SAHRA PALAEOTECHNICAL REPORT

PALAEONTOLOGICAL HERITAGE OF MPUMALANGA

View of the current coal mining area. Photograpgh: David Groenewald

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GENERAL INTRODUCTION

The core purpose of this SAHRA palaeotechnical report (PTR) is to briefly but comprehensively document the palaeontological heritage resources in South Africa in an accessible and useful format. Following the request by SAHRA, the report is presented in the form of two sections. The first section outlines the general geological history of South Africa and the second section provides a more detailed, geological history of the Free State, Gauteng, North West, Limpopo and Mpumalanga Provinces with specific reference to the palaeontological sensitivity of geological formations and their importance to the development of life through 3600 million years of time in Earth history.

The first section summarises the geological history of South Africa and gives a very brief description of the six major events that shaped the Earth over time. The known and predicted fossil heritage within all the major fossiliferous stratigraphic units (formations, groups etc) that crop out in South Africa are presented on a map that relates directly to the composite geological map of South Africa where mapping was done on a 1:250 000 scale. The palaeontological sensitivity of geological units was allocated sensitivity ratings on a five point scale: very high sensitivity, high sensitivity, moderate sensitivity, low sensitivity and very low sensitivity (Table 1). When used in conjunction with published geological maps, this report can be used by heritage managers and environmental impact assessors, as well as private developers, to rapidly evaluate the potential impact of proposed developments on fossil heritage. (Please note that this scheme is provisional, and will need to be modified in the light of discussions with heritage managers and palaeontological colleagues). Early assessment of palaeontological sensitivity – preferably at the NID or BID phase - is highly advantageous for developers and heritage managers alike, as well as providing the best safeguard for fossil heritage.

The second section of the report consists of concise summaries of the geological history of the Free State, North West, Gauteng, Limpopo and Mpumalanga Provinces. The geological history is specifically related to the development of life as it is recorded in the fossil content of the geological formations. A colour coded palaeontological sensitivity map is provided for each province, with colours referring to the five sensitivity classes described in Table 1. The maps must be read in conjunction with a tabular database for each individual province. The database for each province explicitly relates palaeontological heritage to well-defined stratigraphic units – normally successions of sedimentary rocks – rather than to known fossil sites. This is because a site-specific approach is normally inappropriate for assessing the potential impact of new developments on fossil heritage. The best predictors of fossil heritage at any unstudied locality are the stratigraphic units present there. An undue emphasis on fossil sites (eg map showing all known localities) would be counterproductive since it would give the misleading impression that areas between known sites are less palaeontologically sensitive than the sites themselves. Furthermore, a site specific database could not be made freely available since it would undoubtedly endanger localities of scientific importance.

Despite the comparatively good legal protection offered to palaeontological heritage in South Africa by the current legislation, hitherto this aspect of natural heritage has been largely ignored by developers and professional heritage managers alike. In part this stems from pervasive ignorance about the extent of fossil resources in this country, as well as a widespread confusion between palaeontological and archaeological heritage.

LEGISLATIVE FRAMEWORK

Fossil heritage in South Africa is protected, with important exceptions, by the **National Heritage Resources Act of 1999** (NHRA, Act 25 of 1999). This act replaces the earlier National Monuments Act of 1969 (Act 28 of 1969). Under the new act, fossils are treated as a category of heritage – *palaeontological heritage* - and are regarded as part of the National Estate (NHRA, 1999, p14 and section 32.1(a)).

Definitions

The NHRA does not define the term "fossil" but does offer its own definition of the term "palaeontological" which might be reasonably taken to circumscribe all fossil heritage:

(xxxi) "palaeontological" means any fossilised remains or fossil trace of animals or plants which lived in the geological past, other than fossil fuels or fossiliferous rock intended for industrial use, and any site which contains such fossilised remains or traces (NHRA, 1999, p. 10)

Formal Protections

SAHRA and PHRAs must identify those places with qualities so exceptional that they are of special significance and must investigate their desirability as National and Provincial Heritage Sites, including sites of exceptional palaeontological significance. Any person may submit a nomination to SAHRA for a place to be declared a National Heritage Site or to the provincial heritage resources authority for a place to be declared a Provincial Heritage Site.

27. (18) No person may destroy, damage, deface, excavate, alter, remove from its original position, subdivide or change the planning status of any heritage site without a permit issued by the heritage resources authority responsible for the protection of such site.

Palaeontological objects can be listed as "Heritage objects" in terms of section 32 of the NHRA, (1999), however this requires a formal process.

32. (1) An object or collection of objects, or a type of object or list of objects, whether specific or generic, that is part of the national estate and the export of which SAHRA deems it necessary to control, may be declared a heritage object, including—

(a) objects recovered from the soil or waters of South Africa, including archaeological and **palaeontological objects**, meteorites and rare geological specimens;

General Protections

The import of foreign cultural property into South Africa is prohibited and requires evidence of permission from the country of origin.

33. (1) No person may import into South Africa any foreign cultural property other than through a customs port of entry, and the export permit or other permission issued in the country of origin of such object must be produced to a customs officer before import to South Africa is effected or allowed.

According to the NHRA it is illegal to own, collect, damage or destroy South African fossils without a permit (NHRA, 1999, 35, p58). Such permits would usually be granted only to qualified palaeontologists or other heritage specialists. It is also illegal to buy or sell South African fossils.

35. (1) Subject to the provisions of section 8, the protection of archaeological and palaeontological sites and material and meteorites is the responsibility of a provincial heritage resources authority: Provided that the protection of any wreck in the territorial waters and the maritime cultural zone shall be the responsibility of SAHRA.

(2) Subject to the provisions of subsection (8)*(a)*, all archaeological objects, palaeontological material and meteorites are the property of the State. The responsible heritage authority must, on behalf of the State, at its discretion ensure that such objects are lodged with a museum or other public institution that has a collection policy acceptable to the heritage resources authority and may in so doing establish such terms and conditions as it sees fit for the conservation of such objects.

(3) Any person who discovers archaeological or palaeontological objects or material or a meteorite in the course of development or agricultural activity must immediately report the find to the responsible heritage resources authority, or to the nearest local authority offices or museum, which must immediately notify such heritage resources authority.

(4) No person may, without a permit issued by the responsible heritage resources authority—
(a) destroy, damage, excavate, alter, deface or otherwise disturb any archaeological or palaeontological site or any meteorite;

(b) destroy, damage, excavate, remove from its original position, collect or own any archaeological or palaeontological material or object or any meteorite;

(c) trade in, sell for private gain, export or attempt to export from the Republic any category of archaeological or palaeontological material or object, or any meteorite; or

(d) bring onto or use at an archaeological or palaeontological site any excavation equipment or any equipment which assist in the detection or recovery of metals or archaeological and palaeontological material or objects, or use such equipment for the recovery of meteorites.

