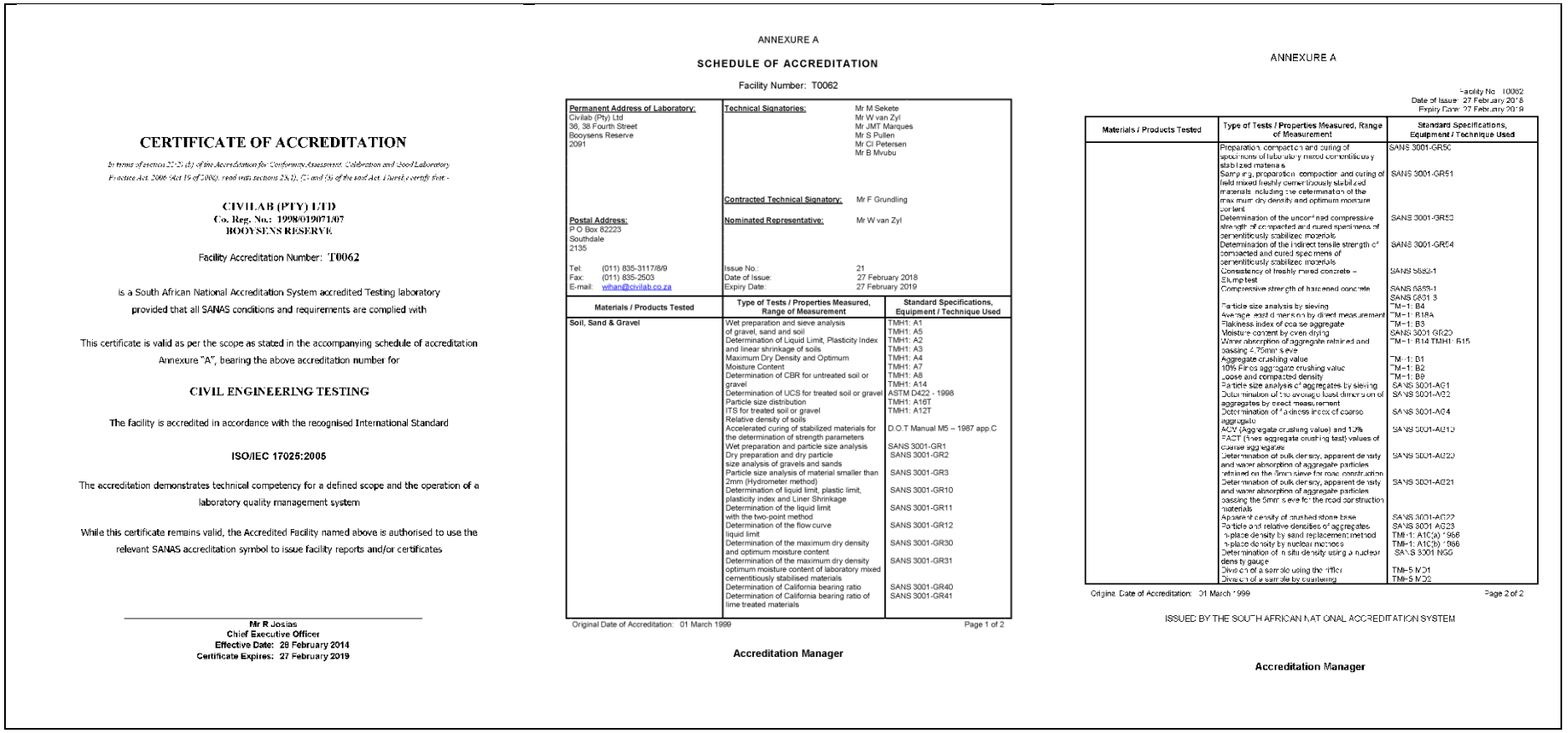
Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Smokey Hills	Phokothaba	African Thunder Platinum Ltd	Platinum	Limpopo	
Smokey Hills Platinum Mine		Phokathabab Platinum (Pty) Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Opencast
So Ver Mine		So Ver Mine (Pty) Ltd	Diamonds Kimberlite	Northern Cape	Opencast
Solitaire Mining		Am Diamond Mning (Pty) Ltd	Diamonds Alluvial ; Diamonds Any	Northern Cape	Opencast
South Deep	Doornpoort, North of Wrench, NoW, Soudex, South of Wrench, South of Wrench East, South of Wrench West, SoW, SoW East, SoW West, Uncle Harry's	Gold Fields Ltd.	Gold	Gauteng	
South Deep Gold Mine		Gold Fields Ltd - J/V Gfi Jv Holdings	Gold; Silver	Gauteng	Underground
Spd	LMZ, LMZ1A, Steelpoortdrift, UMZ	Vanadium Resources Ltd.	Vanadium	Limpopo	
Spitskop Platinum Mine		Eastern Platinum Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Mpumalanga	Opencast
Spitsvale		Bcr Minerals (Pty) Ltd	Chrome Ore	Mpumalanga	Opencast
St George	Saint George	Sa Chrome Jv	Chromite	Limpopo	
St Helena	(part of the Freegold operations - #104290), Free Gold, Joel, Onegund	Harmony Gold Mining Co. Ltd.	Gold	Free State	
Star	Burns, East Star, Micaceous, ML 11/1996, Registration No 1946/022941/07, Wynandsfontein	Frontier Diamonds Ltd.	Diamonds	Free State	
Star Diamonds (Pty) Ltd		Sedi Diamonds (Pty) Ltd	Diamonds Kimberlite	Free State	Underground
Steenkampskraal	MMZ, Rareco, SKK	Steenkampskraal Thorium Ltd	Lanthanides	Western Cape	
Steenkampskraal Monazite Mine		Steenkampskraal Holdings Ltd	Rare Earth Metals Ic	Western Cape	Underground
Stellite Chrome Mine		Ilitha Mining (Pty) Ltd	Chrome Ore	North-West	Opencast
Styldrift 90JQ	Bafokeng Rasimone Platinum, Boschkoppie 104JQ, BRPM Expansion, Styldrift	Royal Bafokeng Platinum Ltd.	Platinum	North-West	
Styldrift Mine		Royal Bafokeng Platinum	PGM; Gold; Cobalt Metal Ic; Copper; Nickel	North-West	Underground
Sub - Nigel Gold Mine		Gold One	Gold; Silver	Gauteng	Underground
Tamboti Platinum (Pty) Ltd		African Rainbow Minerals Ltd	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Surface
Target	Eldorado Reefs, Freddies 7, Freddies 9, Loraine, Loraine 3, Mariasdal,	Harmony Gold Mining Co. Ltd.	Gold	Free State	

