PALAEONTOLOGICAL IMPACT ASSESSMENT: DESKTOP STUDY

# Proposed windfarm at Maanhaarberg near De Aar, Northern Cape Province

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## 1. SUMMARY

**The proposed two-phase wind farm development is situated on the plateaux of the Maanhaarberg and Swartkoppies, about 20km southwest of De Aar in the Northern Cape Province. The majority of the development footprint, including wind turbines as well as ancillary gravel road construction, is underlain by unfossiliferous Karoo dolerite. Non-marine sediments of the Mid Permian Ecca and Lower Beaufort Groups (Karoo Supergroup) crop out on the slopes of the Karoo koppies. The Tierberg, Waterford and Abrahamskraal Formations represented here have a moderate to high palaeontological sensitivity. However, they are largely obscured by Neogene (Late Tertiary) to Recent drift deposits – notably dolerite scree and alluvium - and their fossil potential has been compromised through baking (thermal metamorphosis) by the adjacent major dolerite intrusions. Given the limited effective palaeontological potential of rocks in the region, the comparatively small footprint of the proposed wind farm and the shallow excavations envisaged, no further palaeontological mitigation is recommended for this development. However, should substantial fossil remains be exposed during construction (*e.g.* in borrow pits excavated for new or upgraded gravel roads), the ECO should alert SAHRA so that appropriate action (*e.g.* recording, sampling or collection) can be undertaken by a professional palaeontologist.**

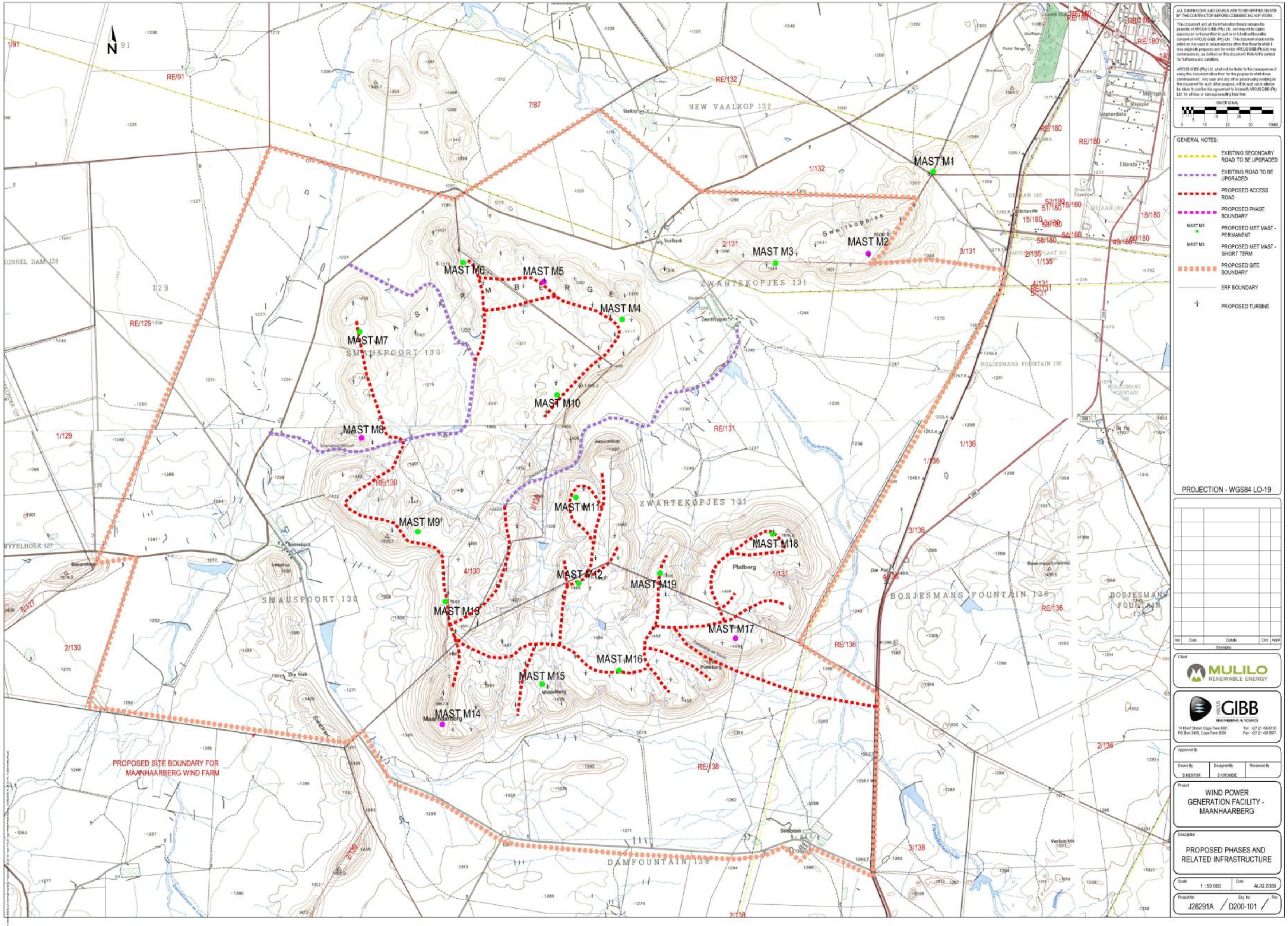
## 2. INTRODUCTION & BRIEF

Mulilo Renewable Energy (Pty) Ltd are proposing to construct a wind power generation facility on the Maanhaarberg and Swartkoppies mountain range *c.* 20 km southwest of De Aar, Northern Cape Province (Figs. 1, 2). The wind farm is situated 22 km from the Hydra Substation to the SE of De Aar. Development would take place in two phases, the first of 110MW capacity and the second of 260MW capacity. The proposed layout of the two phases on the Maanhaarberg range is shown in Fig. 2. The turbines are to be situated on the summit plateaux of the Maanhaarberge and Swartkoppies up to 250m above the surrounding *vlaktes* and at least 450m apart, while the site boundary extends into the *vlaktes* at the foot of the mountain. The two phases occupy an area of approximately 15km (SW-NE) by 13km (NW-SE). The development will involve upgrading of some existing roads (Fig. 1, purple dotted lines) as well as the construction of a considerable network of new gravel roads on top of the Maanhaarberg range (Fig. 1, red dotted lines).

This desktop palaeontological impact assessment for the project has been commissioned by Mr Junaid Moosajee (DJ Environmental Consultants) on behalf of the developers in accordance with the requirements of the National Heritage Resources Act, 1999.