Provincial Heritage Authorities

The NHRA provides for the setting up of Provincial Heritage Resources Agencies (PHRAs) to manage most aspects of fossil heritage including, for example, permits and database management. However, some key issues (*eg* export and destruction permits) are dealt with at a national level by SAHRA (South African Heritage Resources Agency), based in Cape Town. In practice, several provinces have yet to establish PHRAs backed up by appropriate palaeontological expertise. Palaeontological heritage in these provinces is entirely managed by SAHRA. The provinces in which palaeontology is still managed by SAHRA include;

- Mpumalanga
- Northern Cape
- North West Province
- Gauteng
- Limpopo Province

- Free State Province

The following provinces have PHRAs competent in management of palaeontological heritage;

- Eastern Cape: EC PHRA (S. Mokhanya: smokhanya@ecphra.co.za)
- KZN: Amafa (A. Van de Venter-Radford: amafaddps@amafapmb.co.za)
- Western Cape: HWC (T. Smuts: tsmuts@westerncape.gov.za)

GEOLOGICAL HISTORY OF SOUTH AFRICA

1 Introduction

The geological history of South Africa spans a total of at least 3.6 billion years and includes some of the major tectonic events that shaped the Earth since the very early formation of this unique Planet. Several leading scientists have devoted their professional careers to the study of the geological history of this part of the world and comprehensive summaries of their work are contained in four recent publications(Tankard et al (1982), MacRae (1999), McCarthey and Rubidge (2005) and Johnson et al (2006)). A comprehensive summary of research in the Pliocene, Pleistocene and Holocene (4,5Ma to the present) cave deposits in the Cradle of Humankind provides an understanding of the palaeoenvironment as well as the development of humans over time (Hilton-Barber and Berger, 2002).

The aim of this document is to give the average reader a very brief idea of the geological history of Southern Africa, with the specific aim of introducing readers to the important impact that the geological development of the region had on the development and evolution of life during the past 3.6 billion years. For more detailed information the reader is referred to the above mentioned publications as well as a wealth of other publications.

The geological history of South Africa is best summarized in chronological order according to the internationally accepted geological time scale as presently used by the South African Committee for Stratigraphy (SACS) and used in recent publications of the Geological Society of South Africa in Johnson et al (2006).

The geological timescale is basically divided into three major Eons, namely the extremely old (older than 2500 million years) Archaean Eon, the Proterozoic Eon (2500 to 545 million years ago) and the Phanerozoic Eon (545 million years ago to today). The Eons are subdivided into different Era, for example the Palaeozoic (545 to 250ma), the Mesozoic (250 to 65ma) and the Cenozoic (65ma to today) which in turn is subdivided into Periods, with more well known terms such as the Permian (300 to 250ma), Triassic (250 to 200ma), Jurassic (200 to 145ma) Cretaceous (145 to 65ma), Tertiary (65 to 1,8ma) and the Quaternary (1,8 ma to today). The Tertiary and Quaternary Periods are further subdivided into Epoch, or Series, with terms such as for example Miocene (23 to 7ma) and Pliocene (7 to 1,8ma) in the Tertiary. The Quaternary is divided into the Pleistocene (1,8ma to 10 000 years ago) and Holocene (10 000 years ago to today). The constant upgrading of the geological timescale has lead to the fact that specific dates assigned to these time intervals can differ, depending on the specific version of the timescale used by a specific author. The dates used in this report are from Johnson et al (2006).

Geological events have distinct features, which in many cases also have distinct relationships with the palaeontological heritage that is preserved in the rock record. Six major stages of geological development, spanning more than 3600 million years, are reflected in the rock record of South Africa.

The six major stages of development can be summarized as follows:

- Early crustal development during the Archaean Eon, including the greenstone belts such as the Barberton Greenstone Belt. The greenstone belts are areas of tectonism, magmatism and sedimentation that occurred on a more ancient stable piece of continental crust known as the Kaapvaal Craton. These rocks contain evidence of very early life in the form of unicellular organisms and bacteria.
- Increasing stability of the crust to allow for volcano-sedimentary sequences such as the Witwatersrand and Ventersdorp Supergroups to accumulate during the latter part of the Archaean Eon.
- In part contemporaneous with the above, collision of crustal plates to yield metamorphic belts such as the Limpopo Metamorphic Belt and the deposition of sediments in large basins, forming such depositions as the Transvaal Supergroup and the emplacement of large plutonic intrusions such as the Bushveld Complex. During this period Southern Africa was also struck by a meteorite that measured up to 10km in diameter, creating the Vredefort Impact Crator. The sedimentary rocks contain evidence of abundant algal growth in the form of Stromatolites.
- Accretion of depositional basins, such as the Waterberg, Soutpansberg and Olifantshoek basins in the north, Damara and Gariep in the west and the Malmesbury basin in the south. These sediments were deformed and metamorphosed at different times (for example during the Namaqua-Natal Metamorphic Belt) with the accretion of continental plates to the Kaapvaal Craton during the Proterozoic Eon.
- Amalgamation of continental plates to form the Gondwana supercontinent on which extensive intracratonic basins (for example the Karoo Basin) developed during the Palaeozoic and Mesozoic Eras of the Phanerozoic Eon. This period represents a major explosion of life forms and is of extreme importance for the palaeontological heritage of South Africa.
- Fragmentation of Gondwana, accompanied by the extrusion of great volumes of basaltic and rhyolitic magma during the early Mesozoic Era of the Phanerozoic Eon. Extensive deposits of sedimentary rocks accumulated during the later Phanerozoic Eon, known as the Cenozoic Era. These rocks contain important palaeontological evidence of the development of life, including the very important fossilized remains of Mankind.

2 Geological History of Southern Africa

The geological history of southern Africa is briefly discussed in terms of the chronological sequence of events that shaped this part of the world. All the major geological events have been described in several comprehensive publications. For the purpose of this document, specific attention is given to those geological processes that had some influence on the development of life. These units will be of specific importance to the palaeontological heritage of South Africa.

2.1 Ancient continental blocks and the Earliest Forms of Life

The Kaapvaal Craton is one of the oldest single pieces of stable continental crust on Earth (McCarthy and Rubidge, 2005; Johnson et al, 2006) and dates back to the Archaean Eon up to 3600 million years ago. This geological treasure underlies a large part of South Africa and holds evidence of the formation of extremely old crustal plates. The rocks that contain information about these ancient times are best exposed as the Barberton Supergroup in the Barberton Mountain Land, where exposures of ancient cherts contain the remains of spherical, single-celled cyanobacteria. These fossils are between 3300 and 3500 million years old and belong to the Archaean Eon (MacRae, 1999). Although these fossils are extremely small (1 micron in diameter) and not visible with the naked eye, they play a very important role in the story of life and therefore are of extreme importance to the palaeontological heritage of South Africa.

2.2 Archaean Sedimentary and Volcanic deposits

The later part of the Archaean Eon was dominated by a series of geological events that lead to the deposition of large quantities of sedimentary and volcanic rocks in what is today known as the Dominion Group, Witwatersrand and Ventersdorp Supergroups and the Pongola Supergroup. These rocks date from 3080 to 2700Ma and are interpreted to have been deposited in local basins that formed on the Kaapvaal Craton, possibly during the same time that the Kaapvaal Craton collided with the Zimbabwe Craton in the north (Johnson et al., 2006).

Due to very high gold reserves found in them, the Witwatersrand Supergroup is probably to most famous group of rocks in South Africa. This group of mainly sedimentary rocks were deposited in a foreland basin which resulted from the collision of the Kaapvaal Craton with the Zimbabwe Craton (Johnson et al, 2006). These rocks have also attracted the attention of palaeontologists when recent discoveries conclusively indicated that some of the gold deposits were concentrated by biological processes associated with lichens that populated the sedimentaryenvironments (Mac Rae, 1999). This interpretation therefore indicates that more advanced forms of life were present at 2900 to 2700Ma, much earlier than was previously believed.

Advanced algal structures, known as stromatolites, have also been described from the Pongola Supergroup. This confirms the importance of these sedimentary sequences in the palaeontological heritage of South Africa.

