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WHAT OPPORTUNITIES DOES SOUTH AFRICA'S GEOLOGICAL ENDOWMENT OFFER FOR THE COUNTRY'S FUTURE?

BANZI GEOTECHNICS CC

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1.0 INTRODUCTION

South Africa's geological endowment transcends the mineral resources industry. From the country's favourable global location, its geological architecture, stratigraphy, and geomorphic landscape, multiple industries have been born over the millennia of human settlement in the region. While it is recognised that there is a multiplicity of geological resources in southern Africa, in this paper we focus on the linkages between mineral resources and the geology of the subcontinent. We also aim to show that the opportunities that have been and can still be derived from the country's geological resources are an endowment from which all South Africans can and should benefit.

> *South Africa's geological endowment transcends the mineral resources industry.*

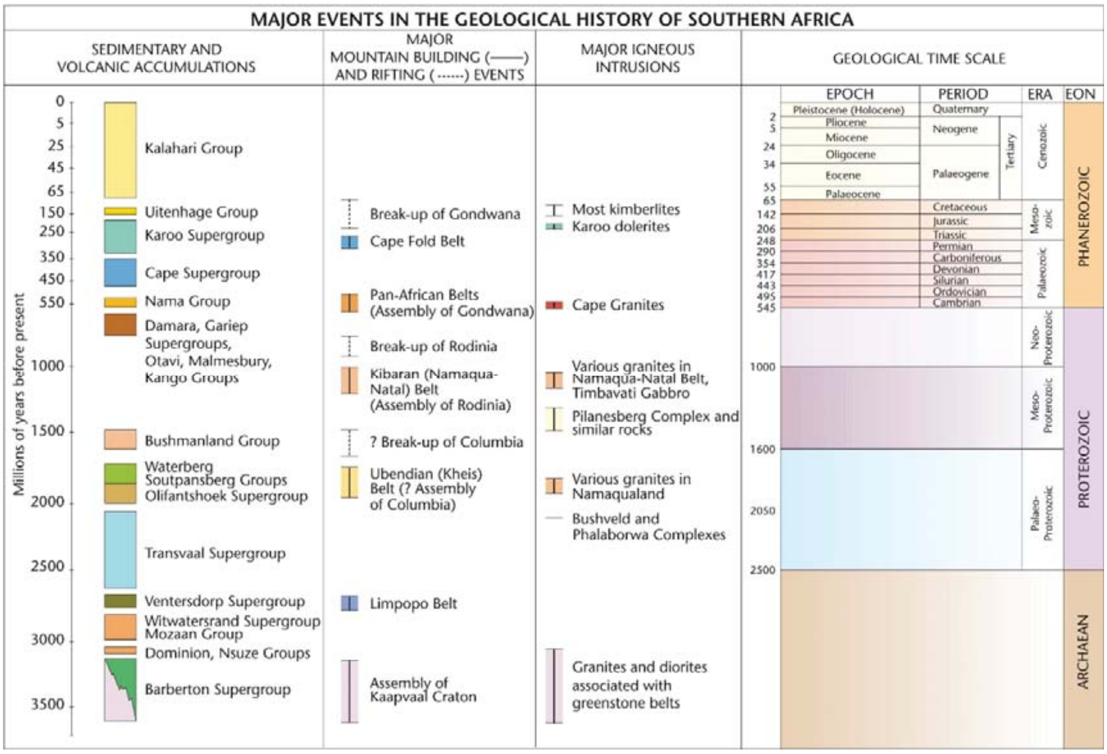
This report aims to provide a synoptic view of this critically important aspect of the country's economy and how it links into all aspects of our living environment both as a country and a nation. To address the opportunities derived from the geology holistically, we begin at the bottom, with the physical foundations of the country: the rock mass. We then build on this, showing how the land surface has revealed the rock mass and how the climate and environment have interplayed with the physical foundations of the country, long-standing processes which gave rise to the natural order and eventually human life. Finally, we discuss how this earth-life paradigm provides opportunities for resource development and environmental sustainability for South Africa and its people.

2.0 SUBCONTINENTAL ROCK MASS

The crustal evolution of the southern African continent provides the architecture for the country's geological endowment. This geological evolution of South Africa hosts approximately 3.6 billion years of Earth history preserved in the rock record, some parts of it continuous and representing an unbroken geological record of over 600 million years of deposition and rock formation (Transvaal Supergroup) (Fig. 1).

Periods of tectonic quiescence coupled with large-scale tectonism (folding and faulting), igneous intrusions (Cape Granite, Sea Point and Bushveld Igneous Complex) and volcanic activity (Stormberg – Drakensburg – Basalts) and deposition of sediments into huge basins ('Wits', Transvaal, Waterberg, Cape and Karoo) took place. These, combined with periods of burial and then uplift to surface, have provided a uniquely concentrated bit of geological real estate which influences property development, mining, groundwater, tourism and practices in engineering of the built environment, and natural sciences.

Fig. 1 : A Summary of the Geological History of South Africa (after McCarthy and Rubidge, 2005)



Like other terranes around the world, the long geological record preserved in South Africa (over 3 billion years) is a significant but still small part of the history of the universe (Table 1). This expands on the events shown in Fig. 1, elaborating on key events, which is critical background for their derivative economic opportunities.

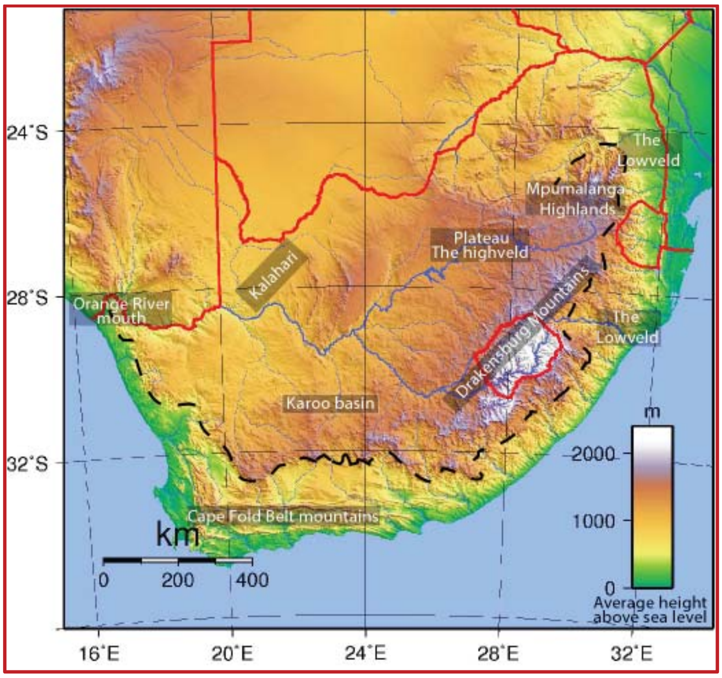
Table 1: Summary of the of Timeline for the Universe and the Geological Architecture of South Africa (after McCarthy & Rubidge, 2001)

Period	Event
15 billion years ago	The Universe forms
13.7 billion years ago	The Big Bang
10 billion years ago	Light elements form
4,67 billion years ago	Earth begins formation
3.5 billion years ago	Free water on earth
3.2 – 3.1 billion years ago	Formation of the centre piece of the subcontinent's tectonic plate. This comprises the granite family of rocks.
2.9 billion years ago	The Witwatersrand Supergroup was deposited as sand and small pebbles in braided river systems, accompanied by **gold** and **uranium** particles, to form the gold reefs which were discovered in 1886 at Langlaagte, 5km west of the Johannesburg city centre. When deposition ended, over 5km of strata were laid down, including volcanic-units which sealed the gold.
2.6 billion years ago	Formation of over 1km thick package of **dolomite rock,** plus **iron and manganese (Northern Cape).** Dolomite extends over large areas of the Highveld, and blankets large areas of the Witwatersrand Supergroup.
2.2 billion years ago	Formation of Pretoria Supergroup of Rocks, including Magaliesberg quartzites

Table 1: Summary of the of Timeline for the Universe and the Geological Architecture of South Africa (after McCarthy & Rubidge, 2001)	
Period	Event
2.061 million years ago	Intrusion of the Bushveld Igneous Complex and associated **platinum group metals**, chrome, vanadium and refractory minerals
2.04 billion years ago	Intrusion of Phalaborwa complex, world's second largest reserve of **vermiculite.** By this time, the atmosphere was fully oxygenated allowing the formation of the first 'red beds' in the sediments being deposited (Soutpansberg and Waterberg Supergroups).
500 to 300 million years ago	Formation of Gondwana, the southern part of supercontinent Pangea. Antarctica and Southern Africa were compressed, and the **Cape Fold Mountain Belt was created**.
310 to 251 million years ago	Sediments were deposited in a basin behind the Cape Fold Belt. The environment changed from deep sea to riverine to swamp-like as the basin filled with sediments which would solidify into the Karoo Supergroup of rocks. **The country's coal reserves begin to form.** This sequence represents about 70% of South Africa's geology which is exposed at surface.
182 to 90 million years ago	Lava poured out over the land heralding the break-up of Gondwana. Sediments and organic material filled into the newly formed ocean basins where the continent pulled apart. The matured ocean basins now form the present day Cape coast in Western and Eastern Cape.
3.3 to 20 million years ago	**Sterkfontein caves** comprising strata including dolomite begin to form. Dolomite dissolves very slowly in rainwater forming cavities and eventually caves.

