Palaeontological heritage assessment: desktop study

PROPOSED HYDROPOWER STATION AND ASSOCIATED INFRASTRUCTURE AT BOEGOEBERG DAM ON THE ORANGE RIVER NEAR GROBLERSHOOP, KHEIS, SIYATHEMBA & SIYANCUMA LOCAL MUNICIPALITIES, NORTHERN CAPE

John E. Almond PhD (Cantab.)
***Natura Viva* cc, PO Box 12410 Mill Street,**
Cape Town 8010, RSA
naturaviva@universe.co.za

September 2013

EXECUTIVE SUMMARY

Boegoeberg Hydro Electric Power (Pty) Ltd is proposing to construct a 15 Megawatt hydropower facility on the northeastern bank of the Orange River, situated adjacent to the existing Boegoeberg Dam and some 26 km southeast of Groblershoop, Northern Cape. The hydropower station would be connected to the existing Fibre Substation that is located 36 km south of the dam site by a high voltage transmission line.

The present report provides a desktop review of palaeontological heritage resources within the study area between Boegoeberg Dam and Fibre Substation, based on the available geological maps and scientific literature. The main limitation for this analysis is the lack of field-based palaeontological studies in the region. Potential impacts of the proposed Boegoeberg hydropower project on fossil heritage are assessed and recommendations are made for inclusion in the Environmental Management Programme.

The development footprints of the proposed Boegoeberg Hydropower Station and associated 132 kV transmission line overlie igneous and sedimentary rocks of Precambrian and much younger, Tertiary or Quaternary age. The main Precambrian bedrock units concerned are basement granites (Skalkseput Granite), Precambrian volcanics of the Venterdorp Group, marine carbonate sediments of the Campbelll Rand Subgroup (Transvaal Supergroup) and a spectrum of shallow marine to fluvial sediments and igneous rocks of the Olifantshoek Supergroup. Late Caenozoic superficial sediments within the development footprint mainly comprise alluvium along the River Orange and more minor watercourses, rubbly colluvium (*e.g.* scree), surface gravels, and aeolian sands of the Gordonia Formation (Kalahari Group).

No areas or sites of exceptional fossil heritage sensitivity or significance have been identified within the Boegoeberg hydropower project study area. The footprint of the hydropower station itself, where substantial excavations are anticipated, is underlain by tectonically deformed Precambrian sedimentary bedrocks of the Olifantshoek Supergroup that are not known to contain fossil remains. It is also noted that potentially fossiliferous ancient river gravels are *not* mapped along this section of the Orange River. The majority of the transmission line corridor from the Boegoeberg Dam site to the Fibre Substation traverses bedrocks of very low to zero palaeontological sensitivity - mainly Ventersdorp Group lavas, basement granites, Kalahari sands. Campbell Rand Subgroup marine carbonates crossed by the transmission line some seven kilometres south of the dam site might contain fossil stromatolites (microbial mounds) but these rocks are probably tectonically deformed and only a small outcrop area is concerned here.

The overall impact significance of the construction phase of the proposed hydropower plant and associated powerline is assessed as LOW with regard to palaeontological heritage resources. This is due to (1) the general scarcity of fossil remains within the bedrocks and superficial deposits represented here, (2) the moderately high levels of bedrock deformation, (3) the comparatively small development footprint, as well as (4) the extensive superficial sediment cover mapped within the study area. This assessment applies equally to all site layout and transmission line route alternatives under consideration since the impacts in all cases will be very similar. The "no-go" option (*i.e.* no hydropower station and transmission line development) will have a neutral impact on fossil heritage resources. The operational and decommissioning phases of the hydropower plant facilities will not involve significant adverse or other impacts on palaeontological heritage.

Given the low impact significance of all the proposed PV solar plant developments as far as palaeontological heritage is concerned, no further specialist palaeontological heritage studies or mitigation are considered necessary for this project, pending the discovery or exposure of any new fossil remains (*e.g.* well-preserved stromatolites, vertebrate bones ands teeth) during development.

During the construction phase all substantial bedrock excavations should be generally monitored for fossil remains by the responsible Environmental Control Officer (ECO). In particular, the ECO should be alerted to the possibility of fluvial gravels containing transported, disarticulated bones and teeth of fossil mammals. Should significant fossil remains such as vertebrate bones and teeth, shells, plant-rich fossil lenses or dense fossil burrow assemblages be exposed during construction, the ECO should safeguard these, preferably *in situ*, and alert the South African Heritage Resources Agency, SAHRA (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za) as soon as possible so that appropriate action can be taken by a professional palaeontologist at the developer's expense. Mitigation would normally involve the scientific recording and judicious sampling or collection of fossil material as well as associated geological data (*e.g.* stratigraphy, sedimentology, taphonomy).