2.3 Late Archaean to Proterozoic Events

During the late Archaean Eon conditions on the Kaapvaal Craton was more stable, leading to the deposition of thick deposits of carbonaceous sediments in extensive shallow basins that today forms the Transvaal Supergroup of rocks. The dolomites that dominate the lower part of the Supergroup (Malmani Subgroup of the Chuniespoort Group in the north and Cambell Rand Subgroup of the Ghaap Group in the south western part of the basin) contain some excellent examples of stromatolites, ranging from centimetre scale to several tens of meters in size. These structures, that are a result of algal growth in shallow water, indicate a very rich growth of algae that would have caused an enrichment in the amount of oxygen in the atmosphere, which in turn would have led to the precipitation of large thicknesses of banded iron formation in the overlying groups of rock sequences (Penge Iron Formation in the Chuniespoort Group and Asbestos Hill Subgroup in the Ghaap Group). The precipitation of iron oxide is probably closely related to the biological processes of cyanobacteria (MacRae, 1999).

The presence of stromatolites and micro-fossils in the rocks of the Transvaal Supergroup is of high palaeontological significance. Reports of other possible “trace fossils structures” from rocks of the Transvaal Supergroup might lead to some very important discoveries of advanced life forms in the lower Proterozoic in the future. The importance of these rock units for the palaeontological heritage of South Africa must not be underestimated.

Two other important geological events that happened during the Proterozoic Eon are the intrusion of the Bushveld Igneous Complex at about 2050Ma and the massive impact of an asteroid at Vredefort at 2023Ma, making it the oldest impact structure on Earth. Although no fossils are directly associated with these events, they are important for the possible influence that they would have had on the development of life on the planet. The fact that most of the life forms on Earth were very primitive at the time reduces the actual impact of these two events (McCarthy and Rubidge, 2005).

2.4 Accretion of Depositional Basins during the Proterozoic Eon

Commencing around 1900Ma, shallow-water marine sediments represented by limestones, dolomites quartzites and mudstones, accumulated in the west, depositing rocks of the Olifantshoek Supergroup. At the same time, rocks of the Waterberg and Soutpansberg Groups in the north were also deposited in local extension basins. The Waterberg and Soutpansberg Groups contain the Earth’s oldest red beds, indicating deposition under an atmosphere that contained free oxygen. Up to this point in time, oxygen produced by cyanobacteria was consumed by iron and manganese dissolved in the oceans and precipitated as banded iron formations (McCarthy and Rubidge, 2005). Although minor indications of possible algal mats have been recorded from these sediments, no major fossil finds have been recorded to date.

Several intrusive events, including the better known Pilansberg Complex, took place during this time, about 1300Ma. These events did not have noticeable impacts on the primitive life of the time.

During a collision event on the southern margin of the Kaapvaal Craton 1750Ma, the Namaqua-Natal Metamorphic Belt was formed but no fossils have up to date been recorded from this sequence. Towards the west the Gariep Basin developed, characterised by shallow marine shelf environments with stromatolitic algal reefs and clean quartz sand deposits (Johnson et al, 2006). Similar conditions probably prevailed in the south where the Malmesbury and related groups were deposited. Very little is known about the fossil content of these rocks and a gap of at least 1950 million years in palaeontological evidence in our knowledge of life on Earth is indicated by MacRae (1999).

2.5 Late Proterozoic and Phanerozoic Developments

The late Proterozoic Eon (600Ma to 500Ma) saw the making of the Gondwana supercontinent and represents a time of incredible diversification of life on Earth (MacRae, 1999; McCarthy and Rubidge, 2005 and Johnson et al, 2006). Accretion of continental blocks led to the folding and deformation of rocks along the margins of the old continents. The Pan-African event (550Ma) encompasses the welding together of the old continents (McCarthy and Rubidge, 2005) and lead to the development of high mountain ranges along what is now the southern Cape as well as the West Coast of South Africa. Sediments from the mountains on the West Coast accumulated in a shallow basin, resulting in the deposition of the Nama Group. The Nama Group of sediments contain some of the best, if not the best examples of some of the oldest multicellular invertebrate animals in the world (Mac Rae, 1999). Rocks of this group also contain very good examples of trace fossils that indicate an age of 543Ma for the boundary between the Proterozoic and the Phanerozoic (also known as the Precambrian/Cambrian boundary) (MacRae, 1999).

During the early Phanerozoic Eon (or early Palaeozoic Era) Southern Africa was the keystone for the early Gondwana Supercontinent and aborted drifting produced elongate troughs along the southern and eastern margins of South Africa , leading to the deposition of the Ordovician to Carboniferous (500Ma to 325Ma) Cape Supergroup and Natal Group of rocks (Jonson et al, 2006). The Cape Supergroup sediments contain a wealth of organisms with hard outer skeletons (MacRae, 1999; McCarthy and Rubidge, 2005), rendering it as one of the palaeontological treasure houses of South Africa.

By mid-Carboniferous times (325Ma) shortening and buckling of the crust lead to the deformation of the Cape Supergroup rocks whilst most of the interior of South Africa was covered in thick ice sheets due to the drifting of this part of Gondwana past the South Pole. Melting of the ice sheets and downwarp to the north of the now actively building Cape Fold

Mountain Range, lead to the deposition of the Karoo Supergroup from 325 to 180 million years ago. Rocks of the Dwyka Formation (glacial deposit), Ecca Group (mainly deep water sediments in the south and deltaic sediments with extensive coal beds in the north), Beaufort Group (mainly fluvial to lacustrine deposits) and Stormberg Group (mainly fluvial, playa lakes and desert deposits) was deposited in a foreland basin that extended far to the north of the Cape Fold Belt. Sedimentation was terminated at about 180 Ma with the extensive eruption of basaltic lava during deposition of the Drakensberg Formation and the Lebombo Group lavas up to 150Ma during the Jurassic Period (MacRae, 1999; McCarthy and Rubidge, 2005; Johnson et al, 2006). The Karoo Supergroup is internationally known for the extreme wealth of palaeontological information relating to the development of life on land, both in the Plant and Animal Kingdoms (MacRae, 1999; McCarthey and Rubidge, 2005). Of specific importance is the evidence for the development of reptiles, mammal-like reptiles, mammals and dinosaurs (MacRae, 1999; McCarthy and Rubidge, 2005). The rocks of the Karoo Supergroup contain a very important part of the palaeontological heritage of South Africa.

2.6 The Break-up of Gondwana and Late Phanerozoic Events

Towards the end of the Mesozoic Era the final break-up of Gondwana lead to the formation of numerous fault-bound basins on the continental margin of Southern Africa during the Cretaceous Period (150Ma to 65Ma). Although most of these deposits are preserved in off-shore basins off the coast of South Africa, the Algoa Basin is particularly well known for the wealth of fossil material from the Kirkwood Formation (including dinosaur remains) and the Sundays River Formation (rich in marine vertebrates, invertebrates and trace fossils) of the Uitenhage Group (Johnson et al, 2006). The most important palaeontological information on conditions that prevailed in the interior of South Africa comes from crater lakes of volcanoes and specifically Kimberlite pipes that erupted during the Cretaceous (McCarthy and Rubidge, 2005).

Apart from the extensive terrestrial deposits of the Kalahari Group in the Kalahari Basin, Cenozoic deposits are largely confined to coastal areas where very rich assemblages of marine fossils (KwaZulu-Natal and Eastern and Western Cape coasts) are recorded (MacRae, 1999; Johnson et al, 2006). These assemblages contribute significantly to the Palaeontological Heritage of the country.

Finally, the Cenozoic Era (65Ma to today), reflects climatic changes, changes in the geomorphology of South Africa and the presence of fossil hominins in certain cave and spring deposits that contributed significantly to the understanding of the evolution of modern man (MacRae, 1999; Hilton-Barber and Berger, 2002; McCarthy and Rubidge,, 2005; Johnson et al, 2006).