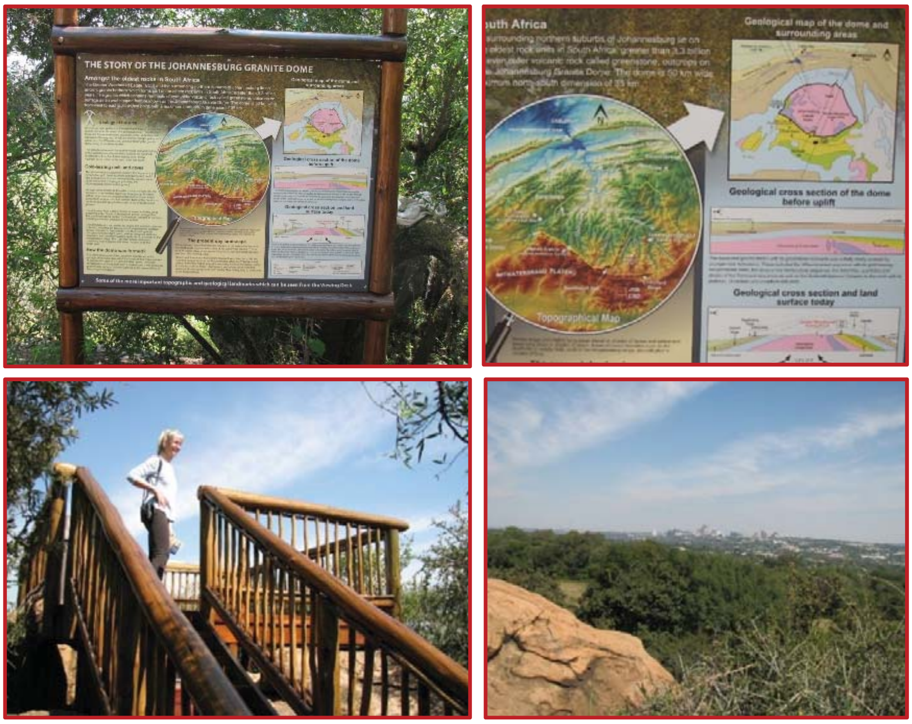
The break-up of the Gondwana supercontinent with South Africa being 'left behind' resulted in significant folding and mountain building along the southern coastline of SA (Fig. 2), and enormous outpouring of lava, preserved along the eastern and south-eastern margin of the country as the Drakensburg mountains. The geological remnants of this period provide both a scenically spectacular geological playground for sport (mountaineering, camping, cycling and even skiing), photography, and near-perfect and conditions for viticulture and other important crops (apples, cherries). Elsewhere along the 2500km 'escarpment' between the Orange River mouth and the highlands of Mpumalanga innumerable similar opportunities exist.

Fig. 2: The landscape of Southern Africa. The black dotted line demarcates the Great Escarpment.



Our geology, shaped through the forces of time, tectonics and climate into the present-day landscape, continues to provide not only a near infinite source of opportunities for earth science such as archaeology, palaeontology, and palaeobotany, but also for engineering, agriculture, sport and recreation. In terms of the latter, our well-exposed geological landscape provides a vast array of opportunities for hands-on exposure to geology and all life forms that rely on it (Fig. 3).

Fig. 3: Geology in Education and Tourism and the Foundation for our Development



Realising these particular opportunities, of course, hinges on funding, political will and intellectual curiosity and interest in the past, present and future of the land we inhabit.

These opportunities may only be superseded by those derived from the superlative metal and mineral deposits, some of which are of the largest or highest grade of their kind in the world.

The fortuitous geologic and tectonic history of the country has resulted in the creation and relatively good preservation both at and under the surface of numerous mineral deposits (more than 80) most notably, gold, platinum, chromium, vanadium, iron and manganese, coal and diamonds and a host of others listed in Table 2, which will continue to meet the appetite for mining and beneficiation of minerals in South Africa.

Table 2: Minerals and metals produced in South Africa (modified after Banzi Geotechnics, 2018)

Commodity	Production in SA	Commodity	Production in SA
Aggregate	S	Nickel	S
Aluminium	S	Coal-Based Products (SASOL)	VL
Andalusite	S	Peat	VS
Sillimanite	VS	Pegmatite deposits	VS
Kyanite	M	Perlite	VS
Antimony	M	Petroleum Oil and Gas	S
Arsenic	M	Platinum	VL

Table 2: Minerals and metals produced in South Africa (modified after Banzi Geotechnics, 2018)			
Commodity	**Production in SA**	**Commodity**	**Production in SA**
Asbestos	NA	Palladium	VL
Barite	M	Rhodium	VL
Beryllium	M	Osmiridium	VL
Bismuth	M	Ruthenium	VL
Chromium	VL	Iridium	VL
Clay	S	Phlogopite	M
Coal Bed Methane	VS	Phosphate	M
Cobalt	S	Pyrite	VL
Copper	S	Rare Earth Elements	VS
Corundum	S	River sand & gravel	S
Diamonds	VL	Salt	S
Dimension stone	S	Sand (Quarry)	S
Dolomite	VL	Silicon	S
Feldspar	S	Silica	M
Fluorspar	M	Silver	S
Garnet	M	Soda	S
Gemstones	M	Sulphur	S
Gold	VL	Talc	VS
Graphite	M	Pyrophyllite	M
Gypsum	M	Tantalum	VS
Helium	VS	Niobium	VS
Iron	VL	Thorium	VS
Kieselguhr	VS	Tin	S
Lead	VL	Titanium	S
Limestone	S	Tungsten	VS
Lithium	S	Uranium	VL
Magnesite	S	Vanadium	VL
Manganese	S	Vermiculite	S
Mercury	VS	Wollastonite	VS
Mica	VL	Zeolite minerals	VS
Mineral sands	VL	Zinc	M
Molybdenum	M	Zirconium	VS
		Hafnium	VS

KEY TO SYMBOLS	
V Large Significant	VL
Significant	S
Minor	M
V Small to Negligible	VS

Note: This Table indicates the importance of minerals in SA. The production importance is estimated (effectively notional). The list of minerals is as provided by the Department of Mineral Resources in prospecting applications.

3.0 THE PHYSIOGRAPHY OF SOUTHERN AFRICA

3.1 Landscape

Geological diversity in a landscape, which is both visually and physically accessible for exploitation, is very dependent on the geomorphological evolution of the land surface. In southern Africa this change of landscape has been a driver of the exploitation of this resource; the rock climber, exploration geologist, township developer and tourist favour well-exposed outcrop versus the miner who develops the minerals preserved below surface, or the gems (diamonds) carried a long way from their source and now buried in sediment far downstream.

Over the last 65My of its existence, the southern African land mass has been subjected to several phases of uplift, tilting, erosion and deposition. These actions have created the distinctive landforms we see today.

3.2 Physiographic Regions

South Africa's continental land surface is asymmetrical with a sharp rise to over 3000m in places along the eastern part of the Great Escarpment from where it gradually wanes to the Atlantic coast in the west. This is due to over 1000m of uplift which commenced some 24 000 years ago along the east and south east coast. The Great Escarpment separates the coastal margin from the rest of the country.

Over the last 65My of its existence, the southern African land mass has been subjected to several phases of uplift, tilting, erosion and deposition. These actions have created the distinctive landforms we see today.

There is an interplay between geology and climate in how the landscape weathers to expose or hide rock strata from view. This process allows for the definition of distinctive physiographic regions based largely on elevation but also with climatic implications. As such, twenty two such regions are recognised in South Africa, and are so defined on elevation above sea level and surface form (landscape) (Fig. 4 & Table 3).

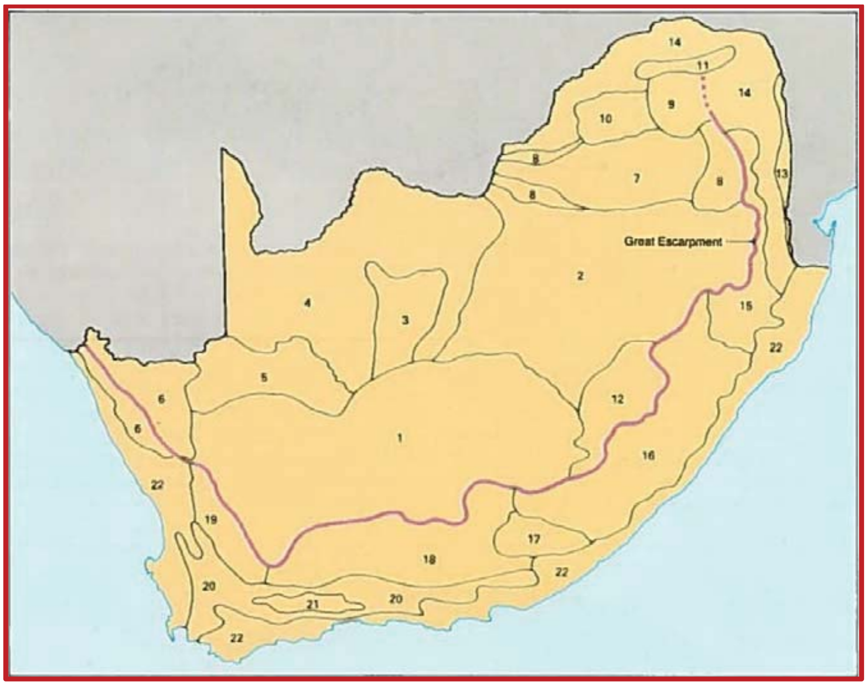
These can be broadly consolidated into two regions using the crest of the Great Escarpment as the dividing line (Fig. 3).

The Great Escarpment is not regarded as a physiographic region. The individual physiographic regions (Table 3) reflect the changing topography and the diversity of the country's vegetation types.

The Upper Karoo and the Highveld together cover most of the interior of the country, while the southern Kalahari spans a large section of the Northern Cape.

The Lowveld (Region. 14) and the Coastal Belt (Region 22) fringe the country, both with unique and distinctive climates, vegetation, scenic splendour and geology.

Fig. 4: Physiographic Regions of South Africa
(Source: Reader's Digest Illustrated Atlas of Southern Africa, 1994)



The inland plateau of South Africa at subcontinental scale is divided into a northern region (2, 7, 8, 9, 10 & 11) and a southern region (1).

The Northern Plateau Region is punctuated in the north by ridges of ancient mountain ranges of the Witwatersrand, Magaliesberg, Olifantshoek, Transvaal, Waterberg, Soutpansberg and Basement Granitic rock sequences. The landscapes defined by these features have had a great, if not vital influence on human settlement and migration as well as urban and mining-related development.

> *The inland plateau of South Africa at subcontinental scale is divided into a northern region and a southern region.*

Whereas ancient Iron Age settlements are recorded along our ridges dating from about 500 years BC to 1850, it was only from the mid-19th Century that large mining projects began and evolved into the 20th Century at Kimberley (Diamonds, 1871), Johannesburg (Gold, 1886), Witbank/eMalahleni (Coal, 1890) and Rustenburg (Chrome, 1921 and Platinum, 1940). Though platinum was first discovered in 1880 at Sheba's Ridge it was first mined near Mookgophong/Naaboomspruit only in 1923. The high grade platinum group metal-rich Merensky Reef, discovered near Steelpoort in 1924 (Barker's Platinum Map of Southern Africa Ed2, 2004) is now mined along a strike length of 550km from Zebediela near Mokopane to Steelpoort and Lydenburg and then westwards past Pretoria, Rustenburg, Pilanesberg and north to Thabazimbi.