1. INTRODUCTION

The present desktop palaeontological heritage assessment was commissioned as part of the Environmental Impact Assessment for the Boegoeberg Dam hydropower plant development (DEA Ref. No. 14/12/16/3/3/2/568) by Aurecon (Contact details: Aurecon Centre, 1 Century City Drive, Waterford Precinct Century City, South Africa. Tel: 021 526 6034. Fax: 021 526 9500. E-mail: simon.clark@aurecongroup.com. Website: www.aurecongroup.com).

This desktop palaeontological heritage specialist report provides a brief comparative assessment of the inferred palaeontological heritage within the hydropower plant development footprint with recommendations for further specialist palaeontological studies where these are considered necessary. The study forms part of a broad-based heritage impact assessment for the project which falls under Sections 35 and 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999). The palaeontological study forms part of the Environmental Impact Assessment Report (EIAR) and also contributes to the relevant Environmental Management Programme (EMPr) to ensure ongoing management of residual impacts throughout the life of the project.

The approach to this palaeontological heritage study is briefly as follows. Fossil bearing rock units occurring within the development footprint are determined from geological maps and satellite images (Section 4). Known fossil heritage from each rock unit is inventoried from scientific literature, previous assessments within the broader study region, and the author's field experience and palaeontological database (Section 5 and Table 1). Based on this data the palaeontological heritage sensitivity of the study area is assessed and project alternatives are compared. Folowing assessment of the impact significance of the project in terms of palaeontological heritage, recommendations for any further specialist studies and / or mitigation are made for incorporation into the Environmental Management Programme (Sections 6 to 8).

1.1 Project outline

The following project outline has been abstracted from the Final Scoping Report for the Boegoeberg Dam hydropower plant development published by Aurecon (2013).

Boegoeberg Hydro Electric Power (Pty) Ltd (Boegoeberg Hydro) intends to construct a hydropower facility with an approximate capacity of 15 Megawatt (MW) on the banks of the Orange River in the Northern Cape. The proposed hydropower facility is located approximately 26 km southeast of the town of Groblershoop in the Kheis Local Municipality, Northern Cape (Figs. 1 to 3). Aurecon South Africa (Pty) Ltd (Aurecon) has been appointed to undertake the requisite environmental process as required in terms of the National Environmental Management Act (No. 107 of 1998) (NEMA), as amended, on behalf of Boegoeberg Hydro.

The proposed Boegoeberg Hydro Electric Power Station will be located on the northeastern bank of the Orange River, adjacent to the existing Boegoeberg Dam, on the farm Zeekoebaart (Remainder of Farm no. 306 and Portion 1 of Farm no. 306). Energy generated by the proposed hydropower station would be evacuated *via* a proposed High Voltage transmission line to the Eskom Fibre Substation situated *c*. 36km south of the site (Fig. 1).

The proposed facility would be a run-of-river hydropower scheme capable of producing approximately 15 MW of electricity through two or three Francis turbines, each having equal capacity. Run-of-the-river facilities use conventional hydropower technology to produce electricity by using the natural flow and drop in elevation of a river and diverting the flow and passing it through turbines that spin generators. The flowing water spins the turbines, which take the kinetic energy from the flowing water to generate electricity in the same way that a coal-fired power station creates steam to turn turbines, and wind turbines use wind. There would be no storage of water off-stream and the power station would thus be subject to seasonal river flows, and would not operate during low flow periods.

The proposed hydropower station would consist of the following main infrastructural components:

- An off-take structure above the existing Boegoeberg weir to facilitate the abstraction of water;
- Water conveyance infrastructure comprising a combination of either an open canal , a pipeline and/or culverts to convey the water to the head pond;
- A head pond;
- Steel (or other suitable pipeline material) penstocks to transfer the water to the power chamber;
- A power chamber to house the turbines and generation equipment;
- Outlet channel (tailrace) to return the abstracted water back into the river; downstream of the power chamber;
- A switchroom and transformer yard;
- A high voltage (HV) distribution line to evacuate the power to the nearby Fibre Substation; and
- Access roads to the site.