**Fig. 1 (below). New road development associated with the proposed wind farm on the Maanhaarberg range *c*. 20km SW of De Aar, Northern Cape (Map prepared by Arcus Gibb Engineering & Science, provided by DJ Environmental Consultants).**

**Fig. 2 (below). Layout of the two development phases of the proposed wind farm on the Maanhaarberg range *c*. 20km SW of De Aar, Northern Cape (Map prepared by Arcus Gibb Engineering & Science, provided by DJ Environmental Consultants).**



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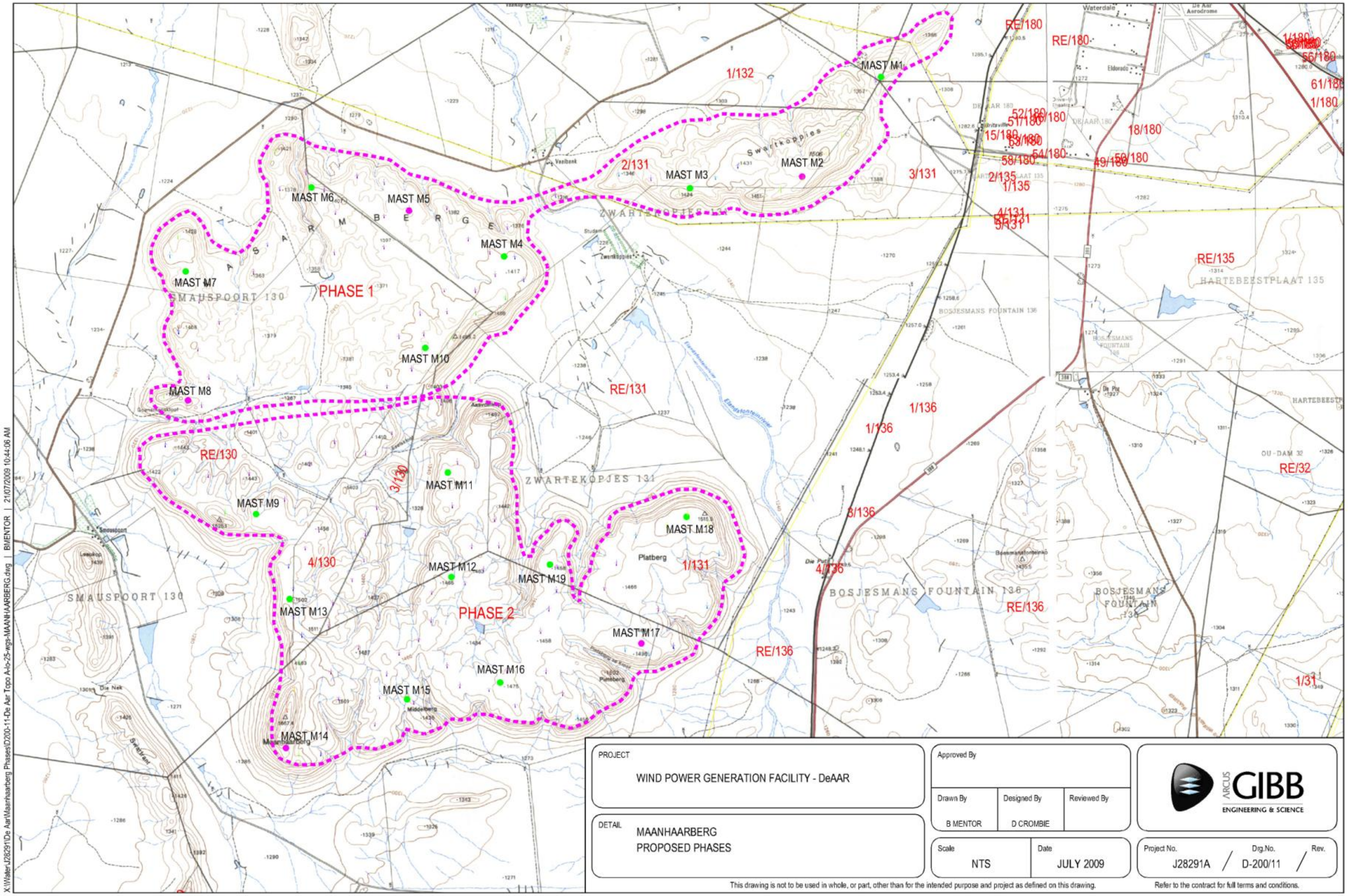
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## 3. GEOLOGICAL BACKGROUND

The geology of the study area southwest of De Aar is shown on the 1: 250 000 geology sheet 3022 Britstown (Prinsloo 1989). Within the site boundary of the proposed wind farm development six rock units are mapped (Fig.3, Table 1). In order of decreasing age, these are:

1. The **Tierberg Fomation** (**Pt**) (Ecca Group, Karoo Supergroup) crops out on the lower slopes of the Swartkoppies in the NE corner of the study area as well as along the northern and eastern edge of the Maanhaarberg. This is a recessive-weathering, mudrock-dominated succession – predominantly dark, well-laminated, carbonaceous shales with subordinate thin, fine-grained sandstones (Prinsloo 1989, Viljoen 2005, Johnson *et al*., 2006). The Tierberg shales are Lower to Mid Permian in age and were deposited in a range of offshore, quiet water environments below wave base. These include basin plain, distal turbidite fan and distal prodelta in ascending order (Viljoen 2005, Almond 2008a). Thin coarsening-upwards cycles occur towards the top of the formation with local evidence of soft-sediment deformation, ripples and common calcareous concretions. A restricted, brackish water environment is reconstructed for the Ecca Basin at this time. Close to the contact with Karoo dolerite intrusions the Tierberg mudrocks are baked to a dark grey hornfels with a reddish-brown crust (Prinsloo 1989).

2. The **Waterford Formation** (**Pc**) (Ecca Group, Karoo Supergroup) crops out above the Tierberg shales along the eastern edge of the Maanhaarberg. The sandstone-dominated uppermost Ecca Group along the northern edge of the Main Karoo Basin between Carnarvon and Philipstown differs from the typical delta-dominated Waterford Formation of the SW Cape. The shallow shelf, storm-dominated successions found in the Northern Cape were previously assigned to a separate **Carnarvon Formation** (*e.g.* Terblanche 1979, Le Roux & Keyser 1988, Siebrits 1987, 1989, Prinsloo 1989, Rust *et al*., 1981) but since 1994 they have been subsumed into the Waterford Formation (Johnson 1994). Although Prinsloo (1989, p. 24) suggests that the typical Carnarvon facies is no longer present further east than 23° 35', in fact the "Carnarvon Formation" (Pc) is mapped almost to the eastern boundary of the Britstown sheet, including the present study area around the Maanhaarberg.

Typical sedimentary features of the typical "Carnarvon-facies" include coarsening- as well as fining-upwards, heterolithic cycles of various scales with pervasive wave ripples, frequent storm-generated hummocky cross-stratification, and soft-sediment deformation (*e.g.* ball-and-pillow load structures, slumping). Sandstones are fine-grained with abundant, lenticular mudflake intraclast conglomerates. Dark brown diagenetic concretions of iron-rich carbonate (*koffieklip*) are common throughout the succession, reaching diameters of a meter or so, and laterally persistent limestones are occasionally found interbedded with the mudrocks (Prinsloo 1989). Levels of bioturbation are often high (See palaeontological Section 4 below). Water depth on the shallow shelf is inferred to have been no more than a few tens of meters, with the Ecca Sea shoreline 200km or more to the west (Rust *et al*., 1991). Prograding storm-generated offshore sandbars have been identified in the uppermost Ecca between De Aar and Philipstown by Smith & Zawada (1988, 1989).