In all these cases the serendipitous combination of geology and topography with thin or no recent quaternary cover (60My and younger) contributed to the discovery of the minerals associated with each city.

The Southern Plateau Region is dominated by the Karoo rocks (Fig. 5). This massive basin commences in the north along a line south of Johannesburg, largely defined by the southward erosional progression of the Vaal River off the Highveld. The line extends east, west and south to the Great Escarpment (Fig. 2 & 3). Famously flat, disturbed only by flat-topped mesas and buttes, the region provides a large range of economic activities and a variety of resources. Uniquely, the flat but high-lying Karoo landscape has proved advantageous.

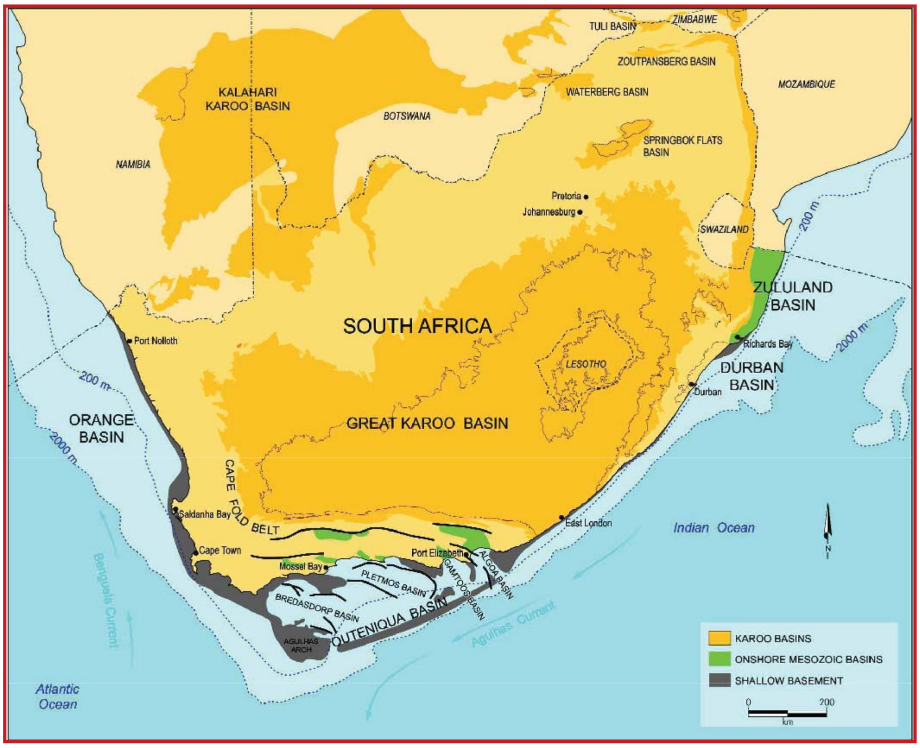
The Southern Kalahari (Fig. 4 and 5, Table 3), extending into Namibia and Botswana and as far as the Democratic Republic of the Congo (DRC), covers an area of 2.5 million km^2, and also represents an even more level surface than the Karoo, mostly north of the South African border.

Table 3: Physiographic Regions of South Africa (after Reader's Digest Illustrated Atlas of Southern Africa, 1994)

Region 1	Upper Karoo: Typically flat scrubland.
Region 2	Highveld: Karoo sediments and dolerite sills which extend from Gauteng east into Mpumalanga.
Region 3	Ghaap Plateau.
Region 4	Southern Kalahari: Camelthorn trees thrive in the sun-baked ochre sands of this region.
Region 5	Bushmanland: Typical of the rocky terrain in the Augrabies National Park in the North Western Cape.
Region 6	Namaqualand Highlands: Granite gneisses form the rock below windblown sands and colluvium, home to the Namaqua daisy, a major annual tourist attraction.
Region 7	Bushveld Basin: Thorn trees, savannah and bush characterise this Limpopo Province Region.
Region 8	Bankeveld: Typically broad plateaus, fringed with foliage.
Region 9	Polokwane Plateau: Typically granitic rocks lie below quartzite-capped mountains towering over grassland.
Region 10	Waterberg Plateau: Rugged, mountainous landscapes characterise this region.
Region 11	Soutpansberg: Red, quartzitic sandstone-capped ridges form a rugged mountainland rising from the Polokwane Plateau.
Region 12	Lesotho Highlands: Tranquil streams and rivers of this region typically traverse basalt ridges and high peaks.
Region 13	Lebombo Uplands: This narrow region embraces the imposing Lebombo Mountains.
Region 14	Lowveld: Vegetation here consists mainly of dry woodlands, thornbush and grassland.
Region 15	Middleveld: Dense forests cover the undulating Middlevel.
Region 16	Eastern Midlands: Erosion has cut deep swathes through this Transkei landscape.
Region 17	Winterberg Uplands: Mountains of the Eastern Cape of the kind traversed by the the Katberg Pass.
Region 18	Great Karoo: A sparse environment.
Region 19	Doring Karoo: Scrubland in the south western Cape.
Region 20	Cape Folded Mountains: Barren peaks typified by the Swartberg range.
Region 21	Little Karoo: The rugged Little Karoo is surrounded by the Cape Folded Mountains.
Region 22	Coastal Belt: The country's marine boundary with the Atlantic and Indian Oceans.

The coastal shelf, extending into the ocean from the coastal margin, is relatively shallow and contains four major offshore sedimentary basins (Orange, Outeniqua, Durban and Zululand basins) which formed during the break-up of Gondwana, when South America, Antarctica, and Australia pulled away from southern Africa. The undersea basins filled up with organic matter eroded from the land surface.

Fig. 5: The Great Karoo Basin and the Inland Plateau of South Africa (Petroleum Agency of South Africa, 2014)



Some basins may contain oil and gas reserves due to the maturation over tens of millions of years of the organic matter (Selley and van der Spuy, 2016). PetroSA has a refinery plant in Mossel Bay (Outeniqua Basin) which condenses gas transported to that plant from various producing zones around the basin.

3.3 Climate

Climate plays a critical role in the process of erosion and the consequent exposure of rocks. As discussed above, the interplay of uplift and climate (temperature, humidity and rainfall) produces the variety of geologically-linked landforms we see as we travel the country.

Fig. 6 View over the Great Escarpment into Lesotho. 'Littleberg' in foreground with deeply weathered mantle of residual soils on Basalt underlain by Sandstone (Barker, 2012)

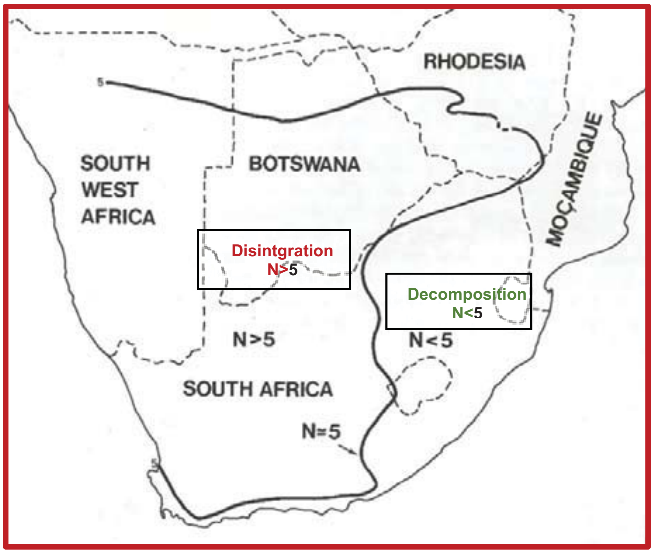
In humid areas with high relief (the Drakensberg in KwaZulu-Natal and in Cape Town (Kloof Nek Road), both physical and chemical processes hold sway, while in the dry and desert areas of the western parts of the country, physical processes dominate to erode and redeposit the weathered products.

Decomposition is caused by chemical action on the rock and leads to the formation of residual soil which is able to carry vegetation (Fig. 5), while disintegration is the mere physical breakdown of a rock and results in gravel (Fig. 6).

A clear distinction is drawn between disintegration and decomposition as the two forms of weathering in rocks due to the influence of the atmosphere, and to a lesser degree, the hydrosphere (Fig. 8). Here, an algorithm designed by H. H Weinert at the CSIR provides a guideline for the separation of these two weathering processes, where his 'N' value is less than 5. This has a profound influence on the products of weathering and thus the environment, land use and engineering applications in terms of mining and construction.

Fig. 7 Physical weathering of granitic rocks near Springbok Northern Cape with thick talus at base of slope supporting dense hardy vegetation (Barker, 2017)

Fig. 8: Climatic Macro Division of South Africa, N> 5 meaning landforms mostly physically disintegrated, N<5, landforms mostly chemically decomposed (after H H Weinert, 1964)



The Great Escarpment and the Drakensberg mountains (Fig. 2) provide physical barriers to air moving over the country from the east and south-southwest. Relatively permanent atmospheric patterns are influenced in their journey by the shape of the surface of South Africa. This also means that for the most part, extreme weather events are relatively rare.

The relatively flat Highveld receives heavy summer rains in water-bearing low pressure air cells descending southward from Angola. There is no large mountain range to prohibit this airflow to the central interior of the country. Conversely, air on the east coast rises above the warm Indian Ocean waters and moves landward, only to be blocked from moving further westward to the interior of the county by the Great Escarpment and Drakensburg. This relationship between the topography and air pattern results in the retention of moisture on the eastern boundary of the country, which feeds the dense and lush vegetation of the Lowveld, KwaZulu-Natal and the Eastern Cape.