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
	Paradise, Siberia, South Block, Sun South and North, Target 1, Target 2, Target 3, Target North				
Target Operations		Harmony Gold Mining Company Ltd	Gold; Silver	Free State	Underground
Tau Lekoa	Goedgenoeg, Jonkerskraal, Vaal River, Weltevreden	Heaven-Sent Gold Group Company Ltd.	Gold	North-West	
Tau Lekoa Gold Mining Company (Pty) Ltd		Village Main Reef (Pty) Ltd	Gold; Silver	North-West	Underground
Thaba Chronimet Chrome Mine		Cronimet Chrome Mining Sa (Pty) Ltd	Chrome Ore	Limpopo	Opencast
Thabazimbi	Donkerpoort, Kwaggashoek, Phoenix, Postmasburg, Project Infinity, Vanderbijl, Vanderbijlpark	Arcelormittal South Africa Ltd.	Iron Ore	Limpopo	
Thabazimbi	Cornwall, Donkerpoort, Klipgat, Leeuwbosch, Maroelasfontei, Meletse, Randstephne, Rotterdam, Target C, Vlaknek	China Baowu Steel Group Co.Ltd.	Iron Ore	Limpopo	
Thabazimbi Iron Ore Mine (Pty) Ltd		Arcelormittal	Iron Ore	Limpopo	Opencast
Tharisa	Farm 342JQ, Genesis, MG0, MG1, MG2, MG3, MG4, MG4A, Rooikoppies 297JQ, Voyager, West Pit	Tharisa PLC	Platinum	North-West	
Tharisa Mine		Tharisa Minerals (Pty) Ltd	Chrome Ore; Gold; PGM; Cobalt Metal Ic; Copper; Nickel; Sulphur;	North-West	Opencast
Thembelani Mine		Sibanye Platinum Rustenburg	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sodium Sulphate; Sulphur	North-West	Underground
Thorncliffe		Sa Chrome Jv	Chromite	Limpopo	
Thorncliffe Mine		Xstrata Alloys	Chrome Ore	Mpumalanga	Underground
Thutse Mine (Pty) Ltd		Pd Price	Chrome Ore	North-West	Opencast
Tjate	Dsjate 249KT, Fernkloof 539KS, Quartzhill, Quartzhill 542KS	Jubilee Metals Group Plc	Platinum	Limpopo	
Toekomste Skyn Myn		Limabrite (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Townlands Extension 9	Extension 9	Sa Chrome Jv	Chromite	North-West	
Transvaal Gold Mining Estates Ltd		Theta Gold Mines Sa Ltd	Gold; Silver	Mpumalanga	Underground
Tsantsabane Mining (Pty) Ltd		Tsantsabane Managing Board	Iron Ore	Northern Cape	Opencast

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Tshepong Chrome Mine		Corridor Mining Resources (Pty) Ltd	Chrome Ore	Limpopo	Opencast
Tshepong North	B Reef, Basal Reef, B-Reef, Freddies 4, Free Gold, Free State Geduld 4, Freegold, Harmony One, Horizon, Leeubosch, Midas, Nyala, Phakisa, Sub 66 decline, Sub 71 decline, Tshepong decline	Harmony Gold Mining Co. Ltd.	Gold	Free State	
Tshipi Borwa	Borwa, Mamatwan, Tshipe Ntle, Tshipi, Tshipi Kalahari	Jupiter Mines Ltd.	Manganese	Northern Cape	
TSHIPI É NTLE MANGANESE MINING (PTY) LTD		Tshipi É Ntle Manganese Mining (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Twickenham	Ga-Phasha, TPM	Anglo American Platinum Ltd.	Platinum	Limpopo	
Twickenham Platinum Mine		Anglo American Platinum	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	Limpopo	Surface; Underground
Two Rivers	Buffelshoek, Dwaars Rivier Farms, Dwaarsrivier, Dwars Rivier Farms, Dwarsrivier, Kalkfontein, LP 178 MR, Merensky, Tamboti, Tweefontein	African Rainbow Minerals Ltd.	Platinum	Limpopo	
Two Rivers Platinum		African Rainbow Minerals / Impala Platinum Jv	PGM; Gold; Chrome Ore; Cobalt Metal Ic; Copper; Nickel; Sulphur;	Mpumalanga	Underground
Umk	United Manganese of Kalahari	United Manganese Of Kalahari (Pty) Ltd.	Manganese	Northern Cape	
Union Section	Richard, Spud, Union North, Union South	Siyanda Resources Pty Ltd.	Platinum	North-West	
United Manganese Of Kalahari (Pty) Lt		Majestic Silver (Pty) Ltd	Manganese Ore	Northern Cape	Opencast
Upward Spiral 1471		Upward Spiral 1471	Gold; Silver	Gauteng	Opencast
Uranium Ezulwini	Ezulwini, Middle Elsburg, Randfontein Four Shaft	Sibanye Stillwater Ltd.	U3o8	Gauteng	
Vaal River Operations (Mine and Plants)		Harmony Gold Mining Co Ltd	Gold; Silver; Uranium	North-West	Underground
Vametco	Krokodilwaal 426 JQ, Uitvalgrond 431 JQ	Bushveld Minerals Ltd.	Vanadium	North-West	
Vanadium And Magnetite Expl and Dev Co (Pty) Ltd		Vanadium And Magnetite Expl and Dev Co (Pty) Ltd	Iron Ore	Limpopo	Opencast

Mine Name	Also known as	Mine Owner	Commodity	Province	Type Of Mine
Veremo	Magnetite Layer 21, Stoffberg	Kermas Group	Iron Ore	Limpopo	
Virginia Diamond Field (Pty) Ltd		South Africa Equity Investments Limited	Diamonds Kimberlite	Free State	Opencast; Underground
Vlakpoort		Afarak Group Se	Chromite	Limpopo	
Volspruit	Volspruit North, Volspruit South	Sylvania Platinum Ltd.	Platinum	Limpopo	
Waterberg	Bayswater 370LR Waterberg Extension, Waterberg I, Waterberg II, Waterberg III, Waterberg IV, Waterberg JV	Platinum Group Metals Ltd.	Palladium	Limpopo	
Waterval Chrome		Glencore Merafe Venture	Chrome Ore	North-West	Surface; Underground
Waterval West	Waterval mine	Glencore PLC	Chromite	North-West	
West End Diamond Mine		Rex Exploration (Pty) Ltd	Diamonds Kimberlite	Northern Cape	Underground
West Wits Operations		Harmony Gold Mining Co Ltd	Gold; Silver	Gauteng	Underground
Western Chrome Mines		Kermas	Chrome Ore	North-West	Surface; Underground
Western Platinum Pty (Ltd		Sibanye-Stillwater	PGM; Gold; Cobalt Metal Ic; Copper; Nickel; Sulphur	North-West	Opencast; Underground
White Rivers/Harmony Gold Jv		White Rivers Exploration Pty Limited	Gold	Free State	
Winkelhaak	Evander	Pan African Resources Plc	Gold	Mpumalanga	
Witwatersrand Basin	12E Winze Shaft, Bird, Bird Reef, Bird Reef Central, Bird Reef East, Bird Reefs, BR, BRC, BRE, Circular Shaft, Commander, Deeps, Donkey, DRD, DRD Lease, Durban Deeps, Durban Roodepoort Deep	West Wits Mining Ltd.	Gold	Gauteng	
Worcester		Eastern Goldfields Sa (Pty) Ltd	Gold; Silver	Mpumalanga	Opencast
Xstrata - Kroondal Mine		Glencore Merafe Venture	Chrome Ore	North-West	Underground
Zandkopsdrift	A Zone, B Zone, Central Zone	Frontier Rare Earths Ltd.	Lanthanides	Northern Cape	
Zebediela	1074PR, 11921PR, 148PR, Amatava 41 KS, Bloemhof 4 KS, Critical Zone, Piet Potgietersrust, SAN Nickel JV, Townlands 44 KS, Uitloop 3 KS, Zeb	Zeb Nickel Corp.	Nickel	Limpopo	
Zeerust Chrome Mines		Assore	Chrome Ore	North-West	Opencast