3 Conclusion

The geological history of Southern Africa spans at least 3.6 billion years of time and includes several major geological events that not only shaped the geological formation of the area, but had profound impacts on the development of life on Earth. Most of the ancient Archaean and Proterozoic rock sequences contain only very primitive forms of life whereas the rock units that date back to the late Proterozoic and specifically the Phanerozoic, contain some of the richest treasure houses of fossils in the world. Fossils from these younger units bear witness to the development of higher forms of life, including the development of mammals from reptiles and also the development of humankind from very early ancestors.

4 References

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GEOLOGICAL HISTORY OF THE MPUMALANGA PROVINCE

1 Introduction

The geological history of the Mpumalanga Province spans a total of 3600 million years, including some of the major events that lead to the deposition of a wealth of economically important sequences of rocks. Although most of the Archaean and Proterozoic aged rocks are better known for their mineral wealth, rather than their palaeontological importance, the discovery of some of the earliest indications of life in the Barberton Supergroup is of specific importance. Phanerozoic deposits are of importance in the study of the evolution of life during the last 300 million years.

The palaeontological sensitivity of geological formations depends on the significant fossils that are preserved in the rocks that characterise the formation. For the sake of this investigation, geological formations were classified in terms of the significant fossils they contain and also the extent to which development of infrastructure on these formations will impact on significant palaeontological heritage in South Africa. The palaeontological sensitivity map of the Mpumalanga Province gives an indication of the aerial extent of geological formations and the colour coding for the palaeontological sensitivity of the geological formations are summarised in Table 1. A comprehensive database of all the geological units of the Mpumalanga Province is provided in Appendix 1.

2 Significant Palaeontological features in the Mpumalanga Province

2.1 Archaean and Proterozoic Eons

Rocks belonging to the Archaean and Proterozoic Eons contain fossils of ancient life in the form of unicellular organisms such as cyanobacteria. Fossils of these unicellular organisms, belonging to the Kingdom Monera, have been described from chert deposits in the Zwartkoppie Formation of the Onverwacht Group in the Barberton Mountainland and are estimated to be as old as 3300 million years (Mac Rae, 1999). Another convincing line of evidence for the presence of living organisms is in the discovery of Stromatolites in the Fig Tree Group of the Barberton Supergroup. Stromatolites are finely layered structures in the form of flat domes or small columns that developed during the growth of mats of photosynthetic cyanobacteria on the ancient sea floor (Mac Rae, 1999; McCarthy and Rubidge, 2005). Due to the fact that the fossils associated with these rocks are extremely difficult to recognise and also the fact that most of the fossils are only visible under large magnification, a low palaeontological sensitivity is allocated to most of the ancient rocks. However, it must be noted that any records of fossils that are discovered during future investigations of these units will be very valuable.

Stromatolites have been interpreted as ancient examples of modern algal mats as early as 1933 (MacRae, 1999). Stromatolites have been recorded from the Nsuze Group in the Pongola Supergroup, indicating the development of more advanced life forms during the deposition of this Group. Examples of cyanobacteria have been described from the gold bearing conglomerates of the

Witwatersrand Supergroup (MacRae, 1999). These are significant recordings as it gives a possible indication of very early life forms, possibly ancient lichens that existed up to 2900 million years ago. These structures are for example associated with the Carbon Leader Seam in the Carltonville Goldfield, with native gold visible to the naked eye (MacRae, 1999). The recording of these fossils is only possible through electron microscope work and as such, any future recordings of these fossils will be of high significance.

Stromatolite structures have been recorded from borehole data in the Rietgat Formation of the Ventersdorp Supergroup in the Free State Province and any recordings from the rocks of this Supergroup in Mpumalanga Province will be significant.

The Transvaal Supergroup contains thick deposits of stromatolitic dolomite. Stromatolites have been recorded in the Wolkberg Group, and very good examples of Stromatolites have been described from the Malmani Subgroup of the Chuniespoort Group of the Transvaal Supergroup near Pretoria where these structures were studied in detail by scientists such as Young, Bart Nagy and Murray Macgregor since 1974 (MacRae, 1999). These structures are significant indicators of palaeoenvironments and provide evidence of algal growth between 2640 and 2432 million years ago (MacRae, 1999). Stromatolites have also been reported in many of the sediments of the Pretoria Group, with algal mat structures also present in sediments of the Waterberg Group north of Pretoria, indicating earliest known terrestrial cyanobacterial mats recorded from playa lake deposits of the Makgabeng Fm (Waterberg Group) (1800 million years ago). The presence of Stromatolites and algal mat structures contributes significantly to the understanding of the palaeoenvironments that prevailed during the deposition of the strata. These structures therefore contribute significantly to the palaeontological heritage of Mpumalanga.

Informal reports of "sedimentary structures" that might have a biogenic origin have been reported from sedimentary rocks in the Pretoria Group of the Transvaal Supergroup and the Waterberg Group to the north of Pretoria (Colin MacRae, pers comm 2014). If these structures are indeed biogenic in origin, they will be some of the oldest recordings of more advanced life in the history of life on Earth, dating back to about 2200 million years ago.

No fossils have up till now, been described from the Rooiberg Group, and this, mainly volcanic sequence of rock is allocated a low palaeontological sensitivity.

Although of no palaeontological interest, the rock units that overlie the Pretoria Group form part of the economically very important Bushveld Igneous Complex. This igneous intrusion contains the largest reserves of Platinum Group minerals in the world and intruded the Transvaal Supergroup rocks about 2050 million years ago. There is no obvious indication that this event had a profound influence on life at that stage, or with a following period of major alkaline intrusion (for example the Phalaborwa complex) into the Kaapvaal Craton between 2100 and 1200 million years ago.

The dolomites of the Transvaal Supergroup underlie the well-known "Cradle of Humankind" World Heritage Site in Gauteng. Deposits of Cenozoic aged cave breccia associated with sinkholes and karst formations. The deposits at Makapansgat in the Limpopo Province, for example, contain the fossilized remains of plants and animals, including the remains of the ancestors of man (MacRae, 1999; Hilton-Barber and Berger, 2002) The Cenozoic aged cave breccia formations are not mapped out on the geological maps and for this reason the entire outcrop area of the Chuniespoort Group is allocated a very high palaeontological significance with a high palaeontological significance allocated to the outcrop areas of the Pretoria Group.

2.2 Phanerozoic Eon

The base of the Phanerozoic Eon is known for the sudden explosion of diversity of life (MacRae, 1999; McCarthy and Rubidge, 2005). There are no outcrops of rocks that date from the lower or early Phanerozoic (Cambrian, Ordovician, Silurian and Devonian) and the first deposits of this age are the Carboniferous to Permian-aged sediments of the Dwyka Formation. Plant fossils have been described from outcrops of the Dwyka Formation in Limpopo Province, with special reference to this formation in the Springbok Flats region. Outcrops of the formation are however rare in the Mpumalanga Province and any recording of fossils will be highly significant.

The Permian Ecca Group sediments that overlie the Dwyka Formation are well-known for the wealth of plant fossils of the *Glossopteris* faunal assemblage present in the sequence of sandstone and mudstone. Sediments of the Ecca Group contain significant reserves of coal and the interbedded shale is an important source of clay for brick making. The Pietermaritzburg Formation rarely forms good outcrops and fossils are rare and difficult to find. A moderate palaeontological sensitivity is allocated to this formation. The overlying Vryheid Formation is the main coal producing formation in South Africa and is of very high palaeontological significance. A wealth of fossils is recorded from this formation, including rich fossil plant assemblages of the Permian *Glossopteris* flora. Abundant, low diversity trace fossils, rare insects, possible conchostracans, non-marine bivalves and fish scales have also been reported from this formation (MacRae, 1999). The overlying Volksrust Formation consists of a monotonous sequence of grey shale and fossils are significant, but rarely recorded. Fossils include rare temnospondyl amphibian remains, invertebrates, minor coals with plant remains, petrified wood, and low-diversity marine to non-marine trace fossil assemblages.