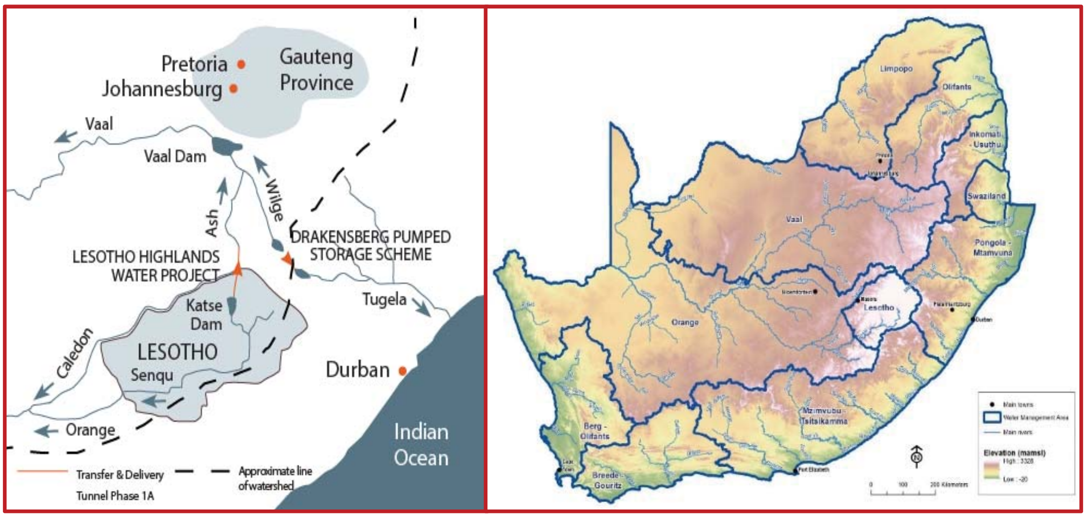
Likewise, on their arrival at the mountains of the Cape Fold Belt, cold fronts moving north-eastward from the Atlantic Ocean are constrained along the high ridges along the Southern Cape coast, providing both surface and groundwater to that region, due to the brittle nature of the quarzitic sandstone of the Table Mountain Group.

While farmlands in the valleys of the Cape Fold Belt enjoy the spoils of borehole-pumped water fed by a high water table in rainy winters, northward into the Karoo basin, a semi-arid climate exists all year round with little evidence that winter rainfall occurs just over the hinterland. The flat expanses of the semi-arid Karoo basin and the Kalahari are overlain by a steady atmospheric feature which rarely experiences disturbance. The climate and terrain here are renowned for their suitability for farming of hardy livestock.

3.4 Surface Water, Supply and Topography

The Highveld and Gauteng in particular is the most populated region of South Africa. The population and industry here have an insatiable appetite for water, and even though the Highveld summer rainfall usually fills dams adequately and recharges aquifers which supply groundwater, the region is still water stressed, much like the rest of the country, and has frequently been placed on Level 1 water restrictions in recent times.

Fig. 9 (Left) The Tugela-Vaal Transfer Scheme. (Right) The water management areas of South Africa. The Vaal is supplied by the Tugela-Vaal Transfer Scheme.



The Tugela-Vaal Transfer Scheme and Lesotho Highlands Water Project (Fig. 9 left) supply water to the Vaal catchment (Fig. 9 right). The Drakensburg Pumped Storage Scheme, completed in 1981, also contributes electricity to the national grid through hydroelectric generation as water passes through turbines at four dams down the escarpment. Most significantly, water is imported from Lesotho after being collected in the Katse Dam, and piped through to Johannesburg and the entire Vaal catchment.

This schematic map of the water scheme in the Lesotho Highlands demonstrates the Highveld's reliance on Lesotho's water supply. The Lesotho Highlands Water Project is directly influenced by the geology of the country; the watershed separating the Tugela catchment from the Vaal and Orange catchments is defined by the Drakensburg mountain range.

With climate change set to bring about more extreme events in sporadic cloud bursts of precipitation, it remains to be seen if the infrastructure in the Highlands Water Project and local water pipelines can withstand higher water flux. 'Possible impacts on water supply and demand in cities under climate change has been assessed in a few studies, ranging from semi-quantitative to quantitative. In most cases, the spread of precipitation projections, coupled with high natural variability of precipitation, lead to considerable uncertainties in the potential climate impacts on water in cities' (Ziervogel, et al., 2014 and references therein).

By 2014, national government had developed a National Climate Change Response White Paper, but had not yet translated it into policy that mainstreams adaptation in everyday practice and longer-term planning in government (Ziervogel, et al., 2014, and references therein).

3.5 Surface Water

Surface water is derived from rainfall which does not seep into the ground but moves across the land surface under the influence of gravity and its own momentum.

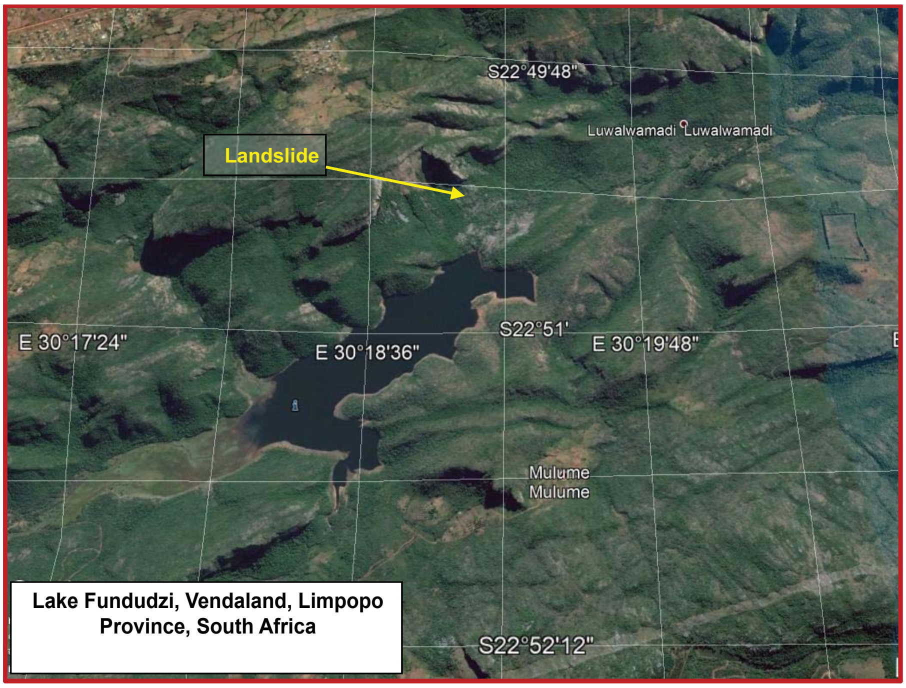
South Africa's mountainous terrains, seasonally met with rainfall from cold fronts (south Cape coast), or subtropical low pressure regimes (Highveld and Lowveld), provide the setting for the channelling and distribution of rainwater towards lakes, dams and pans.

3.6 Natural Lakes

Lake Fundudzi in Vendaland was formed from a landslide.

It may be one of the only natural dams in South Africa formed in this manner. The date of its formation due to the landslide is not known. The lake is sacred to the Venda People.

Fig. 10 Lake Fundudzi in Vendaland was formed by a landslide from the N ridge of the Mutale River.



3.7 Dams

There are 180 man-made dams in South Africa with a total holding capacity of about 33 billion m^3. The geological settings are variable as are the designs and methods of construction.

3.8 Pans

Pans are widespread in the Mpumalanga Highveld near Lake Chrissie and Carolina and in the panveld of the Northern Cape. There are also numerous pans around the gold mines on the East Rand (Fig. 12) as well as many other places, including Mpumalanga and the Northern Cape.

Fig. 11 Pans typically occur as round or round-edged closed water bodies

3.9 Derivative Opportunities

The landscape of South Africa, shaped by climate and the non-uniform weathering of the underlying geology provides a wide range of opportunities to the country. These include opportunities for geo- and bio-tourism and, uniquely, a perfect setting for the development of astronomy to bolster the country's international publication rankings.

3.9.1 Tourism

In his 2018 State of the Nation Address, President Cyril Ramaphosa was emphatic about the potential of tourism in South Africa, a large proportion of which is geo-tourism. The diversity in landscapes across the country offers opportunities for many tastes, from desert safaris to forest and vineyard trails, from tropical beaching to mountain skiing.

In 2017, South Africa welcomed 10.3 million foreign tourists (visitors who stayed overnight), which is only 2,4% greater than 2016's number. This is not competitive with the global average increase of 7% for international visitors (StatsSA, 2017).

If tourism is to be a driver of economic growth, there needs to be at least a twofold growth in visitors numbers, changes to tourism visa regulations, especially with respect to children visitors, and better marketing of the geo-heritage of South Africa.

> *The landscape of South Africa, provides a wide range of opportunities to the country. These include opportunities for geo-and bio-tourism and, uniquely, a perfect setting for the development of astronomy to bolster the country's international publication rankings.*

3.9.2 Astronomy

The flat landscape of the Northern Cape Karoo, the general seismic quiescence there, as well as its dry climate and clear sky, provide pristine conditions for the construction and use of various astronomical instruments. The SALT telescope – a collaboration among a consortium of international partners from South Africa, the United States, Germany, Poland, India, the United Kingdom and New Zealand – is the largest optical telescope in the Southern Hemisphere and seeks to image phenomena deep into the visible universe.

It provides year-round opportunities for astronomers and specialised technicians to collect data from and service the instrument. Publications derived from analyses there are frequently updated online. Scientists stationed at SALT made a significant contribution to the field of astronomy in late 2015. SALT was the third observatory in the world to provide spectrum changes in that area of the universe following the collision of two neutron stars. This collision produced the first ever detection of a gravity wave by the LIGO observatory in the United States. Moreover, SALT provided the first dataset of visible light changes in the universe that testified to this cataclysmic event (Potter and Vaisanen, 2017).

The Square Kilometre Array is another opportunity in science and innovation which was jointly won by South Africa and Australia. Both South Africa and Australia are favourable geologically and climatically to host the radio telescopes which will produce the highest resolution images in the field of astronomy. This project will see the construction of a matrix of very sensitive radio telescopes in the Karoo and deep outback of Australia, to make the world's most sensitive radio telescope at 100 times the capacity of current radio telescopes. This project requires, among other phases, a foundation investigation phase which involves the study of the subsurface soil and rock to determine suitable civil engineering solutions to steady the telescopes.

MeerKAT is the South African-funded contingent of the radio telescope array, and will eventually consist of 64 receptors. When all 64 radio telescopes are operational, the questions answered by data collected from SALT and the SKA may put South Africa in equal standing with other international institutes which study the origins of the universe (DST, 2016).