9.3.7 Annexure C-7: Certificate of accreditation, showing the facility identification, international standard, and test types



CERTIFICATE OF ACCREDITATION

In terms of section 22(2) (b) of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act 19 of 2006), read with sections 23(2), (3) and (5) of the said Act, I hereby certify that -

CIVILAB (PTY) LTD
Co. Reg. No.: 1998/019071/07
BOOYSENS RESERVE

Facility Accreditation Number: T0062

is a South African National Accreditation System accredited Testing laboratory provided that all SANAS conditions and requirements are complied with

This certificate is valid as per the scope as stated in the accompanying schedule of accreditation Annexure "A", bearing the above accreditation number for

CIVIL ENGINEERING TESTING

The facility is accredited in accordance with the recognised International Standard

ISO/IEC 17025:2005

The accreditation demonstrates technical competency for a defined scope and the operation of a laboratory quality management system

While this certificate remains valid, the Accredited Facility named above is authorised to use the relevant SANAS accreditation symbol to issue facility reports and/or certificates

Mr R Josias
Chief Executive Officer
Effective Date: 28 February 2014
Certificate Expires: 27 February 2019

ANNEXURE A

SCHEDULE OF ACCREDITATION

Facility Number: T0062

Permanent Address of Laboratory: Civilab (Pty) Ltd 36, 38 Fourth Street Booysens Reserve 2091	**Technical Signatories:**	Mr M Sekete Mr W van Zyl Mr JMT Marques Mr S Pullen Mr CI Petersen Mr B Mvubu
	Contracted Technical Signatory:	Mr F Grundling
Postal Address: P O Box 82223 Southdale 2135	**Nominated Representative:**	Mr W van Zyl
Tel: (011) 835-3117/8/9 Fax: (011) 835-2503 E-mail: whan@civilab.co.za	Issue No.: Date of Issue: Expiry Date:	21 27 February 2018 27 February 2019

Materials / Products Tested	Type of Tests / Properties Measured, Range of Measurement	Standard Specifications, Equipment / Technique Used
Soil, Sand & Gravel	Wet preparation and sieve analysis of gravel, sand and soil	TMH1: A1
	Determination of Liquid Limit, Plasticity Index and linear shrinkage of soils	TMH1: A5 TMH1: A2 TMH1: A3
	Maximum Dry Density and Optimum Moisture Content	TMH1: A4 TMH1: A7
	Determination of CBR for untreated soil or gravel	TMH1: A8 TMH1: A14
	Determination of UCS for treated soil or gravel	ASTM D422 - 1998
	Particle size distribution	TMH1: A16T
	ITS for treated soil or gravel	TMH1: A12T
	Relative density of soils	
	Accelerated curing of stabilized materials for the determination of strength parameters	D.O.T Manual M5 – 1987 app.C
	Wet preparation and particle size analysis	SANS 3001-GR1
	Dry preparation and dry particle size analysis of gravels and sands	SANS 3001-GR2
	Particle size analysis of material smaller than 2mm (Hydrometer method)	SANS 3001-GR3
	Determination of liquid limit, plastic limit, plasticity index and Liner Shrinkage	SANS 3001-GR10
	Determination of the liquid limit with the two-point method	SANS 3001-GR11
	Determination of the flow curve liquid limit	SANS 3001-GR12
	Determination of the maximum dry density and optimum moisture content	SANS 3001-GR30
	Determination of the maximum dry density optimum moisture content of laboratory mixed cementitiously stabilised materials	SANS 3001-GR31
	Determination of California bearing ratio	SANS 3001-GR40
	Determination of California bearing ratio of lime treated materials	SANS 3001-GR41

Original Date of Accreditation: 01 March 1999 Page 1 of 2

Accreditation Manager

ANNEXURE A

Facility No: T0062
Date of Issue: 27 February 2018
Expiry Date: 27 February 2019

Materials / Products Tested	Type of Tests / Properties Measured, Range of Measurement	Standard Specifications, Equipment / Technique Used
	Preparation compaction and curing of specimens of laboratory mixed cementitiously stabilized materials	SANS 3001-GR50
	Sampling, preparation, compaction and curing of field mixed freshly cementitiously stabilized materials including the determination of the maximum dry density and optimum moisture content	SANS 3001-GR51
	Determination of the unconfined compressive strength of compacted and cured specimens of cementitiously stabilized materials	SANS 3001-GR52
	Determination of the indirect tensile strength of compacted and cured specimens of cementitiously stabilized materials	SANS 3001-GR54
	Consistency of freshly mixed concrete – Slump test	SANS 5862-1
	Compressive strength of hardened concrete	SANS 6883-1 SANS 6831-3
	Particle size analysis by sieving	TMH1: B4
	Average least dimension by direct measurement	TMH1: B18A
	Flakiness index of coarse aggregate	TMH1: B3
	Moisture content by oven drying	SANS 3001 GR20
	Water absorption of aggregate retained and passing 4.75mm sieve	TMH1: B14 TMH1: B15
	Aggregate crushing value	TMH1: B1
	10% Fines aggregate crushing value	TMH1: B2
	Loose and compacted density	TMH1: B6
	Particle size analysis of aggregates by sieving	SANS 3001-AG1
	Determination of the average least dimension of aggregates by direct measurement	SANS 3001-AG2
	Determination of flakiness index of coarse aggregate	SANS 3001-AG4
	ACV (Aggregate crushing value) and 10% FACT (Fines aggregate crushing test) values of coarse aggregates	SANS 3001-AG10
	Determination of bulk density, apparent density and water absorption of aggregate particles retained on the 5mm sieve for road construction	SANS 3001-AG20
	Determination of bulk density, apparent density and water absorption of aggregate particles passing the 5mm sieve for the road construction materials	SANS 3001-AG21
	Apparent density of crushed stone base	SANS 3001-AG22
	Particle and relative densities of aggregates	SANS 3001 AG23
	In-place density by sand replacement method	TMH1: A1C(a) 1986
	In-place density by nuclear methods	TMH1: A1C(b) 1986
	Determination of in situ density using a nuclear density gauge	SANS 3001 NG5
	Division of a sample using the riffler	TMH-5 M31
	Division of a sample by quartering	TMH-5 M32

Original Date of Accreditation: 01 March 1999 Page 2 of 2

ISSUED BY THE SOUTH AFRICAN NATIONAL ACCREDITATION SYSTEM

Accreditation Manager

Figure 9-1: Example of certificate of accreditation, showing the facility identification, international standard, and test types

9.4 Annexure D: Examples of further information

9.4.1 Progression of discourse regarding analysis based on empirical tools

9.4.1.1 Rock Quality Designation (RQD)

- In the review of twenty years of application of the Rock Quality Designation (RQD), Deere and Deere (1989, p9) clarify that "*an incorrect reference was cited inadvertently in this paper accrediting Deere with the introduction of the RQD in his 1964-paper "Technical Descriptions of Rock Cores for Engineering Purposes." Actually, two mistakes were involved. First, the date of the cited paper should have been 1963, not 1964; and second, the RQD concept was not given in that paper as it was not developed until 1964 and was only available in file copies of consulting reports".*
- Despite the recognition of the errors in print, the candidate observes that many authors reproducing modified summary tables from Stewart and Forsyth (1995) and Palmström (1995) continue to cite the origination of Deere's RQD incorrectly.
- Using RQD as the focus of discourse, Pells *et al.* (2017) and Demetrious (2018) show an example of the progression of discourse regarding analysis based on empirical tools – motivating for and then defending against, respectively, the notion that the time has come for RQD "to rest in peace" [cease to be used].