3. The **Abrahamskraal Formation** (**Pa**) (Lower Beaufort Group, Adelaide Subgroup, Karoo Supergroup) crops out above the Ecca Group along almost the entire circumference of the Maanhaarberg, especially in the south (*N.B.* This unit is mistakenly referred to as the Middleton Formation by Prinsloo 1989). The Lower Beaufort sediments were

deposited by large-scale meandering river systems flowing northwards from the youthful Cape Fold Belt across the extensive floodplains of the ancient Karoo Basin (Smith 1980, Rubidge 1995, McCarthy & Rubidge 2005, Johnson *et al*. 2006). They mainly comprise fine-grained overbank mudrocks with subordinate lenticular channel sandstones. These last commonly have a basal conglomeratic lag of rolled mudflake pellets and calcrete nodules, the latter reflecting the prevailing semi-arid climates in Middle Permian times. Small, often transient playa lakes were also present on the floodplain. In the Britstown - Williston sheet areas the Lower Beaufort succession consists largely of blocky-weathering, blue-grey and reddish floodplain mudrocks, showing occasional mudcracks. There are also subordinate siltstones, fine-grained, lenticular, current cross-bedded channel sandstones, flat-laminated crevasse-splay sandstones, and occasional playa lake deposits (Prinsloo, 1989, Viljoen 1989). Carbonate concretions, including ferruginous *koffieklip*, as well as calcrete nodules (pedogenic limestones) and silicified gypsum rosettes ("desert roses") are common. According to Rubidge (2005), the Abrahamskraal Formation belongs to the Capitanian Stage of the Middle Permian, dated some 266 to 260 Ma (million years ago). In the Maanhaarberg region the Lower Beaufort sediments are extensively intruded and baked by sills of Karoo dolerites. The mudrocks adjacent to the igneous intrusions have been baked to tough, splintery hornfels, while the sandstones have metamorphosed to well-cemented quartzites. Surface exposure of fresh Beaufort Group rocks within the development footprint itself is likely to be poor, judging from satellite images, apart from stream beds, dongas and steeper hillslopes. The hill slopes are typically mantled with a thin layer of colluvium or slope deposits (*eg* scree of dolerite, sandstone and hornfels; see pervasive rusty brown dolerite scree in satellite image, Fig. 4).

4. The **Karoo Dolerite Suite** (**Jd**) is an extensive network of basic igneous bodies (dykes, sills) that were intruded into sediments of the Main Karoo Basin in the Early Jurassic Period, about 183 million years ago (Duncan & Marsh 2006). These dolerites form part of the Karoo Igneous Province of Southern Africa that developed in response to crustal doming and stretching preceding the break-up of Gondwana. A major dolerite sill (*i.e.* subhorizontal, sheet-like intrusion) of Karoo dolerite forms the rugged plateaux of the Maanhaarberg and the Swartkoppies, intruding and baking both Lower Beaufort and Ecca rocks respectively. Hard cappings of blocky, reddish-brown to rusty-weathering dolerite are a very typical feature of the flat-topped *koppies* in the Great Karoo region.

5. **Neogene (Late Tertiary) to Quaternary calcretes** (**T-Qc**) – a small outcrop of this unit is mapped near the Damfontein farmstead in the SE of the study area that is traversed by a minor road. In the Britstown sheet area Caenozoic calcretes - *i.e.* pedogenic limestones reflecting near-surface precipitation of carbonate from groundwater under semi-arid climatic conditions - are mainly found overlying Ecca Group shales, around pans and on dolerite sills, but are largely absent in the Beaufort Group outcrop area (Prinsloo 1989). They occur variously as nodular zones, continuous hardpans or calcretized gravels.

6. **Quaternary to Recent superficial deposits ("drift")** cover all but the steepest slopes of the Karoo koppies as well as most of the plains at their feet, including dry river courses such as the Brakrivier and the Elandsfonteinrivier in the study area. Various types of superficial deposits of geologically young, Late Caenozoic (Miocene / Pliocene to Recent) age (< 5 Ma) occur throughout the Great Karoo region (Prinsloo 1989, with more extensive discussion in Holmes & Marker 1995, Cole *et al.* 2004, Partridge *et al*. 2006). They include pedocretes (*eg* calcretes), colluvial slope deposits (dolerite, sandstone and hornfels scree *etc*), sandy, gravely and bouldery river alluvium, as well as spring and pan sediments. These colluvial and alluvial deposits may be extensively calcretised (*ie* cemented with soil limestone), especially in the neighbourhood of dolerite intrusions (See T-Qc above).