Overlying the Ecca Group is the late Permian to early Triassic Beaufort Group of sediments, presented in Mpumalanga by only a few scattered outcrops of the Adelaide Subgroup in the south-eastern part of the Province. The northern outcrop of the Adelaide Subgroup is known as the Normandien Formation and it contains rich assemblages of vascular plants (*Glossopteris* Flora, including spectacular petrified logs) and remains of insects. Vertebrate remains are restricted to terrestrial and freshwater tetrapods of the *Dicynodon* Assemblage Zone (MacRae, 1999; McCarthy and Rubidge, 2005; Johnson et al, 2006).

The Triassic aged, mostly red coloured sediments of the Upper Karoo Supergroup belong to the Red Rocks Member of the Clarens Formation and contain fossils of vertebrates (notably dinosaurs such as "*Euskelesaurus*" and *Massospondylus*), invertebrates as well as trace fossils such as *cruziana* and *skolithos*. Aeolianites, belonging to the Jurassic aged Tshipise Member of the Clarens Formation contain petrified logs, trace fossils of insects (including controversial fossil termitaria) and dinosaur trackways (possibly *Massospondylus, Syntarsus / Coelophysis*).

The Cretaceous Malonga Formation contains significant fossils, including petrified wood (*Podocarpus*), arthropod trace fossils (*Termitichnus, Taenidium*) and indeterminate bone fragments. The formation is interpreted as a terrestrial deposit associated with Cretaceous marine deposits towards the west in Mozambique. The unit is allocated a very high palaeontological sensitivity.

Significant fossil finds are recorded from Cenozoic cave breccia associated with the karst topography in areas underlain by dolomite of the Transvaal Supergroup. These rock formations are invariably associated with underground deposits (such as the Sudwala Cave) and are not mapped on the geological maps. Very comprehensive description of sites and fossils are provided by MacRae (1999). New recordings of deposits of cave breccia will be of very high significance to the study of life during the Cenozoic. This will include the study of the development of early man (MacRae, 1999; McCarthy and Rubidge, 2005). Most of the fossil material is housed at the Evolutionary Studies Institute (ESI) at the University of the Witwatersrand in Johannesburg and at the Ditsong National Museum of Natural History.

The superficial deposits are allocated a moderate palaeontological sensitivity due to the fact that many fossiliferous rocks might be covered in a thin layer of soil, where fossils are only found where the topsoil has been removed by erosion.

Alluvial deposits associated with recent water courses of main rivers and streams are presently not well studied and records of fossil occurrences are mainly associated with archaeological reports. Fossils recorded from these beds are highly significant and contributes significantly to our understanding of the development of life in South Africa.

3 Conclusion

The Mpumalanga Province is underlain by some of the most valuable geological formations in the world, including the Witwatersrand Supergroup (gold ore resources) and Bushveld Complex (platinum group of minerals). The ancient sediments of the Barberton Supergroup, other greenstone belts and the Transvaal Supergroup contain significant micro-fossils as well as Stromatolite structures associated with ancient life forms. The fossils are of significant importance to the understanding of the development of life and it is essential that good examples of the structures be recorded and, if possible, be preserved as part of the palaeontological heritage of South Africa. The dolomites of the Transvaal Supergroup are associated with very important Cenozoic cave deposits with fossil remains of early man. These rocks are therefore allocated a very high palaeontological sensitivity.

The Permian Ecca Group contains significant plant fossils. These fossils provide us with unique opportunities to study ancient ecosystems and areas underlain by the Vryheid Formation are allocated a very high palaeontological significance. Rocks of the Permian Adelaide Subgroup are restricted to a small outcrop area in the south-eastern part of the Province and contain important plant remains of *Glossopteris* fauna.

The Triassic aged red sediments of the upper Karoo Supergroup are rich in vertebrate remains, with specifically dinosaur remains. These rock sequences are also allocated a very high palaeontological sensitivity. The Cretaceous Malonga Formation contains significant fossils and is allocated a very high palaeontological sensitivity. Significant fossils of mammals, including fossils of Hominins or early man, are associated with Cenozoic cave breccias that are present in the Karst landscape underlain by dolomite of the Transvaal Supergroup. The Sudwala Caves in Mpumalanga are an example of a typical cave formation in the dolomites. Due to the possibility of finding significant remains of Cenozoic aged mammals as well as the remains of man, the entire outcrop area of the Chuniespoort

Group where these Cenozoic cave breccias might occur, is allocated a very high palaeontological significance.

The superficial deposits as well as alluvial deposits are allocated a moderate palaeontological sensitivity due to the fact that many fossiliferous rocks might be covered in a thin layer of soil and significant palaeontological material might be present in alluvial deposits along the present river courses.

4 References

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PALAEONTOLOGICAL SIGNIFICANCE/VULNERABILITY OF ROCK UNITS	
The following colour scheme is proposed for the indication of palaeontological sensitivity classes. This classification of sensitivity is adapted from that of Almond et al 2008.	
RED	Very High Palaeontological sensitivity/vulnerability. Development will most likely have a very significant impact on the Palaeontological Heritage of the region. Very high possibility that significant fossil assemblages will be present in all outcrops of the unit. Appointment of professional palaeontologist, desktop survey, phase I Palaeontological Impact Assessment (PIA) (field survey and recording of fossils) and phase II PIA (rescue of fossils during construction) as well as application for collection and destruction permit compulsory.
ORANGE	High Palaeontological sensitivity/vulnerability. High possibility that significant fossil assemblages will be present in most of the outcrop areas of the unit. Fossils most likely to occur in associated sediments or underlying units, for example in the areas underlain by Transvaal Supergroup dolomite where Cenozoic cave deposits are likely to occur. Appointment of professional palaeontologist, desktop survey and phase I Palaeontological Impact Assessment (field survey and collection of fossils) compulsory. Early application for collection permit recommended. Highly likely that aPhase II PIA will be applicable during the construction phase of projects.
GREEN	Moderate Palaeontological sensitivity/vulnerability. High possibility that fossils will be present in the outcrop areas of the unit or in associated sediments that underly the unit. For example areas underlain by the Gordonia Formation or undifferentiated soils and alluvium. Fossils described in the literature are visible with the naked eye and development can have a significant impact on the Palaeontological Heritage of the area. Recording of fossils will contribute significantly to the present knowledge of the development of life in the geological record of the region. Appointment of a professional palaeontologist, desktop survey and phase I PIA (ground proofing of desktop survey) recommended.
BLUE	Low Palaeontological sensitivity/vulnerability. Low possibility that fossils that are described in the literature will be visible to the naked eye or be recognized as fossils by untrained persons. Fossils of for example small domal Stromatolites as well as micro-bacteria are associated with these rock units. Fossils of micro-bacteria are extremely important for our understanding of the development of Life, but are only visible under large magnification. Recording of the fossils will contribute significantly to the present knowledge and understanding of the development of Life in the region. Where geological units are allocated a blue colour of significance, and the geological unit is surrounded by highly significant geological units (red or orange coloured units), a palaeontologist must be appointed to do a desktop survey and to make professional recommendations on the impact of development on significant palaeontological finds that might occur in the unit that is allocated a blue colour. An example of this scenario will be where the scale of mapping on the 1:250 000 scale maps excludes small outcrops of highly significant sedimentary rock units occurring in dolerite sill outcrops. Collection of a representative sample of potential fossiliferous material recommended.