  The stance of Pells *et al.* (2017) is that RQD has '*outlived its usefulness and is no longer effective as a classification and rock characterisation method'*. The authors present examples in justification of their argument. In contrast, Demetrious (2018) writes in defence of the RQD system and asserts that there is no valid technical reason to discontinue its use. Demetrious (2018) also puts forward suggestions for a different approach that allows quantification of important characteristics of rock formations.
- Yang *et al.* (2020) further the questioning on the use of RQD in rock engineering and its implications for future rock slope design.

9.4.1.2 Q-system

- Following from the origination in 1974, Barton (2002) provided several new Q-value correlations to assist in site characterisation.

- Palmström[63] and Broch (2006) discuss the use and misuse of rock mass classification systems, with particular reference to the Q-System
- Fereidooni *et al.* (2015) explore the applicability of a modified Q classification system, as the Q-system itself was not suitable for the conditions described in the study. Using RMR and SMR rock mass classification systems, Fereidooni *et al.* (2015) produce a modified rock mass classification system namely Slope Quality Rating (SQR) based on the correction of the Q classification parameters and calculating some new parameters such as dip and strike of discontinuities and the method of rock excavation or blasting.

9.4.1.3 Water and Stress in Rock Mass Characterisation

- Seemingly prompted by a report from a rock mass classification workshop held in Australia in 2000, a letter to the editor of the Journal of the International Society for Rock Mechanics (ISRM) by Barton (2001) aims to emphasise the incorporation of water and stress to rock mass characterisation and classification, stating that it intimated during the workshop "*that the subject of rock mass classification has been definitively debated, and that an important conclusion has been reached for the profession to follow…… Of concern…, is the fact that… developers of two of the principal classification methods under discussion, were not able to give…. alternative points of view….*" And the explanation continues that "*the key dilemma is whether the 'internal' and 'external' so-called boundary conditions of water and stress should be permitted in a rock mass characterisation scheme" .* The letter uses a number of inputs into rock mass classification schemes to explain the stance and re-iterate the importance of water and stress in rock mass characterisation. In reply, Milne *et al.* (2002) promote the process and spirit of academic discourse.

9.4.1.4 Hoek-Brown Failure Criterion

- Initially published in 1980, the Hoek-Brown Failure Criterion '2018 edition' (Hoek and Brown, 2018) describes the evolution of the criterion to incorporate both intact rock and discontinuities, in order to to estimate the mechanical behaviour of various rock masses. Hoek and Brown (2018) remark that, in general, the criterion has been found to provide

[63] It is understood that the paper is preceded by another, but the precursory paper is published in Norwegian, not English i.e. Palmström A., Blindheim O.T. and Broch E. (2002). The Q-system - possibilities and limitations (in Norwegian). Norwegian National Conference on Tunnelling, Norwegian Tunnelling Association, .pp. 41.1 – 41.43.

satisfactory estimates but that there are several questions on the limits of its applicability and on the inaccuracies related to the quality of the input data.

- Rafiei Renani and Cai (2022) review and reflect on forty-years of the Hoek–Brown Failure Criterion, citing the unique framework for integrating the strength properties of intact rock and geological observations in the field as drivers to the popularity of the system, and motivating that understanding "*the basis and development of the Hoek–Brown failure criterion is essential for proper use of the system within its limits of applicability and with realistic expectations of reliability".*

9.4.1.5 The Geological Strength Index (GSI)

- The applications and limitations are described by Marinos *et al.* (2005), including recommendations and cases where GSI is not applicable – including the opinion that quantification needed for analyses.
- Hoek *et al.* (2013) then gave quantification of the GSI chart.
- Yang and Elmo (2022) detail why engineers should not attempt to quantify GSI, while recognising that "*adopting fundamental changes may be challenging, and… that revisions …. proposed [by the authors] about redundant GSI quantification methods could attract criticism. However, if not questioned, practices established over time [may] becoming empirical habits. There also remains the hazard of assigning […] a priori validity to empirical methods based on personal experience without attempting any form of scientific reproducibility."*

  Yang and Elmo (2022) also state that, to the best of their knowledge, their paper *" represents the first time that all the different GSI tables and quantification methods that have been proposed over the past two decades are collated and compared critically. In [the] critique, [they] argue against the paradigm whereby the quantification process adds the experience factor for inexperienced engineers. Furthermore, [they] discuss the limitations of the notion that GSI quantification methods could transform subjectivity into objectivity since the parameters under considerations are not quantitative measurements*

  The authors conclude their paper by referring to the *paradox proposed by Elmo et al. (2022) that "The purpose of industry standards is to act in ways that regular and predictable engineering decisions can be made. However, the same regularity and predictability become natural enemy of changes since engineers—like most humans—tend to perceive changes as a loss". This aspect is a demonstration of the concerns expressed in [2,64] that research may yield a diminishing return if we*

continue seeking answers in the same research areas that have yielded answers before without offering a true major breakthrough. Accordingly, rather than proposing new GSI quantification methods, we believe that research efforts should focus on introducing new characterisation and quantification methods that are better integrated with advancements in digital collection methods".

The collection and critical evaluation is an essential undertaking of validating a system for use – and the statement that the undertaking is the first in over twenty years, points to the entrenched norms from years gone by.

9.4.1.6 The Geological Strength Index (GSI) from Rock Mass Rating (RMR)

- Terbrugge (2011) explores the subject of determining Geological Strength Index (GSI) from Rock Mass Rating (RMR),
- The mention the rule of thumb that "GSI is RMR minus five" is shown in Terbrugge (2011), Russo and Hormazabal (2019), and Somodi *et al* (2021).

9.4.1.7 Stability Graphs

- The use of stability charts – such as that developed by Mathews *et al.* (1981), have been critically reviewed e.g. Suorineni (2012).
  Suorineni's (2012) findings include that empirical databases should not be used without questioning (a well-accepted stance currently), calibration of stability graph factors should be used in place of the original stability graph factors, new stability graph factors (such as those for faults and stress) need to be calibrated, time and blast induced fractures should be included, and there must be consistency in the use of the stability graph to improve its reliability, with a 'unified stability graph' being required for application to wide and narrow vein orebodies according to Suorineni (2012), where the unified stability graph must be based on systematic and consistent database.

9.4.1.8 Correlations

- Barton (2002) provides several new Q-value correlations to assist in site characterisation.
- Cellabos *et al.* (2014). Examine the relationship between RMRb and GSI using *in situ* data.