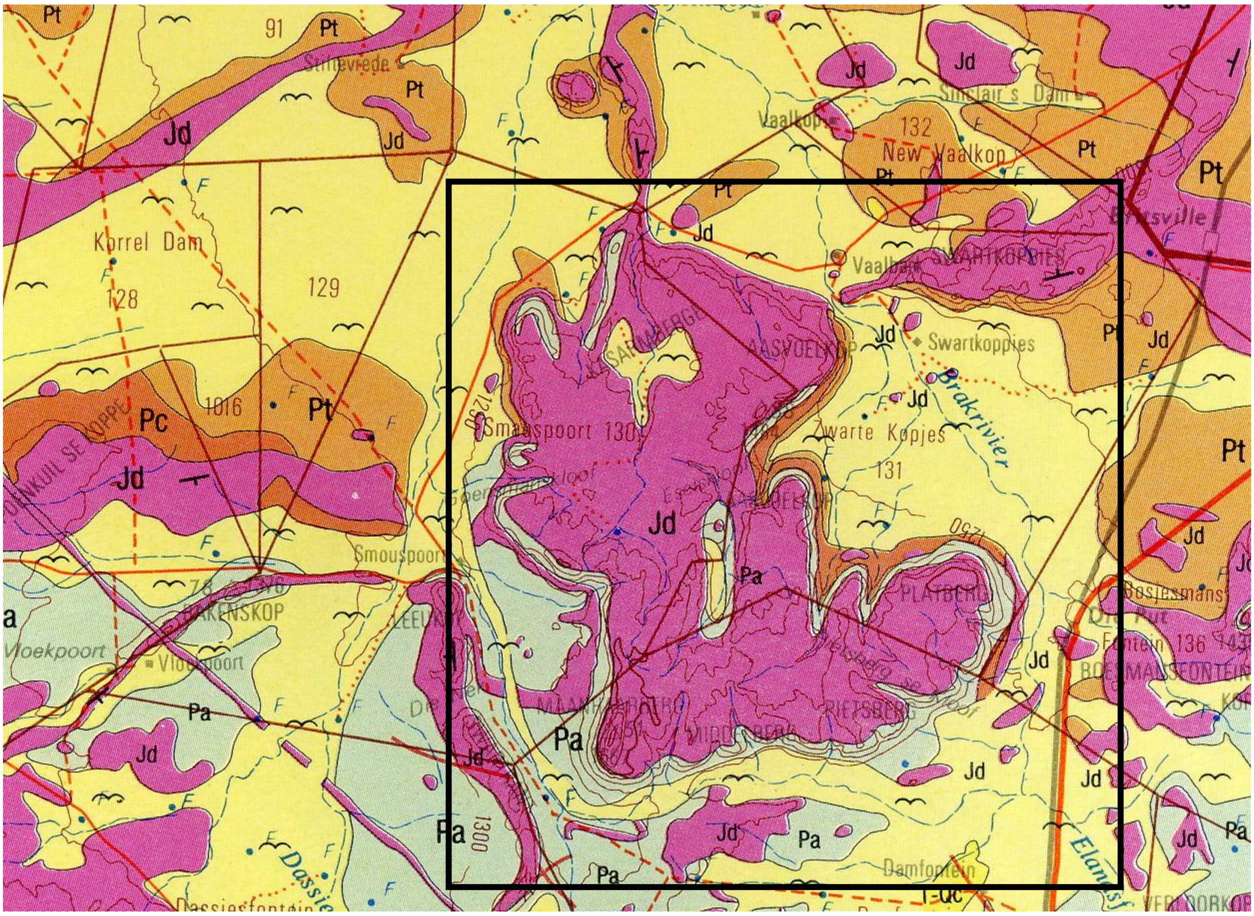


**Fig. 3. Geological map of the study area (black rectangle) *c*. 20km SW of De Aar (Abstracted from 1: 250 000 geology sheet 3022 Britstown, Council for Geoscience, Pretoria).**

**The following rock units are mapped in the study area:**
**pale orange (Pt) = Tierberg Formation (Ecca Group)**
**dark orange (Pc) = Waterford (previously Carnarvon) Formation (Ecca Group)**
**pale green (Pa) = Abrahamskraal Formation (Beaufort Group)**
**pink (Jd) = Karoo Dolerite Suite**
**dark yellow (T-Qc) = Neogene to Quaternary calcretes**
**pale yellow = Quaternary to Recent superficial deposits (alluvium, colluvium *etc*)**

**Fig. 4. Oblique aerial view of the Maanhaarberg range from the southwest, also showing the Swartkoppies in the distance (Image provided by DJ Enviromental Consultants). Note that most of the upper plateau on these koppies is covered with brown dolerite and the slopes are mantled with dolerite scree. Exposure of fresh, potentially fossiliferous sediments of the Karoo Supergroup is therefore likely to be very limited.**

# 4. PALAEONTOLOGICAL HERITAGE

Fossil biotas recorded from each of the stratigraphic units mapped in the study area are briefly reviewed in this section. Bedding dips of the Karoo Supergroup sediments in the study region are generally shallow. Low levels of tectonic deformation and cleavage development are expected here, favouring good fossil preservation. However, extensive dolerite intrusion has compromised fossil heritage in the Karoo Supergroup sediments due to resulting thermal metamorphism.

## 4.1. Tierberg Formation

The fossil record of the Tierberg Formation has been reviewed in detail by Almond (2008a). Rare body fossil records include disarticulated microvertebrates (*eg* fish teeth and scales) from calcareous concretions in the Koffiefontein sheet area (Zawada 1992) and allochthonous plant remains (leaves, petrified wood). The latter become more abundant in the upper, more proximal (prodeltaic) facies of the Tierberg (*eg* Wickens 1984). Prinsloo (1989) records numerous plant impressions and unspecified "fragmentary vertebrate fossils" within fine-grained sandstones in the Britstown sheet area. Dark carbonaceous Ecca mudrocks are also likely to contain palynomorphs (*e.g.* pollens, spores, acritarchs).

The commonest fossils by far in the Tierberg Formation are sparse to locally concentrated assemblages of trace fossils that are often found in association with thin event beds (*eg* distal turbidites, prodeltaic sandstones) within more heterolithic successions. A modest range of ten or so different ichnogenera have been recorded from the Tierberg Formation (*eg* Abel 1935, Anderson 1974, 1976, Wickens 1980, 1984, 1994, 1996, Prinsloo 1989, De Beer *et al*., 2002, Viljoen 2005, Almond 2008a). These are mainly bedding parallel, epichnial and hypichnial traces, some preserved as undertracks. Penetrative, steep to subvertical burrows are rare, perhaps because the bottom sediments immediately beneath the sediment / water interface were anoxic. Most Tierberg ichnoassemblages display a low diversity and low to moderate density of traces. Apart from simple back-filled and / or lined horizontal burrows (*Planolites, Palaeophycus*) they include arthropod trackways (*Umfolozia*) and associated resting impressions (*Gluckstadtella*), undulose fish swimming trails (*Undichna*) that may have been generated by bottom-feeding palaeoniscoids, horizontal epichnial furrows (so-called *Scolicia*) often attributed to gastropods (these are also common in the co-eval Collingham Formation; Viljoen 1992, 1994), arcuate, finely striated feeding excavations of an unknown arthropod (*Vadoscavichnia*), beaded traces ("*Hormosiroidea*" or "*Neonereites*"), small sinusoidal surface traces (*Cochlichnus*), small star-shaped feeding burrows (*Stelloglyphus*) and zigzag horizontal burrows (*Beloraphe*), as well as possible narrow (<1cm) *Cruziana* scratch burrows. The symmetrical, four-pronged trace *Broomichnium* (= *Quadrispinichna* of Anderson, 1974 and later authors) often occurs in groups of identical size (*c*. 3.5cm wide) and similar orientation on the bedding plane. This trace has frequently been misinterpreted as a web-footed tetrapod or arthropod trackway (*eg* Van Dijk *et al*. 2002 and references therein). However, Braddy and Briggs (2002) present a convincing case that this is actually a current-orientated arthropod resting trace (cubichnion), probably made by small crustaceans that lived in schools of similar-sized individuals and orientated themselves on the seabed with respect to prevailing bottom currents. Distinctive broad (3-4cm), strap-shaped, horizontal burrows with blunt ends and a more-or-less pronounced transverse ribbing occur widely within the Tierberg mudrocks. They have been described as "fucoid structures" by earlier workers (*eg* Ryan 1967) by analogy with seaweeds, and erroneously assigned to the ichnogenera *Plagiogmus* by Anderson (1974) and *Lophoctenium* by Wickens (1980, 1984). Examples up to one metre long were found in Tierberg mudrocks near Calvinia in 1803 by H. Lichtenstein, who described them as "eel fish". These are among the first historical records of fossils in South Africa (MacRae 1999). These as yet unnamed burrows are infilled with organized arrays of faecal pellets (Werner 2006). Sandstone sole surfaces with casts of complex networks of anastomosing (branching and fusing) tubular burrows have been attributed to the ichnogenus *Paleodictyon* (Prinsloo 1989) but may more appropriately assigned to *Megagrapton* (Almond 1998). These so-called graphoglyptid burrows are associated with turbidite facies from the Ordovician to Recent times and have been interpreted as gardening burrows or *agrichnia* (Seilacher, 2007). Microbial mat textures, such as *Kinneyia*, also occur in these offshore mudrocks but, like the delicate grazing traces with which they are often associated, are generally under-recorded.