GREY	Very Low Palaeontological sensitivity/vulnerability. Very low possibility that significant fossils will be present in the bedrock of these geological units. The rock units are associated with intrusive igneous activities and no life would have been possible during implacement of the rocks. It is however essential to note that the geological units mapped out on the geological maps are invariably overlain by Cenozoic aged sediments that might contain significant fossil assemblages and archaeological material. Examples of significant finds occur in areas underlain by granite, just to the west of Hoedspruit in the Limpopo Province, where significant assemblages of fossils and clay-pot fragments are associated with large termite mounds. Where geological units are allocated a grey colour of significance, and the geological unit is surrounded by very high and highly significant geological units (red or orange coloured units), a palaeontologist must be appointed to do a desktop survey and to make professional recommendations on the impact of development on significant palaeontological finds that might occur in the unit that is allocated a grey colour. An example of this scenario will be where the scale of mapping on the 1:250 000 scale maps excludes small outcrops of highly significant sedimentary rock units occurring in dolerite sill outcrops. It is important that the report should also refer to archaeological reports and possible descriptions of palaeontological finds in Cenozoic aged surface deposits.

EON	ERA	Period	Supergroup/ Sequence	Group	Subgroup	Formation	Member	Lithology	Fossil Heritage	Comments
PHANEROZOIC	Caenozoic	Tertiary to Quaternary.	ALLUVIAL DEPOSITS			mmm; Q-a; Q-sc; Q8. Several symbols used for alluvium, colluvium and scree		Recent sandy and clayey deposists along water courses	Wide range of fossils possible, including mammalian bones and teeth, tortoise remains, ostrich egg etc	Alluvial deposits associated with recent water courses of main rivers and streams. These sediments are presently not well studied and records of fossil occurrences are mainly associated with archaeological reports
			CAENOZOIC SUPERFICIAL DEPOSITS (Q) (Predominantly Pleistocene to Recent (1.6 to 0 Ma))			Q; Qw; Qs; Qg; Qc; Qm For example Masotcheni (Qm) and fluvial Rooibokkraal Formation of Bushveld Basin		Aeolian sand, alluvium, colluvium, spring tufa (calcareous) and sinter (siliceous), lake deposits, peats, pedocretes or duricrusts (calcrete, ferricrete), soils and gravels	Very wide range of possible fossil remains, though these are often sparse, such as: mammalian bones and teeth, tortoise remains, ostrich eggshells, non-marine mollusc shells, ostracods, diatoms and other microfossil groups, trace fossils (e.g. calcretised termitaria, rhizoliths, burrows, vertebrate tracks), freshwater stromatolites, plant material such as peats, foliage, wood, pollens Fossil leaves and palynomorphs within calc tufa	Wide spread and in some cases extensive alluvial and colluvial deposits cut by dongas where fossils might occur
			CAVE PAN DEPOSITS N.B. NOT MAPPED AT 1: 1 MILLION SCALE			Spring deposits associated with dolomite formations along the escarpment		Bone-bearing breccias, calc tufa (flowstones, speleothems), colluvial and alluvial gravels, collapse debris, "cave earth" and other cave deposits (3 to 0 Ma)	Diverse Makapanian to Florisian mammalian biotas (Late Pliocene to Late Pleistocene) mammal fossils including rare fossil hominins (e.g. Australopithecus africanus, Homo heidelbergensis), wide range of micromammals. Also hyaena coprolites, arthropod remains, reptiles (snake, tortoises), seeds, mammal footprints, ESA, MSA, LSAs tone artefacts.	N.B. Numerous undiscovered fossiliferous cave deposits can be expected at or near the ground surface in the karstic-weathered outcrop area of the "Transvaal Dolomites" (Malmani Group etc). Likewise ancient pan deposits may be hidden beneath the surface.
	Mesozoic	Cretaceous	KIMBERLITES Various disparate ages Mainly Group II Province					Kimberlite pipes	No crater lake facies preserved No fossils recorded	Fossiliferous crater lake deposits in Northern Cape, Botswana
						Malonga (Kma) (previously Malvernia Fm)		Mid to Late Cretaceous sediments (pebbly sandstones, conglomerates, marls, limestones)	Petrified wood (*Podocarpus*), arthropod trace fossils (*Termitichnus* , *Taenidium*), indeterminate bone fragments	Outcrops of terrestrial sediment (Kruger Park area) grade eastwards into fossiliferous marine Cretaceous rocks (Mozambique)
		Jurassic	INTRUSIVE ROCKS	TSHOKWANE GRANOPHYRE (Jts)		Syenite (Jt; J2) Ijolite (J3) (Jts)		Syenite, granophyre	No fossils recorded	
			KOMATIPOORT SUITE (Jkg; Jk)			Jk1; Jk2		Granophyre and Gabbro	No fossils recorded	
			KAROO (Undifferentiated Karoo (P-TR; C-Jk))	DOLERITE (Jd)				Dolerite intrusions Early Jurassic 183 2 Ma	No fossils recorded	Karoo-Ferrar igneous intrusions associated with Early Jurassic global mass extinction event
				LEBOMBO		Josini (Jj) Letaba Sabi River (J; Jl; Jle)		Up to 13 km of volcanic rocks (basic and acid lavas) and rare interbedded sandstones. Early Jurassic 183 2 Ma	Fossils might occur within thin sedimentary intervals (e.g. plants, traces, bones)	
		Triassic				Clarens (TR; TRc) (Probably Upper Elliot and Clarens)	Tshipise (Jt)	Cream-coloured aeolian sandstone, playa lake deposits ("Cave Sandstone") Clarens of Main Karoo Basin	Aeolianites contain petrified logs, trace fossils of insects (including controversial fossil termitaria), dinosaur trackways (possibly *Massospondylus*, *Syntarsus / Coelophysis*).	Stratigraphic context of dinosaur fossils often unclear in the literature. Note revised stratigraphy and correlations with Main Karoo Basin proposed in recent papers on Tuli Basin by E. Bordy (UCT): Upper Unit P-Trkb in part Red Rocks Member (Elliot Fm)
							Red Rocks (Jr)	Pale red argillaceous sandstone with calcareous concretions (fluvial / sabkha setting). White silcrete at top of succession, beneath Tshipise Mb Prob. Upper Elliot of Main Karoo Basin	Skeletal remains of dinosaurs (*Massospondylus*), possible dinosaur eggshells, dinosaur and other tracks, trace fossils of insects and root casts	
	Palaeozoic	Permian		BEAUFORT	Adelaide (Pa)	Estcourt (Ps) Normandien (Pne)		Coarse-grained sandstone and carbonateous shale, deltaic deposits grading upwards into coarse to fine-grained sandstone, greenish-grey to dark grey mudstone. Meandering river channel sandstone. Grading upwards brightly coloured mudstone and siltstone. Playa lake deposits associated with arrid braided river environments.	Diverse terrestrial and freshwater tetrapods of *Pristerognathus* to Dicynodon Assemblage Zones (amphibians, true reptiles, synapsids – especially therapsids), palaeoniscoid fish, freshwater bivalves, trace fossils (including tetrapod trackways), sparse to rich assemblages of vascular plants (*Glossopteris* Flora, including spectacular petrified logs), insects.	Richest Permo-Triassic tetrapod fauna from Pangaea / Gondwana Key evidence for evolution of mammalian characters among therapsids Continental record of Late Permian Mass Extinction Events (e.g. Bethulie) Northern outcrop area mainly Dicynodon Assemblage Zone