- Russo and Hormazabal (2019) show correlations Between Various Rock Mass Classification Systems, Including Laubscher (MRMR), Bieniawski (RMR), Barton (Q) and Hoek and Marinos (GSI) Systems
- Somodi *et al* (2021) evaluate correlations Rock Mass Rating (RMR) and Geological Strength Index (GSI) in various igneous rocks

9.4.1.8.1. Characterisation and Classification

Pitfalls and misuses of rock mass classification systems are described by Potvin *et al.* (2012), as does Milne (2007) in relating problems with rock classification for empirical and numerical design, as the dialogue moves from ‘characterisation’ to ‘classification’.

The matter of characterisation and classification was furthered by Hack (1998) and Hack *et al.* (2003) using a slope stability probability classification (SPCC). The classification (shown in Table 9-27) considers the maximum negative influence of parameters as a means of calculating slope stability and therefore, classifying stable geometry.

9.4.1.9 Scale Effects in Rock Masses

The role of scale effects is described by the International Society for Rock Mechanics, ISRM, Commission on Scale Effects in Rock Mechanics (1990), and provides guidance on strength and deformability, determination of hydraulic properties, roughness scale effects, as well as an intriguing special feature on the role of sampling bias and perceived scale effects i.e. bias and disturbance may contribute to what is perceived to be scale effects.

9.4.1.10 General Relationships

Although not prominent in modern discourse, Table 9-26 provides insight into the relationship of rock mass and associated parameters that influence rock mass characterisation systems in general. The purpose of including the infographic is to allow visualisation of the elements and complexity of inputs through a single representation, which is not as easily achieved by listing formulae, equations, and expressions in sequential pages.

Table 9-26: Overview of main design and classification systems in use (modified after Palmström (1995), Stewart and Forsyth (1995), Edelbro (2004), Hyongdoo (2014), and Fereidooni et al. (2015)) [64]

Name of classification	Year	Originator	Application	Remarks	Form 1	Form 2	Type
Rock Load Theory	1946	Terzaghi	Tunnels with steel supports	Alternative name: The Terzaghi rock load classification system	Descriptive	Behaviouristic	Functional
Geological Classification	1950	Stini		Original text in German; Cited in Stewart and Forsyth (1995) and Palmström (1995)			
Subjective Engineering Classification: Stand up time	1958	Lauffer	Tunnelling	Alternative name: Lauffer's stand-up time classification	Descriptive		Functional
New Austrian tunnelling method (NATM)	1964 (Part 1), 1965 (Part 2) and 1975	Rabcewicz	Tunnelling in incompetent (overstressed) ground	For excavation and design in incompetent (overstressed) ground	Descriptive	Behaviouristic	General
Rock-quality designation (RQD)	1967	Deere, Hendron, Patton, and Cording	Core logging, tunnelling	Sensitive to orientation effects	Descriptive	Behaviouristic	
RQD vs Span	1968	Merrit		In Stewart and Forsyth (1995) and Palmström (1995)			
Rock classification for rock mechanical purposes	1968	Coates and Patching	For input in rock mechanics		Descriptive		General
The Unified classification of soils and rocks	1969	Deere, Peck, Monsees, and Schmidt	Based on particles and blocks for communication		Descriptive		General
RQD vs Rock Load	1972	Cording, Hendron and Deere		In Stewart and Forsyth (1995)			

[64] The table is not wholly exhaustive, as it looks to identify those classification systems more prevalent in literature. Additional classification systems are excluded e.g. the Chinese Slope Mass Rating (CSMR), by Chen, 1995)

Name of classification	Year	Originator	Application	Remarks	Form 1	Form 2	Type
The Rock Structure Rating (RSR)	1972	Wickham, Tiedeman, and Skinner		Support determination based on geological predictions. Alternative name: The Ground Support Prediction Model. In Stewart and Forsyth (1995)	Numerical		Functional
Rock Mass Rating (RMR) System	1972	Bieniawski	Tunnels, mines, foundations, etc.	Unpublished base-case records	Numerical		Functional
Q-System (rock mass quality system)	1974	Barton, Lien, and Lunde	Tunnels and large chambers		Numerical		Functional
The size-strength classification	1975	Franklin	Based on rock strength and block diameter; used mainly in mining		Numerical		Functional
Mining Rock Mass Rating (MRMR) System	1975	Laubscher	Mining	Published in Laubscher *et al.* 1976	Numerical		Functional
The Typological Classification	1978	Matula and Holzer	For use in communication		Descriptive		General
The Unified Rock Classification System (URCS)	1980	Williamson	For use in communication	Published in Williamson, 1984	Descriptive		General
Basic Geotechnical Description (BDG)	1981	International Society for Rock Mechanics (ISRM)	For general use		Descriptive		General
Rock Mass Strength (RMS)	1982	Stille, Groth, and Fredriksson	Modified RMR	Original text in Swedish; Cited in Nord and Stille (1983)	Numerical		Functional
Modified Basic RMR (MBR)	1982	Cummings *et al*.			Numerical		Functional
Simplified Rock Mass Rating	1985	Brook and Dharmaratne	Mines and tunnels	Modified RMR and MRMR	Numerical		Functional
Slope Mass Rating	1985	Romana	Slopes		Numerical		Functional

Name of classification	Year	Originator	Application	Remarks	Form 1	Form 2	Type
Slope Rock Mass Rating	1988	Robert	Cuttings in hard rock	Based on RMR; provides for weak, altered rock mass materials from drillhole cores			
Ramamurthy-Arora	1993	Ramamurthy and Arora	For intact and jointed rocks	Modified Deer and Miller approach	Numerical		Functional
Geological Strength Index (GSI)	1995	Hoek *et al*.	Mines and tunnels		Numerical		Functional
Rock Mass Number (N)	1995	Goel *et al*.		Stress-free Q-System	Numerical		Functional
Rock Mass Index (Rmi)	1995	Palmström	Rock characterisation, rock engineering, communication		Numerical		Functional

Notes:
Descriptive form: the input to the system is mainly based on descriptions
Numerical form: the input parameters are given numerical ratings according to their character
Behaviouristic: the input and classes are based on the behaviour of the rock mass in a tunnel
General: the system is worked out to serve as a general characterisation
Functional: the system is structured for a special application (for example for rock support)

Table 9-27: Parameters and their influence in existing classification systems (Hack, 1998)

MAXIMUM NEGATIVE INFLUENCE OF PARAMETERS (in percentage from final maximum rating)(1)(2)																	
classification system(2)	rating range	Intact Rock Strength	RQD	Discontinuities								Future weather-ing	pressure or load		excavation		method of excavation
				amount of sets	persist-ence	spacing	aperture	roughness (scale) large	roughness (scale) small	infill	altera-tion walls		rock	water	dimension	orienta-tion	
EARLY SYSTEMS (for underground excavations)																	
Deere (RQD)	0 - 100		100														
Wickham (RSR)	19 - 120	24 (general area geology parameter)				35		7						7		11	17
RECENT SYSTEMS (for underground excavations)																	
Bieniawski (RMR)	0 - 100	15	20		6	20	6	6		6	6		15		100(4)	12	
		(reductions are not enough for a change of class)															
Barton(3) (Q)	0.00006 - 2666	with rock load parame-ter(3)	90 extr. good	97 very good				90 extr. good		99 good			97 very good	95 extr. good	100(4)		
Laubscher	0 - 120	17 (no change of class)	13(5)	21(5)(6) good				5	9	15	5	70 poor	40 good	3(7) (no change)	100(4)	37 good	20 (no change)
								(no change in class)									
SLOPE SYSTEMS																	
Selby	0 - 100	20			7	30	7			*(8)		10(9)		6		20	
Bieniawski (RMR)	0 - 100	15	20		6	20	6	6		6	6		15			60	
Vecchia	0 - 100	88														12	
Robertson (RMR)(10)	0 - 100	30	20		6	20	6	6		6	6					(100) (10)	
Romana (SMR)	0 - 115	13	17		5	17	5	5		6	6		13			52	13
Haines	0 - 100	17	13(5)	21(5)(6)				5	9	15	5	70	40	3(7)	(note 11)		20