Energy generated by the proposed hydropower station would be evacuated from the site transformer yard *via* a proposed *c*. 36 km transmission line of not more than 132 kilovolt (kV) capacity to a nearby

Eskom substation (Siyathemba and Siyancuma Local Municipalities). The overhead transmission line would connect the powerhouse to Fibre Substation where it would feed into the national grid. New gravel access roads 4 m in width would be constructed to follow the transmission servitude, where existing roads do not exist for construction and maintenance purposes.

Project alternatives that will be assessed during the EIA phase have been summarized as follows in the Final Scoping Report by Aurecon (2013):

1. Location alternatives - none
   - Only the current location of the proposed hydropower station will be considered.

2. Activity alternatives
   - Energy generation by means of a hydropower station; and
   - No-go" alternative to hydropower energy production.

3. Site layout alternatives
   - Two powerhouse and tailrace layout alternatives;
   - Two water conveyance and head pond alternatives;
   - Transmission line and road access alternatives.

4. Technology alternatives - none
   - Only one technology alternative will be considered.

Where necessary, the site layouts will be amended during the EIA Phase in response to any particular environmental sensitivities or technical constraints identified which will be presented and assessed in the Draft EIAR (Environmental Impact Assessment Report). Layout alternatives for the access roads are limited as it is proposed to use existing road alignments, as far as possible. The layout for the transmission line will also follow the project's alignment as far as possible. Where the transmission line extends beyond the project's alignment it will follow the shortest available route towards the existing Eskom Fibre Substation to the south. This route may be adapted should specialist studies indicate that this is required to avoid any sensitive areas. Details will be provided in the EIAR.

Fig. 1. View north-eastwards along the existing Boegoeberg weir showing site of the proposed hydropower station on the far, north-eastern bank of the Orange River (Image abstracted from the Final Scoping Report by Aurecon 2013).

Fig. 2. Layout of the main infrastructural components of the proposed Boegoeberg hydropower station on the River Orange River (Image abstracted from the Final Scoping Report by Aurecon 2013).