4.0 ROCK-LINKED RESOURCES

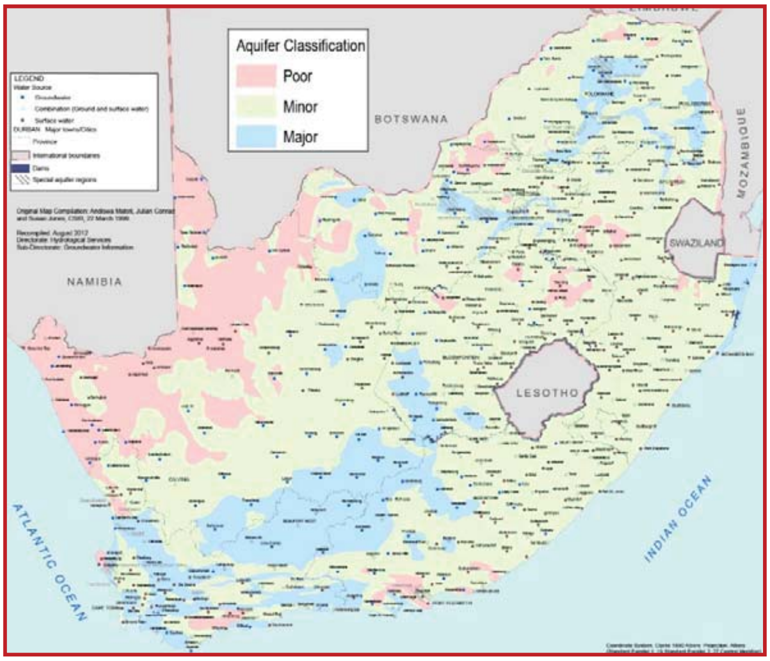
This section discusses the rock-related raw materials present and relatively accessible in the southern African crust. The derivative opportunities from these materials are posed for each category of rock-linked resources.

4.1 Water

4.1.1 Groundwater

Groundwater is defined as water that collects or flows beneath the Earth's surface, filling the porous spaces in soil, sediment, and rocks. Groundwater originates from rain and from melting snow and ice and is the source of water for aquifers, springs, and wells. The upper surface of groundwater is the water table.

Fig. 12: Aquifer classification map (after Matoti et al, 1999)



An aquifer hosts the groundwater in fractures (secondary aquifers) or in permeable and porous granular rocks (sandstone or weathered igneous or hypabyssal rock e.g. granite/norite/gabbro/diabase/dolerite) or unconsolidated sand, silt, clay and gravel, respectively (primary aquifers). About one quarter of South Africa is host to major aquifers, with the majority of the country underlain by minor aquifers .

'Shallow, weathered and/or fractured-rock and relatively low-yielding aquifer systems are underlain over 80 percent of South Africa. By contrast, appreciable quantities of groundwater can be abstracted at relatively high rates from dolomitic and quartzitic aquifer systems located in the northern and southern parts of the country respectively, as well as from a number of primary aquifers situated along the coastline' (Pavelic, et al. 2012, pg 179)

a. Surface Water

The effect of mining and other industrial practices on surface water is a critical issue for water supply in South Africa. In March 2017, the Water Research Commission in association with Golder Associates, launched a sophisticated analysis of mine water in South Africa (South African Mine Water Atlas). This atlas details the effect of mine water on surface and groundwater in a series of risk maps over large portions of South Africa. The reader is referred to this publication for detail of risk in each catchment area. What is important is that the atlas connects geology, mineral resources and groundwater. It is a landmark publication.

Fig. 13: In the East Rand of Gauteng, tailings dams related to old gold mining (light shapes) are in close proximity to pans (round, dark shapes) and river courses, as well as residential areas.

Mine water in particular was classically pumped into depressions close to the mines on the Witwatersrand (Randfontein to Springs). The Boksburg Lake system occurs close to the old gold mines on the East Rand, and is fed by runoff from the suburbs and streams in the areas that surround the old mines. This system, including the Germiston Lake, are centres for aquatic sports today. For many years they were famous for flocks of flamingos which seem to have disappeared. This may be due to contaminated water and increasing salts and acid from infiltration of groundwater into the lake system. Environmentally hazardous conditions occur in proximity to natural pans and tailings dumps in the East Rand of Gauteng.

4.1.2 Opportunity derived from Acid Mine Drainage

Acid mine drainage (AMD) is a significant problem affecting groundwater in gold mines. Where mines are no longer operating, the water is not being pumped out, and is accumulating rapidly to the point that in places it is threatening to decant (Crown Mines). The chemical reaction which creates corrosive low-pH water involves the interaction of deep-flowing groundwater with ore minerals in the wall rocks of gold mines under oxygenated conditions. This reaction also occurs in surface tailings dams from gold, coal, and copper mines, when rainwater interacts with the fine particles of ground minerals. The products of this reaction are an acidic compound in solution as well as heavy metal solid particles in suspension in water. Both the acid and solid metal particles are toxic.

The responsibility for dewatering the voids in gold mines remains a grey area, a legacy issue from historical negligence, and ownership changes without environmental regulations being met before sale or after mine closure. The high degree of interconnectivity of the Witwatersrand gold mines means that if one mine is not operating and dewatering is not taking place, the water overflows into adjacent mines and accelerates the AMD process.

A worst case scenario occurred in 2002 when a West Rand mine (Roodepoort) overflowed to surface and began decanting acid mine water into the Crocodile River, on which many farmers are reliant for irrigation, and then into the Cradle of Humankind (Council for Geoscience, 2010).

The Department of Water and Sanitation has responded positively in the last decade to assist mining companies with two water treatment plants, one operating in Germiston for treating water pumped out of the Central Gold basin, and the other operating in Krugersdorp, for treating water pumped out of the Western Basin. The Eastern Basin Acid Mine Drainage Treatment plant is the largest in the world and was opened in February 2017. It can process 110 mega litres of water a day, and directs the treated water back to the Vaal River system along which wetlands will also be fed (Mzamo, 2017).

> *Mine dewatering may also open opportunities to engineering works if mines seek to be re-opened again.*

The CSIR is developing nanoclay to address the issue of energy-intensive AMD-water processing plants and has a patent pending on this technology. The nanotechnology also has the potential to concentrate the heavy metals generated by the AMD reaction, which would then be sold (Kilian, 2018).

Treated AMD water is suitable for industrial use, as seen in gold tailings reprocessing operations where there is substantial use of treated AMD water. Treated water, however, is not suitable for agriculture. Further purification is required. The opportunity of treated mine water lies in perfecting the purification process to restore the water quality to potable standard, which would create a near water-neutral mining sector. Water treatment is a large business opportunity for service providers to the mining industry and the water management authorities.

Mine dewatering may also open opportunities to engineering works if mines seek to be re-opened again. Currently, mines across the Wits Basin are dewatered to a designated critical level via pumping of that water to the treatment plants (Coetzee, 2016). A re-opening of old flooded gold mines will depend on the gold price and technology which can access more complex and deep zones (2000-4000m depth below surface or bs) of old mines, lower grade areas, and targets at greater depths(+4000m bs) and even work under water with amphibious mining supported by artificial intelligence.

4.2 Minerals

The mineral wealth of the country evokes much pride in South African citizens. The minerals industry has been battered by decreasing and flat commodity prices (coal, platinum and gold respectively), dangerous working conditions (gold) and a reduction in exposure of large multinationals to the SA market (e.g. Rio Tinto and BHP Billiton) (coal, base metals). Added to this, regulatory issues such as slow turnaround time in the processing of prospecting rights by the Department of Mineral Resources, are just some of the negative issues that have plagued the industry for the past 14 years.

In this section a synopsis is presented of examples of how South Africans, where applicable, could derive benefits from a selected group of minerals and their mining styles.

4.3 Metallic

4.3.1 Precious Metals

4.3.1.1 Gold

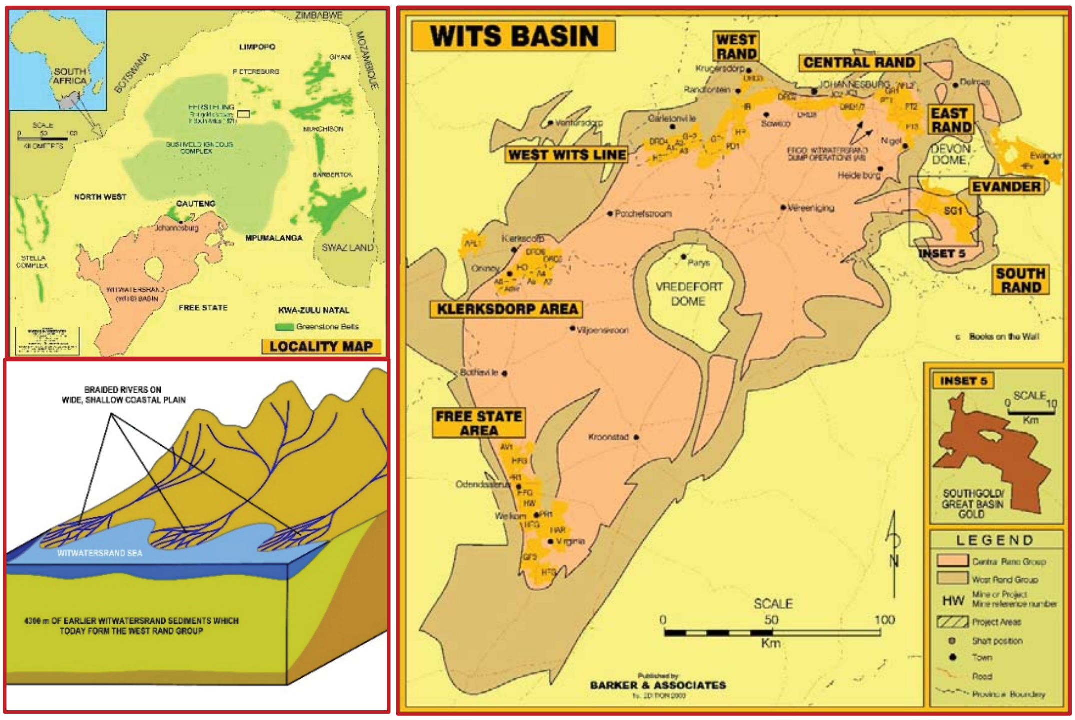
The Witwatersrand Supergroup of rocks formed in the ancient Wits Basin hosts the world's largest known resource of gold, and the third largest proven reserves in the world (Chamber of Mines, 2016).

Gold (including uranium) is extracted from predominantly underground mines. The 5 to 7km thick sequence of sediment and gold particles was deposited in vast sedimentary basins fed by braided river systems [Fig. 6]. A major outpouring of lava across the basin sealed the sediments and their minerals in conglomerate reefs. This protection from Earth's atmosphere as well as from direct contact with rain water preserved the ore minerals for approximately 3 billion years until humans discovered the reefs in 1886 and learnt how to exploit the resource.