### 4.2. Waterford (= Carnarvon) Formation

The fossil record of the Waterford Formation has been summarized by Almond (2008b). Delta platform sediments here contain abundant, low diversity trace assemblages of the *Scoyenia* ichnofacies. They are dominated by the rope-like, horizontal and oblique burrows (5-6mm wide) of the ichnogenus *Scoyenia* itself. These tubular, meniscate back-filled scratch burrows were constructed by small arthropods and characterise intermittently moist, firm substrates such as channel and pond margins on the upper delta platform (Smith & Almond 1998, Buatois & Mángano 2004).

The shallow shelf "Carnarvon-type facies" of the Waterford Formation displays not only marginal *Scoyenia* Ichnofacies traces but also shallow offshore trace assemblages of the *Cruziana* ichnofacies and turbulent, inshore *Skolithos* ichnofacies vertical burrows (Siebrits 1987, Rust *et al*., 1991). Good examples of Carnarvon facies trace fossils, often associated with wave-rippled surfaces, are recorded from thin-bedded sandstones and siltstones in the Britstown sheet area by Prinsloo (1989) and further west near Carnarvon itself by Rust *et al.* (1991). Medium-sized, horizontal to oblique, cylindrical burrows of *Palaeophycus striatus* ("*Fucusopsis*") with a distinctive, longitudinally ridged surface ornament are common (see Prinsloo 1989, fig. 12). There are also simple horizontal burrows (*Planolites*), rarer *Cruziana*-type arthropod burrows, J-shaped *Rosselia* spreiten burrows, funnel-shaped *Monocraterion*, simple *Skolithos* vertical dwelling tubes, and the complex-walled vertical burrow *Siphonichnus* (Siebrits 1987, Smith & Zawada 1988, Rust *et al*., 1991, Almond 1998).

Thin, laterally-persistent limestone units interbedded with mudrock facies are finely laminated and contain small stromatolite-like structures (micromounds?) that may have been generated by microbial mats (Prinsloo 1989, p. 24).

Petrified wood and other plant material (*e.g.* leaf and twig compressions) of the *Glossopteris* Flora (*e.g. Glossopteris. Phyllotheca*) is also common in the Waterford Formation (Anderson & Anderson 1985, Prinsloo 1989, Siebrits 1989, Viljoen 1989, Wickens 1984, 1996, Rubidge *et al*. 2000). Leaves and stems of arthrophytes (horsetail ferns) such as *Schizoneura* have been observed in vertical life position. Substantial fossil logs (so-called "*Dadoxylon*") showing excellent seasonal growth rings are quite common, especially in the storm-dominated "Carnarvon-type" facies of the central Karoo. Most Ecca fossil woods are silicified, but partially or completely calcified wood is also known (Viljoen 1989). Thin section studies of petrified gymnospermous woods from the Ecca Group have differentiated at least two genera, *Prototaxoxylon*, and *Australoxylon*, both of which probably have affinities with the progymnosperm glossopterids (Bamford 1999, 2004).

Tantalising but poorly preserved fragments of rolled tetrapod bone occur in channel lags within the upper Waterford Formation, as seen in the Williston sheet area (Viljoen 1989) and in the southern Great Karoo. These probably belong to temnospondyl amphibians ("labyrinthodonts") but large fish and terrestrial therapsids are also possibilities. The resting traces of impressive, crocodile-sized amphibians have recently been discovered in shoreline sediments of the Ecca Sea in the Main Karoo Basin in Kwazulu-Natal (Estcourt Formation of the Lower Beaufort Group; see McCarthy & Rubidge 2005, pp. 212-213). Scattered palaeoniscoid fish scales are common in the Waterford Formation, and several genera of non-marine bivalves have been described from the southern Karoo (Bender *et al*. 1991, Cooper & Kensley 1984).

### 4.3. Abrahamskraal Formation

The overall palaeontological sensitivity of the Beaufort Group sediments is high (Almond & Pether 2008). These fluvial and lacustrine sediments have yielded one of the richest fossil records of land-dwelling plants and animals of Permo-Triassic age anywhere in the world. Well-preserved tetrapod fossils, from isolated skulls and post-cranial bones to fully articulated skeletons, are mainly found in overbank mudrocks, often in association with pedogenic calcretes (palaeosol horizons). Disarticulated, water-worn bones occur in the channel lag conglomerates (Smith 1980, 1993). Playa lake deposits may be associated with disarticulated amphibian bones and a range of trace fossils (*e.g. Scoyenia*). Fossils embedded within metamorphosed sediments (quartzites, hornfels) adjacent to dolerite intrusions may be well-preserved, but are very difficult to prepare out from the matrix and therefore usually of limited scientific value.

A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Kitching (1977), Keyser and Smith (1979) and Rubidge (1995). The first two articles do not specify an assemblage zone for the study area near De Aar. The paucity of fossil data for the Lower Beaufort succession in the Britstown sheet explanation (Prinsloo 1989) also suggests that this region is palaeontologically under-explored. However the map in Rubidge (1995) assigns the Lower Beaufort beds to the southwest of De Aar to the *Tapinocephalus* Assemblage Zone. A review of the rich fossil biota of this assemblage zone has been given by Smith and Keyser (1995) and an illustrated account by Almond (2010) is appended with this report. In brief, the vertebrate fauna includes primitive bony fish (palaeoniscoids), large rhinesuchid amphibians, a small range of reptiles like the rhino-sized herbivorous pareiasaurs and the small, tortoise-like *Eunotosaurus,* as well as a wide variety of therapsids. These so-called "mammal-like reptiles" feature an impressive range of large carnivorous and plant-eating dinocephalians, two-tusked herbivorous dicynodonts, and several genera of carnivorous biarmosuchians, gorgonopsians and therocephalians. Invertebrates are poorly represented – largely for taphonomic reasons - mainly comprising freshwater bivalves and a few insects (mostly undescribed). Trace fossils include arthropod trackways, fish swimming trails, vertebrate footprints and coprolites (droppings) as well as various burrows, some of which are quite large and probably attributable to burrowing dicynodonts. Mid Permian plant life is only represented by silicified woods ("*Dadoxylon*"), sparse glossopterid leaves and twigs as well as abundant equisetalean ferns (horsetails) in damper settings. Further references to *Tapinocephalus* Assemblage Zone biotas are provided in the appendix.

### 4.4. Karoo Dolerite Suite

The dolerite outcrops in the northern part of the study area are in themselves of no palaeontological significance. These are high temperature igneous rocks emplaced at depth within the Earth's crust so they do not contain fossils. However, as a consequence of their proximity to large dolerite intrusions in the Great Escarpment zone, some of the Ecca and Beaufort Group sediments in the study area will have been thermally metamorphosed or "baked" (*ie*. recrystallised, impregnated with secondary minerals). Embedded fossil material of phosphatic composition, such as bones and teeth, is frequently altered by baking – bones may become blackened, for example - and can be very difficult to extract from the hard matrix by mechanical preparation (Smith & Keyser 1995). Thermal metamorphism by dolerite intrusions therefore tends to reduce the palaeontological heritage potential of Beaufort Group sediments. In some cases (*e.g.* fossil moulds of mesosaurid reptiles and palaeoniscoid fish) baking may enhance the quality of preservation of Ecca fossils while other fossil groups (*e.g*. carbonaceous remains of plants, organic-walled palynomorphs) are more likely to be compromised.