EON	ERA	Period	Supergroup/ Sequence	Group	Subgroup	Formation	Member	Lithology	Fossil Heritage	Comments
PHANEROZOIC	Palaeozoic	Permian	KAROO (Undifferentiated Karoo (P-Tr))	ECCA (Undifferentiated (Pe))		Volksrust (Pvo)		Basinal dark mudrocks with phosphatic / carbonate / sideritic concretions, minor coals Offshore shelf, but possibly also nearshore / lacustrine / lagoonal deposits	Rare temnospondyl amphibian remains, invertebrates (bivalves, insects), minor coals with plant remains, petrified wood, organic microfossils (acritarchs), low-diversity marine to non-marine trace fossil assemblages Late Permian *Cistecephalus* Assemblage Zone biotas	
						Vryheid (Pv)		Deltaic mudrocks and sandstones, locally coastal and fluvial deposits, with occasional coal seams (Ecca "Coal Measures")	Rich fossil plant assemblages of the Permian Glossopteris Flora (lycopods, rare ferns and horsetails, abundant glossopterids, cordaitaleans, conifers, ginkgoaleans), rare fossil wood, diverse palynomorphs. Abundant, low diversity trace fossils, rare insects, possible conchostracans, non-marine bivalves, fish scales.	Globally important fossil floras from Middle Permian Gondwana. Seriously under-collected in recent years, despite ongoing mining for coal
						Pietermaritzburg (Pp)		Dark grey shale	Trace fosisils very rare	
		Carboniferous				Dwyka (C-Pd; C-Pd1)		Tillite, massive and stratified diamictite, massive carbonate-enriched diamictite, conglomerate, sandstone and mudstone facies. Glacial deposits in a marine environment.	Most of the fossils recorded from the mudstone facies and include spores, polen, plant remains, arthropod trackways and fish trails	
		Devonian								
		Silurian								
		Ordovician								
		Cambrian								
PROTEROZOIC	Namibian									
	Mokolian		INTRUSIVE ROCKS			Mt; Md; Ms; Ma; s; di; Mk; Mm; Mn; Mr; Mg; Msy; Mle; M5; M30; r; r1; r2 r3; r4; Timbavati Gabbros (Mti; ti); M2		Gabbro and Granites, Diabase	No fossils recorded	
				WATERBERG		Wilgerivier (Mw; wg)		Quartzitic sandstone and conglomerate	Sedimentary structures resembling trace fossils have been noted. Trace fossils might be present. Continental "red beds" - predominantly braided stream deposits (sandstones, conglomerates with minor mudrocks), also beach, tidal flat, lacustrine, aeolian and possible marine shelf sediments Early to Mid Proterozoic (Mokolian) c. 2 to 1.7 Ga	Earliest known terrestrial cyanobacterial mats recorded from playa lake deposits of the Makgabeng Fm (Waterberg Group) (1.8 Ga) in Limpopo and might also occur in Gauteng and Mpumalanga Early Proterozoic "red beds" provide evidence for the development of an oxygenated atmosphere after c. 2Ga Vrw, Vls previously included within the uppermost Pretoria Group but are now regarded as proto-Waterberg units.
	Vaalian					Rust de Winter (Vrw) Loskop (Vls; Vlo) h; l		Shale, sandstone, conglomerate, volcanic rocks, Leptite		
			VAALIAN INTRUSIONS (VD)			Vdi; Vdj; Vdr; Vsn; Vu; Vkb		Igneous intrusions	No fossils recorded	
				ROOIBERG		Selons River(Vs; Vse) (now renamed subdivided into Kwaggasnek (Vkn) Schrikkloof (Vsf) Fms)		Volcanics plus minor, thin but extensive horizons of metamorphosed sediments (quartzites, sandstones, mudrocks, cherts), mainly of fluvial origin. Volcanics are related to intrusives of the underlying Bushveld Magmatic Province 2.06 Ga Vaalian	No fossils recorded Fossils within minor sedimentary units unlikely because of fluvial depositional setting and subsequent metamorphism.	Possible evidence for a catastrophic event at the base of Rooiberg Group (basin floor collapse, slumping, volcanism) Selons River and Kwaggasnek units previously included within upper Pretoria Group by some geologists
						Damwal (Vdr;Vdm)				
			SPITSKOP COMPLE			sp, sp1, sp2		Ijolite, nepheline syenite, pyroxenite, carbonatite, fenite	No fossil recorded	
			BUSHVELD COMPLE Vvi (dk green) Villa Nora Gabbro Vsl (pale green) Schilpadsnest Subsuite Vpy (pea green) Pyramid Gabbro-Norite Vbi (yellow green) Bierkraal Magnetite Gabbro Vlg (dark orange) Lebowa Granite Suite Vra (pale orange) Rashoop Granophyre Suite Shelter Norite (Vsn)			Vvi; Vsl; Vpy; Vbi; Vlg; Vra; Vu; Vg; Vc; Vl; Vs; Vdr; Vdb; Vsh; Vsh1; Vcr; Vdj; Vds		Intrusive igneous rocks Mafic intrusives of Rustenberg Layered Suite Intrusive granites, gabbro, gabbro-norite granophyres Late Vaalian / Early Proterozoic 2.06 Ga	No fossils recorded	Bushveld Complex has been described as "One of the great geological wonders of the world" – the largest layered igneous complex in the world with the richest reserves of platinum group metals known anywhere. Intruded between Magaliesberg Fm quartzites (Pretoria Group) and the Rooiberg Group volcanics.