The Witwatersrand goldfields have supplied 50% of all gold ever mined. Significantly, it is estimated that there is more gold left unmined today than was extracted over the goldfields' 132-year history. These resources lie at a great depth of over 3000m below surface and are the subject of ongoing advanced research as to how they can be extracted economically and safely, as suggested above.

Working conditions in these gold mines are generally characterised by hard, abrasive quartzitic rock, steep gradients and seismicity due to the release of stress in the rock mass due to mining (opening of voids). With the increasing depth of mining, temperatures continue to rise. Virgin rock temperature at depths of 2 000m below surface can be as high as 40ºC. This requires substantial energy for refrigeration and ventilation. In 2016, South Africa contributed only 4.4% to global gold production, continuing a steady trend of declining production due to increased depth of mining, increased travel time to stopes, and dwindling gold grades with ever more material to move (Chamber of Mines, 2010).

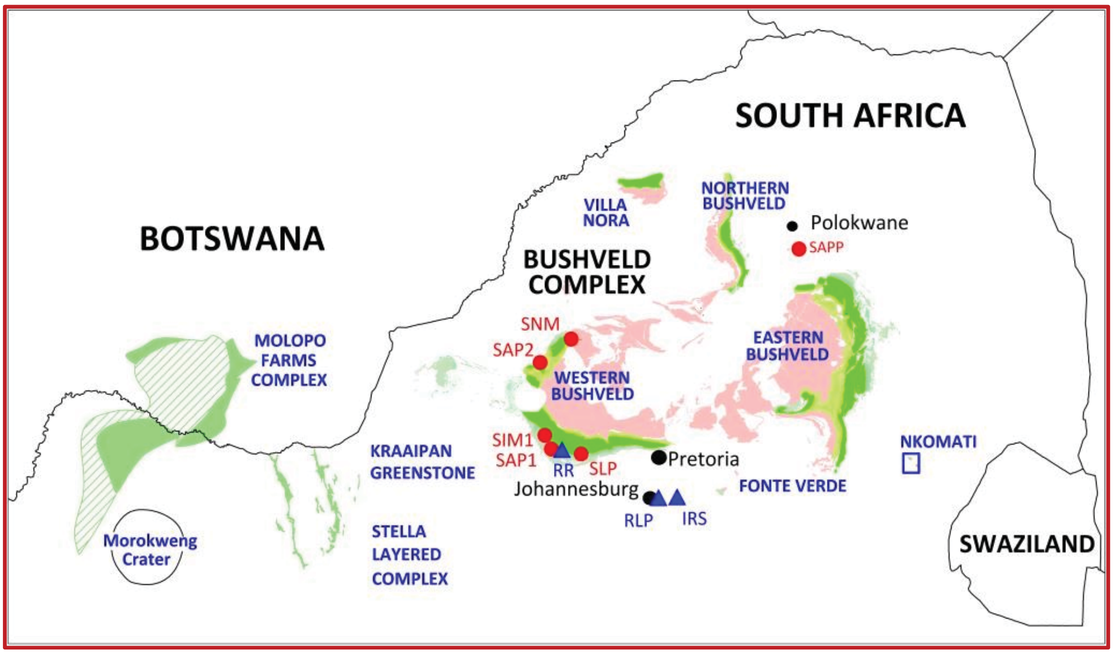
Fig. 14: Top left: The Witwatersrand Basin (red), Bushveld Igneous Complex (light green), and Barberton, Murchison and Giyani greenstone belts (bright green). Bottom left: A Conceptual Model of how 'Wits' gold-bearing reefs formed. Right: The eight gold basins of the Witwatersrand Basin (Source: Barker and Associates, 2003)



4.3.2 Platinum

The Bushveld Igneous Complex intruded into the crust approximately 2 billion years ago, and segregated into various igneous layers containing platinum group elements, chrome, vanadium and refractory minerals and magnetite. It hosts more than half of the world's platinum group elements. The platinum mines have produced more than 75% of the world's platinum output.

Fig. 15: The Bushveld Complex of South Africa (Books on the Wall Publishing, 2011). The contact between the dark green and light green layers marks PGE-bearing horizons.



The Complex has two prominent eastern and western lobes, and two less prominent but no less valuable lobes in Limpopo and Mpumalanga, with a third small unit lying west of the northern limb, the Villa Nora complex. The deposit is saucer-shaped, the inward tilt of the strata having a significant influence on the topography in the North West, Mpumalanga and Limpopo provinces. Additionally, the rock types gabbro, norite and anorthosite are also quarried from the Complex, and are used as dimension stone which adorns many surfaces in homes and offices.

4.3.3 Opportunities in Gold and Platinum

A critical issue facing the precious metals industry worldwide and, no less, in South Africa, is demand. Underground working conditions is also an ongoing issue. On the Bushveld Complex, which is host to 80% of the world's platinum reserves, temperatures can reach 70ºC, which is 30ºC higher than gold mines at the equivalent depth. Today, most deep-level underground mines are ageing with travel times to the face sometimes amounting to an hour or more, impacting significantly on production. This is giving rise to much logistical research in the industry and the Chamber of Mines Research Organisation (CSIR/COMRO) and universities, especially in Johannesburg (Wits) and Pretoria (Tuks).

The introduction of stricter emission standards for combustion-engine motor cars is expected to at least maintain and probably increase demand for PGMs (palladium, platinum, and rhodium), which are used in catalytic converters.

However, the move toward curtailing carbon emissions in developed regions, like Europe and, more recently, China, has led to a drastic decline in the purchase of combustion-engine vehicles, which use platinum in catalytic converters.

Significant changes in policy seek to ban production of diesel and petrol vehicles in the future: France and the UK by 2040, and Scotland by 2032. China is conducting research into their deadline to ban the sale and production of combustion-engine vehicles (World Economic Forum, 2017).

The rise of the battery-powered electric vehicle and its associated battery metals may dwarf the demand for platinum in the near future. Most electric vehicles run on lithium-ion batteries composed of lithium, nickel, cobalt and graphene. However, a competitor innovation to lithium-ion batteries lies in technology used in Fuel Cell Electric Vehicles (FCEVs). South Africa's opportunity is to provide platinum to this particular market which is hoped to buoy the industry. FCEVs use platinum catalysts and run solely on hydrogen, emitting only water from the tailpipe of the vehicle.

While sales of battery-powered vehicles are set to outpace FCEVs in the short term, a long-term view may show a different trajectory. If platinum is going to survive in South Africa, FCEVs need to prove themselves better for the consumer than battery-powered EVs. The benefits of FCEVs over battery EVs relate to recharge time, refilling infrastructure, and better potential for automation. The time it takes to fill an FCEV is faster than the time required to charge a battery EV, which is a considerably attractive factor for potential buyers who lead a fast-paced lifestyle.

> *If autonomous, fuel-cell vehicles can move more material around SA's mines, this bodes well for revenue and will free cash to plug into other innovations and fulfilment of social and labour plans required by all major mining companies.*

Developed nations are adopting FCEV more quickly than proponents of battery vehicles may think, and Honda, Hyundai, Toyota and Mercedes have all released their own FCEVs – a sign of the East's confidence in the technology. In a more industrial application, locally, Anglo American Platinum has developed technology with Shell that can compress hydrogen into liquid. If adopted globally, this technology will strongly influence the uptake of FCEVs. The significance in this innovation is demonstrated in this comparison: a car drives about 100 km on 1 kg of compressed hydrogen, while it drives a mere 1 km on the energy stored in 1 kg of batteries (Mining Weekly, 2018).

Anglo American Platinum will apply this new technology to its own operations in 2019 by way of installing it into vehicles operating around mining workings. If autonomous, fuel-cell vehicles can move more material around SA's mines, this bodes well for revenue and will free cash to plug into other innovations and fulfilment of social and labour plans required by all major mining companies.

In order to innovate and increase the longevity of South Africa's high-potential mining industry, the new Mandela Mining Precinct in Johannesburg was opened on 4th May 2018. The Council for Scientific and Industrial Research (CSIR) and the Chamber of Mines (CoM), in collaboration with the newly established Mining Equipment Manufacturers of South Africa (MEMSA), have developed vital mining research and development (R&D) programmes to be carried through the Precinct, and will guide mining's revival and modernisation. The first priority projects are for the gold and platinum industry, where practices for safer working conditions and change of mining methods need urgent implementation (Creamer, 2018).

Funding averaging R100-million a year over four years is being provided by government and business. The Department of Science and Technology (DST) has allocated R210-million from 2017/18 to 2020/21 for R&D into hard-rock, narrow-reef, metalliferous underground mining. The Chamber of Mines has pledged R33-million for the 2018 calendar year, and the Department of Trade and Industry has provided R8-million.

There are 34 projects on the agenda, placed at various mine sites around the country, which are focused on three main areas: modernisation of current mining operations; mechanisation using drilling and blasting, and non-explosive rock breaking. All these initiatives aim to develop technology which is semi-automated and which puts human operators at much lower risk. Moreover, narrower mine cuttings are also envisioned through bespoke vehicle design.

To encompass all engineering innovations, the Precinct also aims to develop an Internet Of Things model to create a digitised mine with real-time data updates for all operating components of a mine, from dozers to conveyor belts and more. It is hoped that as much as 8 old gold or platinum mines can be re-opened without investment in new infrastructure.

Lastly, property development on undermined land is another derivative opportunity from the gold and platinum mining industries. These developments require stringent geotechnical and geological investigation, as well as verification of the mine voids below the mined area.

The depth to mined-out area has a direct influence on where property may be developed at surface, along with level of risk that undermined ground may face from settlement due to collapse in these stopes resulting from weathering, seismicity or artisanal mining activity ("Zamma Zammas") in purportedly closed mines.

In terms of zinc, South Africa has one of the largest known, undeveloped zinc orebodies in the world.

Five mega-cities are currently planned for construction around Gauteng, one of which, Goudrand Mega City in the Greater Springs area, will be developed on ground where mining operations ceased in 2003 (Gauteng Province, 2017).

4.4 Base Metals

4.4.1 Copper, Nickel, Zinc, Lead, Tin

Copper is widely used in power cables, electrical equipment, automobile radiators, and cooling and refrigeration tubing. The useful metal is found in stratiform deposits in the Northern Cape, and in the Phalaborwa Igneous Complex. Mining of or exploration for this commodity is strongly linked to its price, since it is a bulk mineral, and since SA's reserves are dwarfed by those of DRC and Zambia. Copper production reached 116,973 tonnes in 2007. Since then there has been a steady decline and production stood at 65,257 tonnes in 2016 (Chamber of Mines, 2017a).