1) Influence percentages are only an approximate indication,

Some systems are combinations of adding/subtracting, multiplier/divider, and/or logarithmic parameters, not independent and/or non-linear parameters

Influence percentage = (maximum final rating - rating with the parameter minimum and all other parameter maximum) / maximum final rating x 100 %

For the recent classification systems also the class is indicated that results if the particular parameter has its minimum value. This allows comparison of classes between the logarithmic scale of the a-system and the linear scales of the Bieniawski and Laubscher systems.

2) Terzaghi, Laubscher and NATM systems are not included as they do not use a rating for different parameters.
3) Intersections and portals are not considered. Intact rock strength is only of influence if low compared to stress environment.
4) Graphical (approximately logarithmic) relations between roof span or hydraulic radius, final rating and stand-up time.
5) Laubscher's system. Parameters for RQI} and discontinuity spacing can be replaced by discontinuity frequency.
6) Amount of discontinuity sets, spacing and persistence combined in logarithmic relation.
7) Water influence combined with discontinuity ratings,
8) Infill combined with persistence.
9) Selby rates present degree of weathering (thus nut future weathering for the whole rock mass following BS 5930 (1981).
10) Roberston: If RMR < 40 points slope stability governed by the RMR rating; if RMR > 40 points the stability is fully governed by the orientation and strength of the discontinuities.
11) Haines: Final result from graph relating slope height, dip, safety factor and (MRMR) rating. Adjustment parameter for slope orientation in relation with orientation of discontinuities with maximum of 100%.

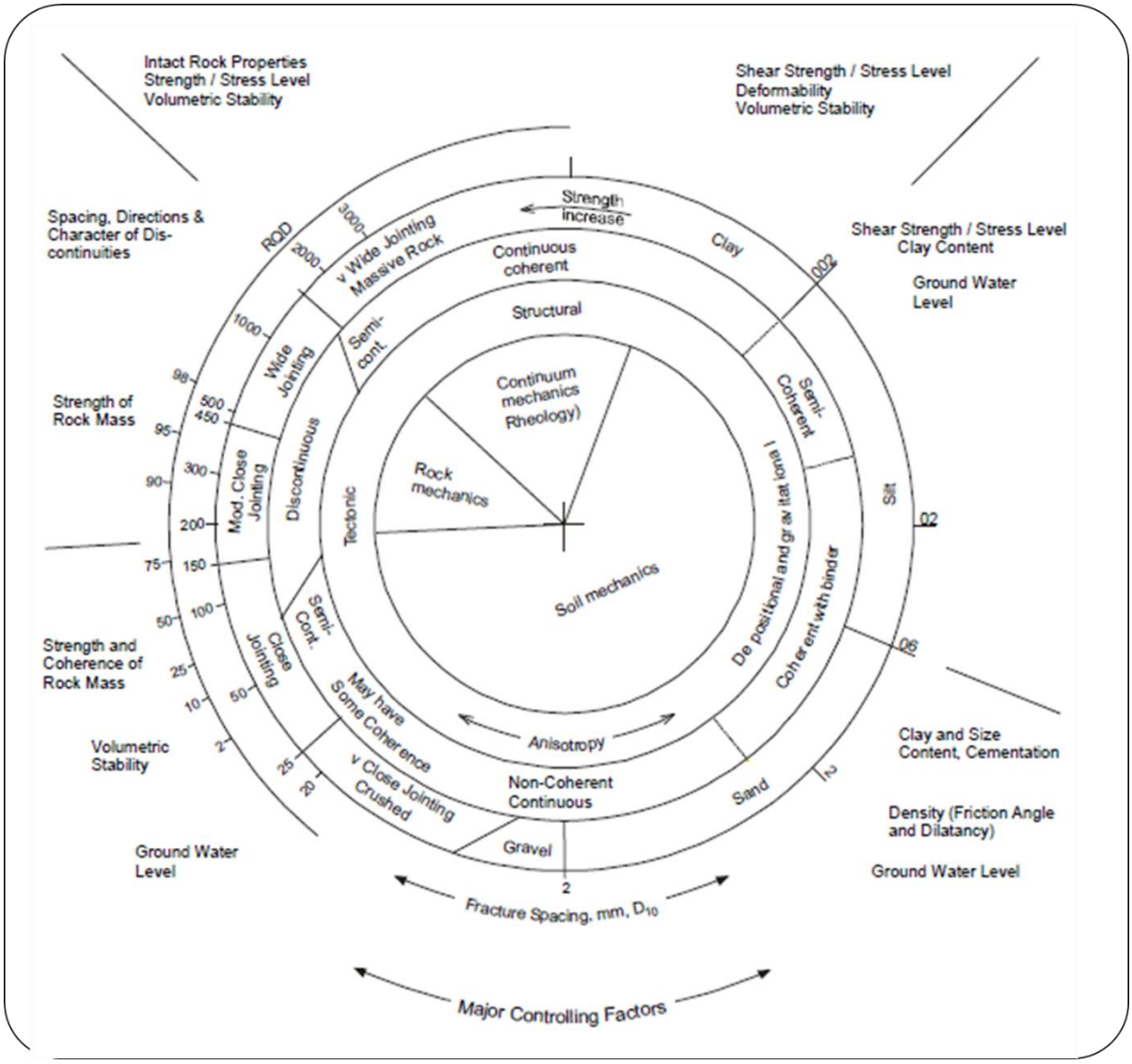


Figure 9-2: The unified classification chart (from Deere et al., 1969 in Palmström, 1995)

There has been a great deal of literature leading up to the attempt to close the conversation (viz. Pells *et al*., 2017 and Demetrious, 2018), where the range of empirical tools that have been used in geotechnical engineering (including stability charts and classification-based support design charts, rock mass classifications etc.), the attributes of the tools, and the suitability of use are shown in Ortlepp (1969); Barton *et al.* (1974); Barton *et al.* (1977); Lilly (1986); Sheorey *et al.* (1989); Chern *et al.* (1998); Potvin (1998); Barton (2002); Hoek *et al.* (2006); Sarsby R. *et al.* (2006); Alejano *et al.* (2008); Nangolo (2011); Carter (2014); Karampinos *et al.* (2014); Maseko (2019); Pagé *et al.* (2021); Hoek *et al.* (1980b); Goktan (2005a); Esterhuisen (2014a); and Elmo *et al.* (2020d); Romana (1985); Grimstad and Barton (1993); Romana *et al.* (2003); Grenon and Hadjigeorgiou (2003); Blindheim (2005); Palmstrom and Broch (2006); Potvin *et al.* (2016a); Bhattacherjee (2002); Hoek *et al.* (2013); and

Li *et al.* (2008) who elaborate on stability charts (for rock slopes) based on the Hoek–Brown failure criterion.