### 4.5. Neogene to Quaternary calcretes

The formation of near-surface calcretes within relatively young superficial deposits such as soils, pan sediments and alluvium may lead to the preferential preservation of termitaria and other invertebrate burrows, rhizoliths (root casts), stem casts, as well as lime-rich skeletal material such as vertebrate bones, teeth and mollusc shells.

### 4.6. Quaternary to Recent superficial deposits

The central Karoo drift deposits have been comparatively neglected in palaeontological terms. However, they may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals as well as remains of reptiles like tortoises. Good examples are the Pleistocene mammal faunas at Florisbad, Cornelia and Erfkroon in the Free State and elsewhere (Wells & Cooke 1942, Cooke 1974, Skead 1980, Klein 1984, Brink, J.S. 1987, Bousman *et al.* 1988, Bender & Brink 1992, Brink *et al*. 1995, MacRae 1999, Meadows & Watkeys 1999, Churchill *et al*. 2000 Partridge & Scott 2000). Other late Caenozoic fossil biotas from these superficial deposits include non-marine molluscs (bivalves, gastropods), ostrich egg shells, trace fossils (*eg* calcretised termitaria, coprolites), and plant remains such as peats or palynomorphs (pollens) in organic-rich alluvial horizons (Scott 2000) and diatoms in pan sediments. In Quaternary deposits, fossil remains may be associated with human artefacts such as stone tools and are also of archaeological interest (*e.g.* Smith 1999 and refs. therein).

## 5. CONCLUSIONS & RECOMMENDATIONS

Palaeontological mitigation generally concerns the construction phase rather than the operational phase of a development, unless this development involves ongoing excavation of bedrock (*e.g.* mining). The inferred palaeontological sensitivity of fossil heritage within each of the six rock units represented in the Maanhaarberg study area near De Aar is summarized in Table 1 below (See also Almond & Pether 2008).

The Ecca and Beaufort Group sediments here generally have a moderate to high palaeontological sensitivity. However, with the exception of some ancillary road construction, the greater part of the proposed wind farm development is situated on the dolerite plateaux of the Maanhaarberg and Swartkoppies that are not palaeontologically sensitive at all. Furthermore, Karoo Supergroup sediments beneath and adjacent to these major dolerite intrusions will have been extensively baked, considerably reducing their original fossil potential.

Given the limited *effective* palaeontological potential of rocks in the region, the comparatively small footprint of the proposed wind farm and the shallow excavations envisaged here, no further palaeontolgical mitigation is recommended for this development. Should substantial fossil remains be exposed during construction, however, the ECO should alert SAHRA so that appropriate action (*e.g.* recording, sampling or collection) can be taken by a professional palaeontologist.

## 6. ACKNOWLEDGEMENTS

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| TABLE 1: FOSSIL HERITAGE IN THE DE AAR AREA | | | | |
|---|---|---|---|---|
| GEOLOGICAL UNIT | ROCK TYPES & AGE | FOSSIL HERITAGE | PALAEONT-OLOGICAL SENSITIVITY | RECOMMENDED MITIGATION |
| Superficial deposits ("drift") | alluvium, colluvium (scree), pan sediments *etc*<br><br>QUATERNARY TO RECENT | sparse remains of mammals (bones, teeth), reptiles, ostrich egg shells, molluscs shells, trace fossils, plant remains, palynomorphs, diatoms<br>stone artefacts | LOW | any substantial fossil finds to be reported by ECO to SAHRA |
| Calcretes (T-Qc) | pedogenic limestones<br><br>NEOGENE TO QUATERNARY | calcretised trace fossils (termitaria, rhizoliths *etc*) possible vertebrate bones, teeth, mollusc shells | LOW | any substantial fossil finds to be reported by ECO to SAHRA |
| Karoo Dolerite Suite (Jd) | intrusive dolerite sills & dykes<br><br>EARLY JURASSIC | NONE | ZERO | none |
| Abrahams-kraal Formation (Pa)<br><br>BEAUFORT GROUP | floodplain mudrocks with lenticular channel sandstones, minor playa lake sediments<br><br>MIDDLE PERMIAN | rich terrestrial vertebrate fauna (esp. therapsids), petrified wood, plant remains, freshwater molluscs, trace fossils (trackways, burrows, coprolites) | HIGH | any substantial fossil finds to be reported by ECO to SAHRA |
| Waterford (= Carnarvon) Formation (Pc)<br><br>ECCA GROUP | storm-deposited shallow shelf sandstones with interbedded mudrocks<br><br>MIDDLE PERMIAN | abundant trace fossils, petrified wood, rare fish & amphibian remains, possible stromatolitic limestones, palynomorphs | MEDIUM | any substantial fossil finds to be reported by ECO to SAHRA |
| Tierberg Formation (Pt)<br><br>ECCA GROUP | dark basinal, prodelta and submarine fan mudrocks with minor sandstones<br><br>EARLY TO MIDDLE PERMIAN | locally abundant trace fossils, petrified wood, plant debris, microvertebrates, palynomorphs | MEDIUM | any substantial fossil finds to be reported by ECO to SAHRA |

## 7. REFERENCES

ABEL, O. 1935. Vorzeitliche Lebenspuren. xv+ 644 pp. Gustav Fischer, Jena.

ALMOND, J.E. 1998. Non-marine trace fossils from the western outcrop area of the Permian Ecca Group, southern Africa. Tercera Reunión Argentina de Icnologia, Mar del Plata, 1998, Abstracts p. 3.

ALMOND, J.E. 2008a. Fossil record of the Loeriesfontein sheet area (1: 250 000 geological sheet 3018). Unpublished report for the Council for Geoscience, Pretoria, 32 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2008b. Palaeozoic fossil record of the Clanwilliam sheet area (1: 250 000 geological sheet 3218). Unpublished report for the Council for Geoscience, Pretoria, 49 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2009. Contributions to the palaeontology and stratigraphy of the Alexander Bay sheet area (1: 250 000 geological sheet 2816), 117 pp. Unpublished technical report prepared for the Council for Geoscience by Natura Viva cc, Cape Town.

ALMOND, J.E. & PETHER, J. 2008. Palaeontological heritage of the Northern Cape. Interim SAHRA technical report, 124 pp. Natura Viva cc., Cape Town.

ANDERSON, A.M. 1974. Arthropod trackways and other trace fossils from the Early Permian lower Karoo Beds of South Africa. Unpublished PhD thesis, University of Witwatersrand, Johannesburg, 172 pp.

ANDERSON, A.M. 1975. Turbidites and arthropod trackways in the Dwyka glacial deposits (Early Permian) of southern Africa. Transactions of the Geological Society of South Africa 78: 265-273.

ANDERSON, A.M. 1976. Fish trails from the Early Permian of South Africa. Palaeontology 19: 397-409, pl. 54.

ANDERSON, A.M. 1981. The *Umfolozia* arthropod trackways in the Permian Dwyka and Ecca Groups of South Africa. Journal of Paleontology 55: 84-108, pls. 1-4.