Nickel is an essential metal in batteries and the emerging technology in electric vehicles. Nickel-based alloys are also used for more demanding applications such as gas turbines and some chemical plants e.g. desalination plants. South Africa's primary nickel producer is Nkomati mine in Mpumalanga, but the metal is also produced as a by-product at platinum mines on the Bushveld Igneous Complex. Small, undeveloped tin deposits also occur at the uppermost, granitic layers of the Bushveld Igneous Complex.

In terms of zinc, South Africa has one of the largest known, undeveloped zinc orebodies in the world. The Gamsberg Zinc project at Black Mountain Mine in Aggeneys in the Northern Cape is nearing end-of-construction for exploiting this orebody. The mine will comprise an open pit mine and dedicated processing plant. Vedanta, the owner company, is considering a refinery on site as well. The mine will produce from Gamsberg mid-2018 (Liedtke, 2018). Zinc's industrial uses range from alloys to paints, rubber, cosmetics, pharmaceuticals, plastics, inks, soaps, batteries, textiles and electrical equipment. Black Mountain Mining currently produces lead, silver and copper over and above its ambitions to develop the zinc resource. The Northern Cape region near Aggeneys is a high prospect for zinc, lead, copper and silver.

4.5 Heavy Metals

4.5.1 Iron, Manganese, Cobalt, Zinc, Cadmium, Mercury, Lead

South Africa's iron ore and manganese is mined in bulk and is shipped to the Far East through Saldanha Bay. The mines are open cast and exploit stratiform deposits which formed during the first oxidation of Earth's ocean and atmosphere. These deposits were later upgraded by a chemical alteration process after initial formation. The iron ore price is strongly linked to a mine's operation in South Africa. The iron ore mines of the Northern Cape are still operating and make use of the Sishen-Saldanha railway line to transport the bulk material. However, Thabazimbi Mine in North West closed in 2015 due to its old age (80 years), and presents geotechnical hazards with steep-sided tailings dumps.

> *Steenkampskraal, which is situated in the Western Cape, has the highest concentration of rare-earth elements in any deposit of its kind around the world and has recently garnered more interest as international manufacturers of smart devices and green technology are looking to diversify their REE supply.*

Also in the Northern Cape is the world's largest on-land resource of manganese, of which South Africa is the world's top producer. This mineral, exported in bulk, improves the strength of steel. The Kalahari Manganese field has been worked since 1927 at Wessels, N'Chwaning and Hotazel mines, which exploit a dome-like geological structure which exposes the iron and manganese-ore horizons. The Postmasburg Manganese field is currently being exploited and the area is promising to junior explorers.

4.5.2 Rare-Earth Minerals

This group of elements are not especially rare, are chemically similar and tend to occur together in nature, which makes their physical separation difficult.

Rare-earth elements (REEs) are a major component in electric motors, and more specifically, permanent magnets. The use of permanent magnets improves the torque of the vehicles. REEs are also used in nickel metal hydride batteries, most commonly known for their use in the Toyota Prius. The oil refining industry also makes use of REEs in components for the cracking process which involves the breaking of molecular carbon bonds in heavy oil. Wind turbines also make use of a substantial amount – tens of kilograms' worth – of one particular rare-earth element.

REEs occur in many household items: in televisions and energy efficient lamps, UV lights and glass-polishing powders, and, most significantly, smartphones.

Because rare earths are used for so many commercial applications, the US, Japan, Europe and other countries could be vulnerable to supply disruptions since China dominates the market – supplying over 80% of the world's rare earth elements in 2017.

Steenkampskraal and Zankopsdrift are two South African REE deposits which gleaned significant interest in the past 5 years. The former, which is situated in the Western Cape, has the highest concentration of rare-earth elements in any deposit of its kind around the world and has recently garnered more interest as international manufacturers of smart devices and green technology are looking to diversify their REE supply to mitigate against supply disruptions from China (Blench, 2017). Prospecting around Zandkopsdrift, which is close to Saldanha Bay in the Northern Cape, was conducted by Canadian firm Frontier Rare Earths Limited. The project has the potential to be one of the lowest-cost and highest-margin new producers of high purity separated rare-earth oxides outside China, and both deposits have the advantage of the existing infrastructure of the N7 highway and the port of Saldanha, which is used for iron ore exports and oil rig docking and repairs.

4.6 Other Mineral Commodities

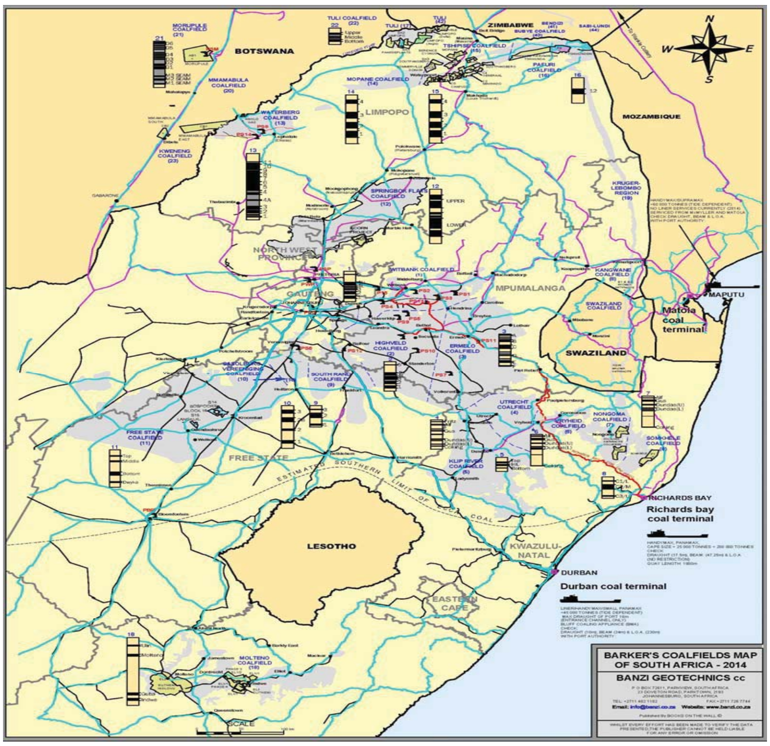
4.6.1 Energy Minerals-Coal

A fourth major boon to South African stratigraphy, and another example of a fortuitous geological history which endowed the country with a valuable (R35B/Annum in 2007) useful natural resource, is coal. Coal is developed in a particular stratum of the Karoo Supergroup of rocks, and dates from 280 and 250 million years ago.

The specific conditions required to preserve coal are exceptional; Southern Hemisphere coal is older than its European counterpart and as such has unique properties that differentiate it from the carboniferous coals of Eurasia and America.

Even though South Africa is home to only 3.5% of global resources, estimates indicate that, based on present consumption, there is sufficient coal of adequate quality to supply South Africa for another century at current production rates.

Fig. 16: The coalfields of Southern Africa occupy the north eastern quadrant of the country (Banzi Geotechnics cc, 2014)



The reserves are located in the north-eastern quarter of the country, and the Richards Bay Coal terminal has a dedicated rail line for coal exports from the country's interior to the port and beyond.

The coal deposits of South Africa occur in the north-eastern quadrant of the country (Fig. 16), and, where mined, are generally shallow (<160m bs), are subject to minor faulting and are shallow dipping (<50). This renders the coal seams amenable to open-cast and mechanised underground mining.

At current rates of production, South Africa has reserves sufficient to satisfy its needs for more than a century. However the locus of production is gradually shifting away from the traditional Witbank or Emalahleni coalfield as collieries approach the end of their productive lives. Emphasis is being placed on exploring and developing the Waterberg coalfield as well as others in the Limpopo province (Chamber of Mines).

In general, South African coal has a comparatively medium ash content which can be reduced by washing before sale. Higher grades of final product are delivered to export markets, with the lower grade product burned by Eskom's specially designed power station boiler hearths (Chamber of Mines, 2016).

An innovative opportunity derived from the coal industry is one which involves making use of fly ash – the waste material from coal mines. Fly ash is made of very fine particles that are corrosive and abrasive. The ash contains many toxic metals and soluble salts which leach into the environment, polluting surface and groundwater. The particles of ash may be harmful if inhaled. Toxic metals such as mercury and chromium in the particles also have negative health effects.

> *At current rates of production, South Africa has reserves of coal sufficient to satisfy its needs for more than a century.*

In South Africa, fly ash is mostly stored in irrigated ash dumps or dry dumps. The chemical weathering of dumps leads to extensive dissolution and leaching of major, minor and trace elements, with very low salt capture. Salt leaching is leading to increased salinization of the country's water catchment areas, rivers, lakes and dams.

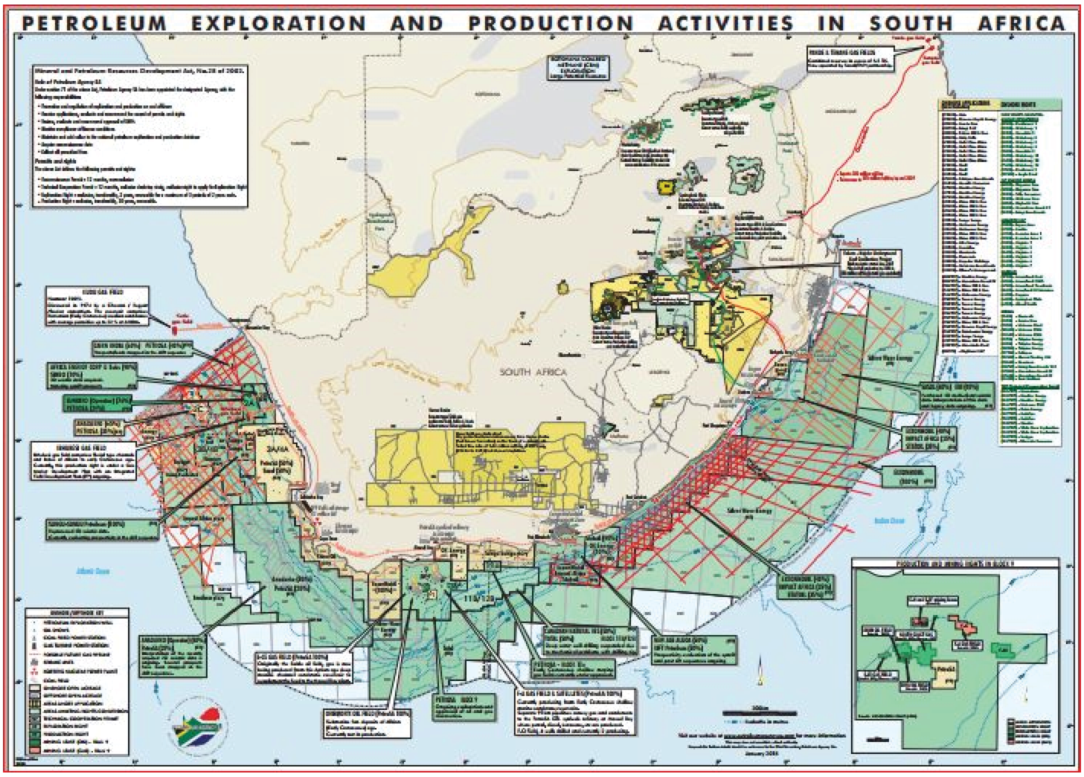
Acid mine drainage can be prevented by making use of fly ash, and contaminated water can be treated successfully with coal fly ash, with a small amount of additional lime and aluminium hydroxide. The treatment leads to water that meets target water-quality range guidelines for irrigation or drinking water.