Rock mass parameters, incorporating the various strength components of intact rock, deformability of intact rock, *in situ* stress, Rock Quality Designation (RQD), the nature and extent of structural discontinuities (including orientation, width, roughness profile, weathering, spacing, etc.), as well as their role in engineering design, are described in a great number of technical publications throughout the preceding decades. Extensive publication on the topic has fostered many discussions and profound understanding. The considerable body of knowledge is shown in Reik *et al.* (1978); Baczynski (1980); Brown (1981); Dershowitz and Einstein (1988); Dershowitz *et al.* (1988); Churcher (1990); Barton *et al.* (1992); Haimson (1992); Hoek *et al.* (1992); Ünal *et al.* (1992); Kirsten (1993); White *et al.* (1996); Duplancic (1999); Barton (2002); Crowder *et al.* (2004); Iannacchione *et al.* (2005); King (2005); Orlecka-Sikora *et al.* (2005); Richardson *et al.* (2005); Sellers *et al.* (2005); Gumede *et al.* (2006); Santi (2006); Brzovic *et al.* (2007); Cai *et al.* (2007); Ford *et al.* (2007); Gaich *et al.* (2007); Gumede (2007); Marinos *et al.* (2007); Mas Ivars *et al.* (2007); Rogers *et al.* (2007); Ulusay *et al.* (2007); Brown (2008); Dyke (2008); Grenon and Hadjigeorgiou (2008); Yoshinaka *et al.* (2008); Cai (2009); Cai (2010); Lato *et al.* (2010); Trifu *et al.* (2010); Narendranathan (2011); Volkwein *et al.* (2011); Narendranathan *et al.* (2016); Vogler (2016); Raffaldi *et al.* (2017); Elmo *et al.* (2018); Kaneki *et al.* (2018); Aminpure (2019); Mngadi *et al.* (2019); Mukoya Adebayo (2019); Vallejos (2019); Baczynski *et al.* (2021); Contreras (1992a); Lemy *et al.* (2003b); Grenon *et al.* (2003d); Ortlepp *et al.* (2005b); Lemy *et al.* (2005e); Cai *et al.* (2007a); Wang *et al.* (2015b); and Baylis *et al.* (2020a).

9.4.2 Development of products for reinforcement of hard rock

The American Shotcrete Association (2020) advocates for the advantage that shotcrete facilitates early and safe re-entry to the face in hard rock mining (without delayed entry through a continuous construction cycle) as do the authors Rispin *et al.* (2003), Methven (2004), Rispin (2005).

The uses of shotcrete linings for underground mining have been shown by Rose (1985), Mundike (2005), Windsor (1998), Venter (1998) - and in surface operations by Potvin *et al.* (2004a) and Stacey (2004b).

Shotcrete properties and advancements (including, for example, the introduction of fibre-reinforcement, viz. fibrecrete) have been described by Morgan *et al.* (1990a), Stacey *et al.* (1995), Vandewalle (1998), Stacey (2001) and related design guidelines for the use thereof formulated by Papworth (2002).

The methods, requirements and results of testing methods for shotcrete-products have been described by Storrie *et al.* (2001), Saydam *et al.* (2003), Stacey *et al.* (2003d), Toper *et al.* (2003), O'Toole *et al.* (2006), Yilmaz (2010).

Analyses of shotcrete stress states for less-than-optimal conditions (e.g. due to varying lining thickness and irregular rock surfaces) are reported by Sjölander, A. (2017) and common errors that influence shotcrete quality are explained by the American Shotcrete Association (2020).

9.4.3 On tools and techniques for risk assessment

Keynes (1921); Knight (1921); Heisenberg (1927); Ellsberg (1961); Head (1967); Lawrence (1976); Kaplan et al. (1981); Wilson et al. (1982); National Academy of Engineering (1986); Gough (1988); Gratt (1989); Kumamoto et al. (1996); International Union of Geological Sciences (1997); Outreville (1998); Rosa (1998); International Organisation for Standardisation (2002); Haimes (2004); Slovic et al. (2004); Campbell (2005); International Risk Governance Council (2005); Aven et al. (2008); Aven et al. (2009); International Organisation for Standardisation (2009); Nordgard (2010); Aven (2011); Rausand (2011); Adams (2014); Johansen et al. (2014); Osmont et al. (2014); Sotic et al. (2014); Williams (2014); Sotic et al. (2015); Šotić et al. (2015); Institute of Risk Management (2018); International Organisation for Standardisation (2018); Institute of Risk Management (undated)

9.4.4 On "risk-based" literature

Kendall et al. (1977); Baecher (1981); Vanmarcke et al. (1982); McCracken et al. (1989); Chowdhury (1992); Pine et al. (1993); National Research Council (1994); Read (1994); Sullivan (1994); Brummer et al. (1995); Carter et al. (1995); Einstein (1996); Pine et al. (1996); Davies (1997); Geotechnical Engineering Office of Hong Kong (1997); International Union of Geological Sciences (1997); Steffen (1997); Foster et

al. (1998); Swart et al. (1998); Jónasson et al. (1999); Little et al. (1999); Simonsen (1999); Australian Geomechanics Society (2000); Baczynski (2000); Olsson et al. (2000); Summers (2000); Xu et al. (2000); van Gelder et al. (2001); Vieira (2002); Viner (2002); Australian National Committee on Large Dams (2003); Hamman (2003); Jonkman et al. (2003); Duzgun et al. (2004); Lee et al. (2004); Ammann (2005); Bell R et al. (2005); Clegg (2005); Durrheim et al. (2005); Duun (2005); Eremenko et al. (2005); Glade et al. (2005); Heuberger (2005); Joughin (2005); Lind (2005); Malone (2005); Owen (2005); Simser (2005); Steffen et al. (2005); du Plessis (2006); Haines et al. (2006); Kasatuka (2006); McGill (2006); Ngcobo (2006); Ortlepp et al. (2006); Smith (2006); Sullivan (2006); Terbrugge et al. (2006); Badenhorst (2007); Chapman et al. (2007); Cowan et al. (2007); Johnson et al. (2007); Quinlivan et al. (2007); Siefert (2007); Stacey (2007); Stacey et al. (2007); Tapia et al. (2007); Alejano et al. (2008); Bawden (2008); International Organisation for Standardisation (2008); Joughin (2008); Steffen et al. (2008); Abdel Sabour (2009); Deloitte Touche Tohmatsu Limited (2009); Durrheim et al. (2009); Hamman (2009); Lai et al. (2009); Porter et al. (2009); Potvin (2009); Standards Australia (2009); Terbrugge et al. (2009); Chiwaye (2010); Chiwaye et al. (2010); Hall (2010); Hartman et al. (2010); Hudyma et al. (2010); Rwodzi (2010); Schutte (2010); Bunce et al. (2011); Butcher et al. (2011); C (2011); Dixon RA et al. (2011); Harley (2011); Kaiser et al. (2011); Read (2011); Rwodzi et al. (2011); Steenkamp (2011); Brown (2012); Contreras et al. (2012); Fenton et al. (2012); Joughin et al. (2012); Quail (2012); Zio et al. (2012); Bidwell et al. (2013); Botin et al. (2013); Lane (2013); Lane et al. (2013); Oboni et al. (2013); Abdellah et al. (2014); Disley (2014); Thomas et al. (2014); Contreras (2015); Jong et al. (2015); Luckmann (2015); Montibeller et al. (2015); Restrepo et al. (2015); Stacey (2015); de Graaf et al. (2016); Deloitte Touche Tohmatsu Limited (2016); Federal Energy Regulatory Commission (2016); Ferrari et al. (2016); Joughin et al. (2016); Mechler (2016); Mishra et al. (2016); Vejrazka (2016); Long et al. (2017); Maseki et al. (2017); Mishra et al. (2017); Ontario Ministry of Labour (2017); Porter et al. (2017); van der Merwe et al. (2017); Diederichs (2018); Golestanifar et al. (2018); Institute of Risk Management (2018); International Organisation for Standardisation (2018); Andrijasevich et al. (2019); Atkins et al. (2019); Brockman et al. (2019); Brown (2019); Conrad et al. (2019); Contreras et al. (2019); Counter (2019); Dunn (2019); Duran (2019); Flores-Gonzalez (2019); Gagnon (2019); Hadjigeorgiou (2019); Hamman et al. (2019); Hebblewhite (2019); Jele et al. (2019); Juldyz (2019); Kanda et al. (2019); Kgarume et al. (2019); Kirkpatrick et al. (2019); Lato et al. (2019); Lupo (2019); Malovichko (2019); Mandisodza et al. (2019); McGaughey (2019); Mishra et al. (2019); Morgan et al. (2019); Narendranathan et al. (2019); Porter et al. (2019); Potgieter et al. (2019); Ross-Watt (2019); Tierney et al. (2019); Vatcher et al. (2019); Venter et al. (2019); Wessels et al. (2019); Whittall et al. (2019); Woods et al. (2019); Barry (2020); Nieto (2020); Mishra et al. (2021); Ngwenyama (2021); Human Rights Watch (2022); Nišić