EON	ERA	Period	Supergroup/ Sequence	Group	Subgroup	Formation	Member	Lithology	Fossil Heritage	Comments
PROTEROZOIC	Vaalian		TRANSVAAL	PRETORIA		Rayton (Vr)		Quartzite and shales	No fossils recorded	Pretoria Group subunits with stromatolites probably also contain microfossils. This may also apply to carbonaceous mudrocks. ALERT FOR POTENTIALLY FOSSILIFEROUS LATE CAENOZOIC CAVE BRECCIAS WITHIN OUTCROP AREA OF CARBONATE SUBUNITS – i.e. LIMESTONES DOLOMITES (breccias not individually mapped) Rooiberg Group was previously included within top of Transvaal Supergroup but now regarded as separate succession
						Dullstroom (Vdb; Vdl; Vdl1)		Volcanic rocks	No fossils recorded	
						Houtenbek (Vh; Vho)		Quartsite, limestone, chert	Stromatolites	
						Steenkampsberg (Vsq; Vsb)		Quartzite and shales	No fossils recorded	
						Nederhorst (Vn)		Fine-grained hornfels and aranite	No fossils recorded	
						Lakenvallei (Vlq; Vla)		Quartzite	No fossils recorded	
						Vermont (Vv; Vve; Vve1)		Hornfels, limestone and chert	Stromatolites	
						Magaliesberg (Vm; Vmg; Vlm)		Coastal sandstones with mudrocks	Microbial mat structures (Desiccated mats sometimes resemble trace fossils)	
						Igneous intrusions (Vsh; Vsh1)		Norite	No fossils recorded	
						Silverton (Vsi)	Lydenburg (Vsl; Vld; Vld1)	Shale, mudstone and carbonate layers	Stromatolites	
							Machadodorp (Vsm; Vsm1; Vsm2; Vmc))	Fine-grained tuff and basic lava	No fossils recorded	
							Boven (Vsb; Vbn; Vbn1)	Marine shale and mudrocks with tuff and minor carbonates	Stromatolites	
						Igneous intrusions (Vdi; di)		Igneous intrusions	No fossils recorded	
						Daspoort (Vda, Vhd, Vdq; Vdp)		Alluvial, fluvial and deltaic sandstones and mudrocks, marine sediments in east	Stromatolites	
						Strubenkop (Vs, Vhd; Vst)		Lacustrine mudrocks with minor sandstone	No fossils recorded	
						Dwaalheuwel (Vdw, Vhd)		Alluvial sandstones, conglomerates and mudrocks	No fossils recorded	
						Hekpoort (Vh, Vhd, Vha)		Volcanics (basalts, pyroclastics) with minor lacustrine shales	No fossils recorded	
						Boshoek (Vb)		Sandstones, conglomerats, diamictite (alluvial fans, slumps)	No fossils recorded	
						Timeball Hill (Vt; Vti)	Klapperkop (Vkp)	Quartzite (ferruginous in places), wacke, siltstone, shale, magnetic ironstone	No fossils recorded	
								Lacustrine and fluvio-deltaic mudrocks with diamictite, conglomerates, quartzite, minor lavas. Shale, siltstone, conglomerate, quartzite	Stromatolites	
						Rooihoogte (Vr)		Basal breccio-conglomerates, quartzites, mudrocks, carbonates (alluvial fan, lakes, karst infill)	No fossils recorded	
ARCHAEAN				CHUNIESPOORT		Duitschland (Vd)		Conglomerate	No fossils recorded	Good examples of stromatolites in Cradle of Humankind region ALERT FOR POTENTIALLY FOSSILIFEROUS LATE CAENOZOIC CAVE BRECCIAS WITHIN "TRANSVAAL DOLOMITE" OUTCROP AREA (breccias not individually mapped)
						Penge (Vp)		Iron-rich shale	Stromatolites	
					Malmani (Vm; Vmd)			Stromatolitic carbonates (limestones / dolomites), minor secondary cherts, mudrocks including carbonaceous shales	Range of shallow marine to intertidal stromatolites (domes, columns etc), organic-walled microfossils	
						Black Reef (Vbr)		Siliciclastic sediments (mature sandstones plus minor mudrocks, conglomerates) deposited during a fluvial to shallow marine transition	Possible equivalent of Black Reef Fm in N. Cape (Vryburg Formation) contains stromatolitic carbonates	
				GROBLERSDAL		Vbl		Quartzite, slate	No fossils recorded	
						Vde		Schist, Rhyolite, Gneiss	No fossils recorded	
				WOLKBERG (Rwo)		Vwu; Vwl; Godwan (Vg)		Siliciclastic sediments (sandstones, conglomerates, mudrocks) of mixed fluvial, deltaic and marine or lacustrine origin plus subordinate lavas	Stromatolites in Limpopo	
	Randian		INTRUSIVE ROCKS			Rm; Rk; Rs; Rg; Rgr; Rs; Rh; Rp; Rpi; Rd; Rt; Vui; Rgs; Rgs1; Rgs2		Granites and Granodiorites	No fossils recorded	
ARCHAEAN						Amsterdam	Rag; Rav	Volcanic rocks	No fossils recorded	
			INTRUSIVE ROCKS			Rt; Rth; Rb; Rpg; Rtg; Rg;		Granite	No fossils recorded	
			VENTERSDORP	PLATBERG (R-Vp)				Basic and acid volcanics with subordinate siliciclastic sediments (breccias, conglomerates, sandstones, mudrocks), with minor limestones and cherts in upper part of succession Late Archaean Randian 2.7-2.5	No fossils recorded	Lacustrine stromatolites and possible microfossils recorded from sediments of Platberg Group elsewhere (Northern Free State) and therefore might also be present in Mpumalanga
				KLIPRIVIERSBERG (Rk)		Ra; Rw				
			WITWATERSRAND (Rw)	CENTRAL RAND	Turffontein (Rt)	Klerksdorp (Rkl)		Mainly quartzites conglomerates (braided fluvial), pyritic sands, minor shales, volcanics, debris-flow diamictites	No fossils recorded	Thin layers of carbonaceous material (kerogen / bitumen) possibly represent ancient microbial mats, but this material probably has an abiogenic origin (e.g. precipitation of inorganic carbon due to irradiation by radioactive uranium minerals) Main source of Wits gold (beds of quartzose, pyritic fluvial conglomerates or "banket" that are known as "reefs") Evidence for earliest known glaciations on Earth (Government Subgroup (Rg) Archaean / Randian c. 2.9-2.7 Ga
						Booyens (Rbo)		Shale		
					Johannesburg (Rjo)			Mainly quartzites conglomerates (braided fluvial), pyritic sands, minor shales, volcanics, debris-flow diamictites		
				WEST RAND	Rj; Rg; Rh	Rc; Ro		Marine shelf quartzites, shales, rare conglomerates, banded iron formation (BIF), volcanics, fluvial sediments, several diamictites		
			PONGOLA	MOZAAN (Rm)	Rkl;	Rr; Rms; Rn; Rnk; Rnk1; Rk; Rmk; Rl; Rlu; Rlb; Rmp; Rmps; Rmps1; Rmps2; Rmps3; Rmu; Rmz; Rkl ; Rla; Rla1; Rmka; Rmka1;		Banded iron formation, quartsite and shale	No fossils recorded	Stromatolites might be present in banded iron formation
				NSUZE	Rbv; Rbv1; Rbv2; Rbv3; Rmsv;	Zb; Znm; Zm; Zma; Rmg; Rr; Rrw		Lava; quartsite		Stromatolites recorded in this group in KwaZulu-Natal
	Swazian		INTRUSIVE ROCKS			Z; Zg; Zgh; Zhd;Zhe; Zmg; Zgg; Zs; Zu; Zn; Znm; Zk; Zs; Zu; Z-Rg; Zkv; Zne1; Zne2; Rcu; Rry; ss; Z7; Zkv; Z8; Z55		Granites and Gneiss	No fossils recorded	
			BARBERTON (Za; Zk)	MOODIES (Zm)		Zmb; Zj; Zmc; Zc; Zbv		Predominantly volcanic igneous rocks, plus some igneous intrusions, minor sediments such as banded iron formation, chert, quartzite, conglomerate, schists	Archaean microfossils and microbial trace fossils (bacterial borings) have been recorded from cherts and volcanic glasses in the Fig Tree Group Onverwacht Group of Barberton.	"Fly speck carbon" in sedimentary Uitkyk Fm of the Pietersburg Greenstone Belt, Limpopo, may be fossilised microbes,or alternatively of inorganic origin (e.g. an inorganic precipitate induced by radioactive irradiation).
				FIG TREE (Zf)		Zfs; Zb; Zfh; Zsh; Zbe				
				ONVERWACHT (Zo; Zo1)		Zz; Zgk; Zh;Zh1; Zh2; Zh3; Zk; Zt; Zts; Za; Zgh; Ztt; Zt1; Zth; Zth1; Zzw; Zkr; Zkr1; Zs; Z36; Z37				
			OTHER GREENSTONE COMPLE ES	Giyani (Sutherland) Belt (Zgi; Zgi1; Zgi2; Zgi3; Zgi4; Zgi5; Z57; Z58) Murchison Belt (Zmu)				Predominantly volcanic igneous rocks, plus some igneous intrusions, minor sediments such as banded iron formation, chert, quartzite, conglomerate, schists Rocks usually tectonised, highly metamorphosed Early to Mid Archaean (Swazian - Randian) 3.5 – 3 Ga Basic intrusions dated 3.5 Ga and younger	Archaean microfossils and microbial trace fossils (bacterial borings) have been recorded from cherts and volcanic glasses	Greenstone Belts provide samples of the oldest known crustal rocks, including minor marine and terrestrial sediments, but the rocks here are usually highly deformed and metamorphosed.