Fly ash can stop the initial formation of acid mine drainage as well. After water treatment using fly ash, the remaining solids can be used to refill mine holes after a mine is no longer in use. This is known as back-filling. These solids have the strength to prevent mines from collapsing. Backfilling prevents the formation of acid mine drainage because sealing the mine voids ensures that air and water don't get in (Petrik, 2015) Fly ash can also be used to create synthetic minerals which are used in the chemical agents industry.

4.6.2 Energy Minerals – Petroleum

There is a wide continental shelf along the coast of South Africa (Fig. 5). It is the focus of considerable environmental interest and the location of very large oil and gas exploration targets managed by PetroSA (the South African Petroleum Agency) in collaboration with a variety of local and international oil explorers and oil companies (PASA, 2018). Onshore gas projects are also shown (Fig. 17).

Fig. 17 PASA Map of petroleum permits and rights in South African waters (Continental Shelf) and on land (unconventional oil and gas)



Inland, shale gas and coal bed methane occur at specific strata in the Karoo basin stratigraphy. In 2012, National Government lifted the moratorium on shale gas exploration to allow for normal exploration under certain conditions, despite environmental lobbyists' concerns. However, the legal challenges and low oil price over the past three years have together caused exploration by private companies to stagnate.

Meanwhile, the Council for Geoscience is conducting a five-year study on the potential effect of shale gas exploration. This study includes stratigraphic drilling, where core of rock is drilled from the subsurface and its microscale features recorded to determine subsurface conditions and possible gas occurrence.

4.6.3 Diamonds

Piercing through the thick southern African crust are members of another superlative group of mineral deposits. It is the very nature of the thick and old southern African plate that provided the optimum conditions for diamonds to crystallise and eventually be shipped to surface via violent kimberlite eruptions.

These eruptions of material set into the crust as carrot-shaped bodies, called kimberlites. They sometimes bear random distributions of diamonds. Southern Africa has an exceptional density of kimberlites. Diamondiferous kimberlites are concentrated in the central interior of the country.

De Beers recently revived diamond exploration in South Africa, by receiving the first granting of prospecting permits since 2015. They intend to re-explore the Northern Cape around Kimberley, where diamond mining initially began 130 years ago. The De Beers group is also investing and developing innovation for a new digital platform service that provides an immutable tracing of a diamond's individual journey through the value chain using blockchain technology (Creamer, 2018a).

South Africa ranks among the top 10 diamond producers globally, producing 10% of the world's diamonds. In 2016, about 8.5 million carats of diamonds were produced locally (Chamber of Mines, 2016).

4.6.4 Industrial Minerals

Industrial Minerals are mined for their commercial value and are used in their natural state or after beneficiation either as raw materials or as additives in a wide range of applications. They are generally high-volume, low-value commodities, and the bulk nature of these minerals means their exploitation must be close to their demand centre, or easily transported there. Consumption of industrial minerals correlates strongly with GDP growth per capita in various sectors like construction and agriculture, and can therefore be a reliable indicator of transformation and job creation. This correlation does not exist as strongly for non-industrial metals and minerals.

The uses of South Africa's many industrial minerals are numerous. Limestone and phosphates are mined for the agriculture and fertiliser industries. Sand, limestone and dimension stone are used in construction. Fluorspar and kaolin are consumed in the creation of pharmaceuticals and chemical agents. Andalusite (aluminosilicate), lime and silica sands are used in the metallurgical sector, kaolin and feldspar in the paint and pigment sectors.

> *South Africa ranks among the top 10 diamond producers globally, producing 10% of the world's diamonds. In 2016, about 8.5 million carats of diamonds were produced locally.*

South Africa's most abundant industrial metals are aluminosilicates and vermiculite, both with a number 1 world ranking for reserves. Vermiculite is currently produced by the Phalaborwa Mining Company, exploiting the Phalaborwa Igneous Complex which injected into the southern African crust approximately 2 million years ago. The mine at Phalaborwa contains vermiculite, as well as significant concentrations of copper and magnetite. Vermiculite has a plethora of industrial uses, since the mineral undergoes significant expansion on heating.

Andalusite is another industrial mineral of which South Africa is the world's largest producer and exporter. The mineral is useful due to its high thermal shock resistance, low-volume expansion, and good resistance to chemical attack/reactions. South Africa's deposits of andalusite occur on the periphery of the eastern and western Bushveld Igneous Complex, and formed due to the intense heating of the crust caused by the magmatic intrusion.

5.0 Our Geological Endowment: Towards an Enabling Environment

Derek Hanekom, Minister of Tourism, stated that '..tourism is the quickest and easiest way to [economic growth], if – as [President Ramaphosa] urged us to do in [his] State of the Nation Address – we remove the barriers standing in the way of tourism growth. We have a magnificent offer, but it is still too difficult for many tourists to come to South Africa.'

When we look at the derivative opportunities offered and implied by South Africa's geological heritage described above, we are reminded of the adage that too much love is as bad as too little. South Africa's geological heritage is extremely large, being so concentrated here at the foot of Africa. Within a three-hour flight or a four-day journey one can cross the subcontinent from north to south and east to west. In so doing one can experience a diversity of climate, elevation, scenery and wildlife, human languages and cultures not seen elsewhere on Earth in such a short journey. It is this cornucopia of resources that is both stimulating but also overwhelming.

This paper has tried to provide a broad sweep of the geological heritage that is South Africa. In so doing we have shown the dependence of the environment on the geological architecture.

How does one unlock this to the benefit of the largest number of the population in a sustainable manner, without causing grief and harm? This is a challenge all of society needs to face and solve in a holistic manner.

The following ideas and suggestions are by no means exhaustive. They are, however, a list of actions and areas of focus that could provide a solution, predicated on enabling legislation, positive leadership, security of tenure, trust in the law and, above all, an informed and stable society.

1. Geologically based tourism and recreation in all forms and kinds is the easiest way to economic growth, and South Africa has a magnificent offer;
2. Water beneficiation from mines, polluted river systems and dams will spawn technological innovation, fixed capital investment and 'downstream' research and technologies for optimising use and consumption of now valued-added water;
3. Symbiotic mining and environmental practices which optimise sustainability of the operations and post-mining environments;
4. Development and international marketing of South African metals and minerals which are strategic to emerging technologies in the Green Revolution and Industry 4.0.

> *When we look at the derivative opportunities offered and implied by South Africa's geological heritage described above, we are reminded of the adage that too much love is as bad as too little. It is this cornucopia of resources that is both stimulating but also overwhelming.*

5. Creating enabling and managed environments for micro-scale (one person) mining and beneficiation projects;
6. Education and training for single-person operations and systematic support in terms of regulation, legislation and safety.

Targets for these have been listed in the paper, but, in summary, they are shown alongside possible study and training institutions:

1. Geo-tourism: Training, education and certification of tour guides at: technical colleges, universities, schools, NGOs and in-service training and self-learning (reading pamphlets, books and by internet);
2. Developing infrastructure and logistics aimed at facilitating tourism;
3. Artisanal mining occurs in all 9 provinces in SA and should be regulated and placed under a specific department of government and in the provinces.

> *There is a need for research to assess the real impact of past and existing interventions on the ASM sector to draw lessons for future development. The ASM sector is an important sector in the economy. Experience in other countries suggests that if the sector is well supported, it could result in socio-economic benefits for local communities and the country as a whole* (Ledwaba, 2017, J SAIMM vol 117 pg 40).

4. Beneficiation of mine wastes is possibly one of the most pressing and important mine-related activities.
    a. This is being done on a large scale in the gold mining region of Witwatersrand with the removal and recovery of gold and uranium from mine-waste deposits (dumps and slimes dams);
    b. It is also being done on a micro scale at glass dumps around silica operations of Consol Glass in Dundee in KwaZulu-Natal and elsewhere;
    c. Winnowing activities exist around all mines, ranging from gold, platinum, chrome, coal, slate and dimension stone
5. The juxtaposition of human settlements and mines has been an intractable problem to post-mining communities the world over.
    a. This has been particularly so in the Witwatersrand where the large, continuous swathes of derelict land have stood idle since 1886 and, particularly so, since the gold mines closed operations over the past 40 years in Johannesburg and east to Springs and west to Roodepoort.
    b. New initiatives are aiming to change this but are hampered by out-of-date legislation and regulation which does not take cognisance of modern assessment methods, science and engineering developments and capabilities;

> *Beneficiation of mine wastes is possibly one of the most pressing and important mine-related activities.*

    c. Another case in point is old coal mines where many hundreds of square kilometres are underlain by huge coal mines, often mined out on more than one seam. Current legislation prevents development over these areas subject to exhaustive scientific study and engineering analysis, often without condonation from the Department of Minerals and Energy (DMR) Mine Health and Safety Inspectorate (MHSI). It is suggested that this is partly due to vested interests (of the mines) and lack of adequately trained, experienced and qualified staff in the DMR's MHSI group, and out-of-date regulations and laws.

6.0 CONCLUSION

In conclusion, there is much that can be done to encourage and empower the population of South Africa to fully and enthusiastically engage with its extraordinary geological heritage.

This must be done in ways that optimise the resources and opportunities in a sustainable manner to the benefit of the largest number of people and the environment as a whole.

How this can be achieved is the subject of much research and debate, but success will depend on political will and adequate financial and technical support underpinned by comprehensive enabling legislation and regulation.

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