et al. (2022); Potvin et al. (2023); Krige (1979b); Morgan et al. (1990b); Lilly (2000a); Baczynski et al. (2001b); Hebblewhite (2003a); Joughin et al. (2004b); Joughin et al. (2005a); Contreras et al. (2006a); Stacey et al. (2006a); Contreras et al. (2006b); Lilly (2006b); Stacey et al. (2006b); Stacey (2007a); Durrheim et al. (2007b); Stacey (2007b); Steffen (2007b); Atkins et al. (2011a); Bartlett (2011a); Bartlett (2011b); Le (2011b); Jakubec et al. (2012a); Ferreira (2012b); Potvin et al. (2013a); Kirsch et al. (2014b); Contreras (2015a); Baczynski (2016c); Vallejos et al. (2017a); Venter et al. (2018a); Bester et al. (2019a); Coffey et al. (2019a); Venter et al. (2019a); Coffey et al. (2019b); McGaughey (2019b); Potvin et al. (2019b); Venter et al. (2019b); Potvin et al. (2019c).

9.4.5 Numerical modelling

Numerical modelling, including Finite Element (FEM) and Discrete Element (DEM) modelling methods have been developed and rigorously debated – including computational components (such as discretisation) and parametric relationships respectively. The topic is introduced in chapter 4, sub-section 4.2.7.3.

The populus body of learning is shown in Zienkiewicz *et al.* (1989); Pariseau (2001); Muhunthan *et al.* (2007); Clausen *et al.* (2008); Maghous *et al.* (2008); Beck *et al.* (2009); Pax (2010); Arndt *et al.* (2018); Bao *et al.* (2018); York (1998a); Hildyard (2001a); Bruneau G. *et al.* (2003b); Durrheim *et al.* (2005a); Cai (2008a); Cai (2008b); Sainsbury *et al.* (2011a); Sjöberg *et al.* (2011a); Esterhuisen (2014a); Castro (2015b); Campbell (2019b); Vallejos *et al.* (2020a); Webber (1990); Kay *et al.* (1991); Duncan-Fama (1993); Ozbay *et al.* (1996); Lorig (2000); Chrzanowski *et al.* (2002); Cundall *et al.* (2003); Jing (2003); Eberhardt *et al.* (2004); Owen *et al.* (2004); Linzer *et al.* (2005); Wiles (2005); Yasitli (2005); Beck *et al.* (2006); Clark (2006); Pine *et al.* (2006); Wiles (2006); Yavuz (2006); Elmo *et al.* (2007); Andrieux *et al.* (2008); Jefferies *et al.* (2008); Malan (2008); Sainsbury *et al.* (2008); Basson *et al.* (2009); Board *et al.* (2009); Castro *et al.* (2009); Rabus *et al.* (2009); Andrieux (2010); Chiwaye (2010); Arshadnejad (2011); Louchnikov (2011); Murphy (2012); Vakili *et al.* (2012); Esmaeili *et al.* (2013); Lorig *et al.* (2013); Pierce (2013); Vatcher *et al.* (2014); Cloete *et al.* (2015); Jones *et al.* (2016); Roberts (2017); Cundall (2020); Porathur *et al.* (2022); York (1998a); Hildyard (2001a); Bruneau G. *et al.* (2003b); Durrheim *et al.* (2005a); Cai (2008a); Cai (2008b); Sainsbury *et al.* (2011a); Sjöberg *et al.* (2011a); Esterhuisen (2014a); Castro (2015b); Campbell (2019b); and Vallejos *et al.* (2020a).

9.4.6 On strategic, tactical, and operational ideals

Geotechnical mining engineering is not carried out in isolation and is simultaneously reliant on decisions made in the business environment. Integrated functions such as

strategic planning [viz. the long-term, broad of the business], tactical planning [viz. the outline of short-term steps and actions to be taken to achieve the long-term goals] and operational execution provide a multi-faceted environment that requires consistent evaluation, reflection and potentially also revision.

In this respect, geotechnical mining engineering considers the varied duties and possibilities regarding strategic, tactical, and operational ideals and needs. These include (but are not limited to) design, planning, ground control (e.g. rockfall), and the variety of practical factors are shown in Steffen *et al.* (2005); Sunter (2005); Bye (2006); Haines *et al.* (2006); Kear (2006); McCarthy (2006); Thin *et al.* (2006); Bawden (2008); Hadjigeorgiou (2008); Alchin *et al.* (2011); Butcher *et al.* (2011); Bye (2011); Duff *et al.* (2011); Dunn *et al.* (2011); Elkington *et al.* (2011); Ferland *et al.* (2011); Fernandez *et al.* (2011); Hall (2011); Hebblewhite *et al.* (2011); Hudyma *et al.* (2011); Jordaan (2011); Knight *et al.* (2011); Lilly (2011); Louchnikov (2011); Lyle *et al.* (2011); Macfarlane (2011); McCarthy (2011); McGill (2011); Nævermo Sand (2011); Pope *et al.* (2011); Potvin (2011); Read (2011); Rwodzi *et al.* (2011); Kloppers *et al.* (2015); Stacey (2006a); Stacey (2006d); Atkins *et al.* (2011a); Bartlett (2011a); Castro *et al.* (2011a); Atkins *et al.* (2011b); Bartlett (2011b); Hadjigeorgiou *et al.* (2011b); Vogt (2011); and Wesseloo *et al.* (2011).