ANDERSON, A.M. & MCLACHLAN, I.R. 1976. The plant record in the Dwyka and Ecca Series (Permian) of the south-western half of the Great Karoo Basin, South Africa. Palaeontologia africana 19: 31-42.

ANDERSON, J.M. & ANDERSON, H.M. 1985. Palaeoflora of southern Africa. Prodromus of South African megafloras, Devonian to Lower Cretaceous, 423 pp. Botanical Research Institute, Pretoria & Balkema, Rotterdam.

BAMFORD, M. 1999. Permo-Triassic fossil woods from the South African Karoo Basin. Palaeontologia africana 35: 25-40.

BAMFORD, M.K. 2004. Diversity of woody vegetation of Gondwanan South Africa. Gondwana Research 7, 153-164.

BENDER, P.A. 2004. Late Permian actinopterygian (palaeoniscid) fishes from the Beaufort Group, South Africa: biostratigraphic and biogeographic implications. Bulletin 135, 84pp. Council for Geoscience, Pretoria.

BENDER, P.A., RUBIDGE, B.S., GARDINER, B.S., LOOCK. J.C. & BREMNER, A.T. 1991. The stratigraphic range of the palaeoniscoid fish *Namaichthys digitata* in rocks of the Karoo sequence and its palaeoenvironmental significance. South African Journal of Science 87: 468-469.

BENDER, P.A. & BRINK, J.S. 1992. A preliminary report on new large mammal fossil finds from the Cornelia-Uitzoek site. South African Journal of Science 88: 512-515.

BOUSMAN, C.B. *et al.* 1988. Palaeoenvironmental implications of Late Pleistocene and Holocene valley fills in Blydefontein Basin, Noupoort, C.P., South Africa. Palaeoecology of Africa 19: 43-67.

BRADDY, S.J. & BRIGGS, D.E.G. 2002. New Lower Permian nonmarine arthropod trace fossils from New Mexico and South Africa. Journal of Paleontology 76: 546-557.

BRINK, J.S. 1987. The archaeozoology of Florisbad, Orange Free State. Memoirs van die Nasionale Museum 24, 151 pp.

BRINK, J.S. *et al*. 1995. A new find of *Megalotragus priscus* (Alcephalini, Bovidae) from the Central Karoo, South Africa. Palaeontologia africana 32: 17-22.

BUATOIS, L. & MANGANO, M.G. 2004. Animal-substrate interactions in freshwater environments: applications of ichnology in facies and sequence stratigraphic analysis of fluvio-lacustrine successions. In: McIlroy, D. (Ed.) The application of ichnology to palaeoenvironmental and stratigraphic analysis. Geological Society, London, Special Publications 228, pp 311-333.

CHURCHILL, S.E. *et al.* 2000. Erfkroon: a new Florisian fossil locality from fluvial contexts in the western Free State, South Africa. South African Journal of Science 96: 161-163.

COOKE, H.B.S. 1974. The fossil mammals of Cornelia, O.F.S., South Africa. In: Butzer, K.W., Clark, J.D. & Cooke, H.B.S. (Eds.) The geology, archaeology and fossil mammals of the Cornelia Beds, O.F.S. Memoirs of the National Museum, Bloemfontein 9: 63-84.

COOPER, M.R. & KENSLEY, B. 1984. Endemic South American Permian bivalve molluscs from the Ecca of South Africa. Journal of Paleontology 58: 1360-1363.

DE BEER, C.H., GRESSE, P.G., THERON, J.N. & ALMOND, J.E. 2002. The geology of the Calvinia area. Explanation to 1: 250 000 geology Sheet 3118 Calvinia. 92 pp. Council for Geoscience, Pretoria.

COLE, D.I., NEVELING, J., HATTINGH, J., CHEVALLIER, L.P., REDDERING, J.S.V. & BENDER, P.A. 2004. The geology of the Middelburg area. Explanation to 1: 250 000 geological sheet 3124 Middelburg, 43 pp. Council for Geoscience, Pretoria.

DUNCAN, A.R. & MARSH, J.S. 2006. The Karoo Igneous Province. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 501-520. Geological Society of South Africa, Marshalltown.

HOLMES, P.J. & MARKER, M.E. 1995. Evidence for environmental change from Holocene valley fills from three central Karoo upland sites. South African Journal of Science 91: 617-620.

JOHNSON, M.R. 1994. Lexicon of South African stratigraphy, 56 pp. South African Committee for Stratigraphy, Council for Geoscience, Pretoria.

JOHNSON, M.R., VAN VUUREN, C.J., VISSER, J.N.J., COLE, D.I., De V. WICKENS, H., CHRISTIE, A.D.M., ROBERTS, D.L. & BRANDL, G. 2006. Sedimentary rocks of the Karoo Supergroup. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 461-499. Geological Society of South Africa, Marshalltown.

KEYSER, A.W. & SMITH, R.M.H. 1979. Vertebrate biozonation of the Beaufort Group with special reference to the western Karoo Basin. Annals of the Geological Survey of South Africa **12**: 1-35.

KEYSER, A.W. & SMITH, R.M.H. 1977-78. Vertebrate biozonation of the Beaufort Group with special reference to the Western Karoo Basin. Annals of the Geological Survey of South Africa 12: 1-36.

KITCHING, J.W. 1977. The distribution of the Karroo vertebrate fauna, with special reference to certain genera and the bearing of this distribution on the zoning of the Beaufort beds. Memoirs of the Bernard Price Institute for Palaeontological Research, University of the Witwatersrand, No. 1, 133 pp (incl. 15 pls).

KLEIN, R.G. 1984. The large mammals of southern Africa: Late Pliocene to Recent. In: Klein, R.G. (Ed.) Southern African prehistory and paleoenvironments, pp 107-146. Balkema, Rotterdam.

LE ROUX, F.G. 1993. Die geologie van die gebied Colesberg. Explanation to 1: 250 000 geology Sheet 3024, 12 pp. Council for Geoscience, Pretoria.

LE ROUX, F.G. & KEYSER, A.W. 1988. Die geologie van die gebied Victoria-Wes. Explanation to 1: 250 000 geology Sheet 3122, 31 pp. Council for Geoscience, Pretoria.

MACRAE, C. 1999. Life etched in stone. Fossils of South Africa, 305 pp. The Geological Society of South Africa, Johannesburg.

McCARTHY, T. & RUBIDGE, B. 2005. The story of Earth and life: a southern African perspective on a 4.6-billion-year journey. 334pp. Struik, Cape Town.

MEADOWS, M.E. & WATKEYS, M.K. 1999. Palaeoenvironments. In: Dean, W.R.J. & Milton, S.J. (Eds.) The karoo. Ecological patterns and processes, pp. 27-41. Cambridge University Press, Cambridge.

PARTRIDGE, T.C. & SCOTT, L. 2000. Lakes and pans. In: Partridge, T.C. & Maud, R.R. (Eds.) The Cenozoic of southern Africa, pp.145-161. Oxford University Press, Oxford.

PARTRIDGE, T.C., BOTHA, G.A. & HADDON, I.G. 2006. Cenozoic deposits of the interior. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 585-604. Geological Society of South Africa, Marshalltown.

PRINSLOO, M.C. 1989. Die geologie van die gebied Britstown. Explanation to 1: 250 000 geology Sheet 3022 Britstown, 40 pp. Council for Geoscience, Pretoria.

RUBIDGE, B.S. (Ed.) 1995. Biostratigraphy of the Beaufort Group (Karoo Supergroup). South African Committee for Biostratigraphy, Biostratigraphic Series No. 1., 46 pp. Council for Geoscience, Pretoria.

RUBIDGE, B.S. 2005. Re-uniting lost continents – fossil reptiles from the ancient Karoo and their wanderlust. 27th Du Toit Memorial Lecture. South African Journal of Geology 108, 135-172.

RUBIDGE, B.S., HANCOX, P.J. & CATUNEANU, O. 2000. Sequence analysis of the Ecca-Beaufort contact in the southern Karoo of South Africa. South African Journal of Geology 103: 81-96.

RUST, I.C., SHONE, R.W. & SIEBRITS, L.B. 1991. Carnarvon Formasie: golf-oorheersde sedimentasie in 'n vlak Karoosee. South African Journal of Science 87, 198-202.

RYAN, P.J. 1967. Stratigraphic and palaeocurrent analysis of the Ecca Series and lowermost Beaufort Beds in the Karoo Basin of South Africa. Unpublished PhD thesis, University of the Witwatersrand, Johannesburg, 210 pp.

SCOTT, L. 2000. Pollen. In: Partridge, T.C. & Maud, R.R. (Eds.) The Cenozoic of southern Africa, pp.339-35. Oxford University Press, Oxford.

SEILACHER, A. 2007. Trace fossil analysis, xiii + 226pp. Springer Verlag, Berlin.

SIEBRITS, L.B. 1987. Die sedimentologie van die Formasie Carnarvon in die omgewing van Carnarvon. Unpublished MSc thesis, University of Port Elizabeth, v + 92 pp.

SIEBRITS, L.B. 1989. Die geologie van die gebied Sakrivier. Explanation of 1: 250 000 geology sheet 3020, 19 pp. Council for Geoscience, Pretoria.

SKEAD, C.J. 1980. Historical mammal incidence in the Cape Province. Volume 1: The Western and Northern Cape. 903pp. Department of Nature and Environmental Conservation, Cape Town.

SMITH, A.B. 1999. Hunters and herders in the Karoo landscape. Chapter 15 in Dean, W.R.J. & Milton, S.J. (Eds.) The Karoo; ecological patterns and processes, pp. 243-256. Cambridge University Press, Cambridge.

SMITH, A.M. & ZAWADA, P.K. 1989. The Ecca-Beaufort transition zone near Philipstown, Cape Province: a marine shelf sequence. South African Journal of Geology 91, 75-82.

SMITH, A.M. & ZAWADA, P.K. 1989. Permian storm current – produced offshore bars from an ancient shelf sequence: northwestern Karoo Basin, Republic of South Africa. Journal of African Earth Sciences 9, 363-370.

SMITH, R.M.H. 1980. The lithology, sedimentology and taphonomy of flood-plain deposits of the Lower Beaufort (Adelaide Subgroup) strata near Beaufort West. Transactions of the Geological Society of South Africa 83, 399-413.

SMITH, R.M.H. 1993. Sedimentology and ichnology of floodplain paleosurfaces in the Beaufort Group (Late Permian), Karoo Sequence, South Africa. Palaios 8, 339-357.

SMITH, R.M.H. & KEYSER, A.W. 1995. Biostratigraphy of the *Tapinocephalus* Assemblage Zone. Pp. 8-12 *in* Rubidge, B.S. (ed.) Biostratigraphy of the Beaufort Group (Karoo Supergroup). South African Committee for Stratigraphy, Biostratigraphic Series No. 1. Council for Geoscience, Pretoria.

SMITH, R.M.H. & ALMOND, J.E. 1998. Late Permian continental trace assemblages from the Lower Beaufort Group (Karoo Supergroup), South Africa. Abstracts, Tercera Reunión Argentina de Icnologia, Mar del Plata, 1998, p. 29.

VAN DIJK, D.E., CHANNING, A. & VAN DEN HEEVER, J.A. 2002. Permian trace fossils attributed to tetrapods (Tierberg Formation, Karoo Basin, South Africa). Palaeontologia africana 38: 49-56.

VILJOEN, J.H.A. 1989. Die geologie van die gebied Williston. Explanation to geology sheet 3120 Williston, 30 pp. Council for Geoscience, Pretoria.

VILJOEN, J.H.A. 1992. Lithostratigraphy of the Collingham Formation (Ecca Group), including the Zoute Kloof, Buffels River and Wilgehout River Members and the Matjiesfontein Chert Bed. South African Committee for Stratigraphy, Lithostratigraphic Series No. 22, 10 pp.

VILJOEN, J.H.A. 1994. Sedimentology of the Collingham Formation, Karoo Supergroup. South African Journal of Geology 97: 167-183.

VILJOEN, J.H.A. 2005. Tierberg Formation. SA Committee for Stratigraphy, Catalogue of South African Lithostratigraphic Units 8: 37-40.

WELLS, L.H. & COOKE, H.B.S. 1942. The associated fauna and culture of Vlakkraal thermal springs, O.F.S.; III, the faunal remains. Transactions of the Royal Society of South Africa 29: 214-232.

WERNER, M. 2006. The stratigraphy, sedimentology and age of the Late Palaeozoic Mesosaurus Inland Sea, SW-Gondwana: new implications from studies on sediments and altered pyroclastic layers of the Dwyka and Ecca Group (lower Karoo Supergroup) in southern Namibia. Dr rer. nat. thesis, University of Würzburg, 428 pp, 167 figs, 1 table.

WICKENS, H. DE V. 1980. Verslag oor kartering in die Calvinia gebied. Unpublished report, Council for Geoscience, Pretoria, 19 pp.

WICKENS, H. DE V. 1984. Die stratigraphie en sedimentologie van die Group Ecca wes van Sutherland. Unpublished MSc thesis, University of Port Elizabeth, viii + 86 pp.

WICKENS, H. DE V. 1992. Submarine fans of the Permian Ecca Group in the SW Karoo Basin, their origin and reflection on the tectonic evolution of the basin and its source areas.

In: De Wit, M.J. & Ransome, I.G.D. (Eds.) Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of southern Africa, pp. 117-126. Balkema, Rotterdam.

WICKENS, H. DE V. 1994. Submarine fans of the Ecca Group. Unpublished PhD thesis, University of Port Elizabeth. 350 pp.

WICKENS, H. DE V. 1996. Die stratigraphie en sedimentologie van die Ecca Groep wes van Sutherland. Council for Geosciences, Pretoria Bulletin 107, 49pp.

ZAWADA, P.K. 1992. The geology of the Koffiefontein area. Explanation of 1: 250 000 geology sheet 2924, 30 pp. Council for Geoscience, Pretoria.

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