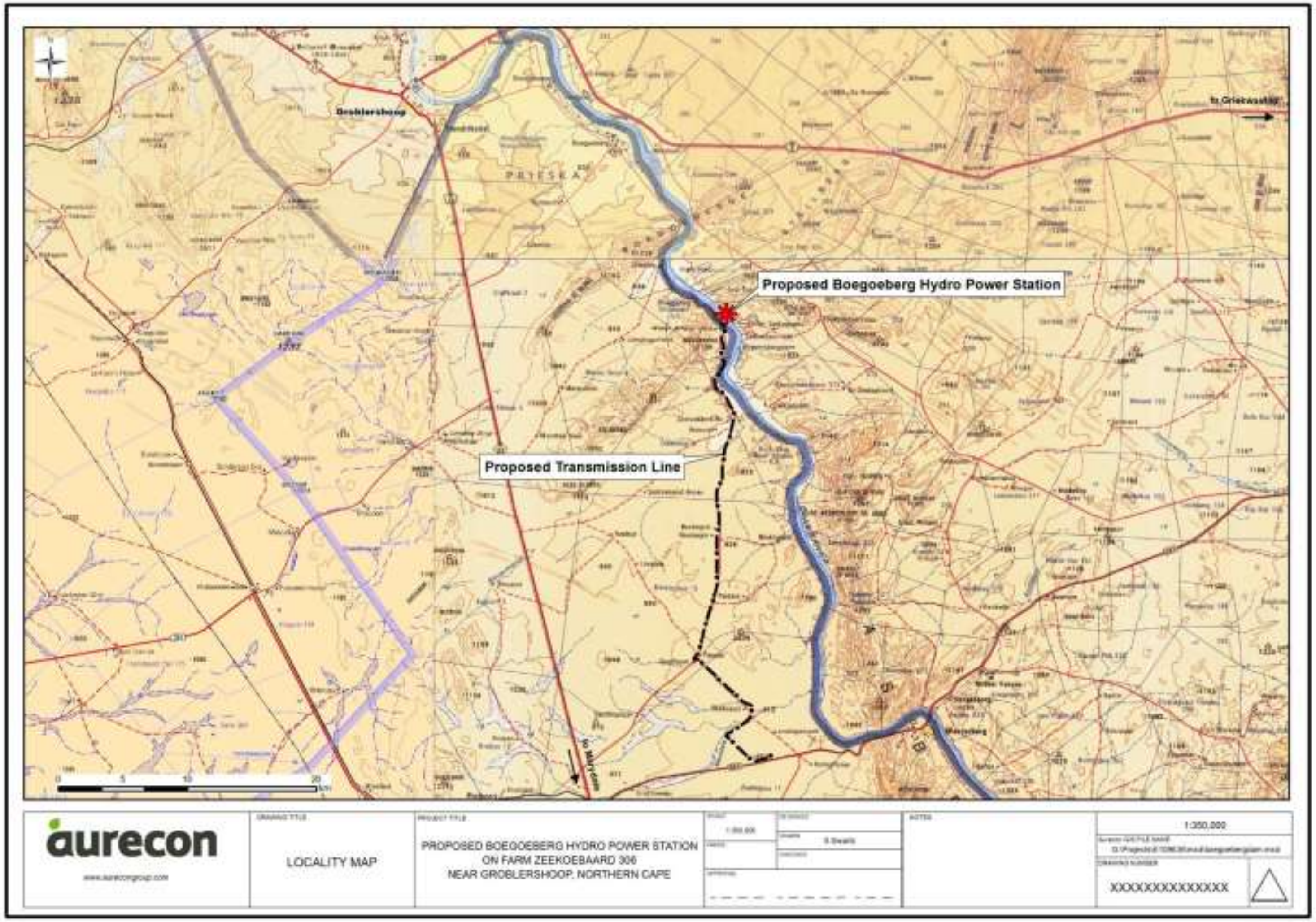

Fig. 3. Topographical map showing the location of the proposed Boegoeberg Hydro Power Station situated on the Orange River about 26 km southeast of Groblershoop, Northern Cape Province, as well as the associated 132 kV transmission line to the Fibre Substation (Image abstracted from the Final Scoping Report produced by Aurecon).

1.2. Legislative context of this palaeontological study

The various categories of heritage resources recognised as part of the National Estate in Section 3 of the National Heritage Resources Act (1999) include, among others:

- geological sites of scientific or cultural importance;
- palaeontological sites;
- palaeontological objects and material, meteorites and rare geological specimens.

According to Section 35 of the National Heritage Resources Act, dealing with archaeology, palaeontology and meteorites:

(1) The protection of archaeological and palaeontological sites and material and meteorites is the responsibility of a provincial heritage resources authority.

(2) All archaeological objects, palaeontological material and meteorites are the property of the State.

(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.

(5) When the responsible heritage resources authority has reasonable cause to believe that any activity or development which will destroy, damage or alter any archaeological or palaeontological site is under way, and where no application for a permit has been submitted and no heritage resources management procedure in terms of section 38 has been followed, it may—

(a) serve on the owner or occupier of the site or on the person undertaking such development an order for the development to cease immediately for such period as is specified in the order;

(b) carry out an investigation for the purpose of obtaining information on whether or not an archaeological or palaeontological site exists and whether mitigation is necessary;

(c) if mitigation is deemed by the heritage resources authority to be necessary, assist the person on whom the order has been served under paragraph *(a)* to apply for a permit as required in subsection (4); and

(d) recover the costs of such investigation from the owner or occupier of the land on which it is believed an archaeological or palaeontological site is located or from the person proposing to

undertake the development if no application for a permit is received within two weeks of the order being served.

Minimum standards for the palaeontological component of heritage impact assessment reports have been developed by SAHRA (2013).

2. APPROACH TO THE PALAEONTOLOGICAL HERITAGE ASSESSMENT

The information used in this desktop study was based on the following:

1. A detailed project outline and maps provided by Aurecon, abstracted from the Final Scoping Report for the Boegoeberg Hydo Power project (Aurecon 2013);

2. A review of the relevant scientific literature, including published geological maps (*N.B.* There is no explanation published for the 1: 250 000 Prieska geology map);

3. The author's database on the formations concerned and their palaeontological heritage.

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps (See Figure 5 and Table 1). The known fossil heritage within each rock unit is inventoried from the published scientific literature, previous palaeontological impact studies in the same region, and the author's field experience (Consultation with professional colleagues as well as examination of institutional fossil collections may play a role here, or later following field assessment during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development (Provisional tabulations of palaeontological sensitivity of all formations in Northern Cape Province have already been compiled by J. Almond & J. Pether 2008). The potential impact of the proposed development on local fossil heritage is then determined on the basis of (1) the palaeontological sensitivity of the rock units concerned and (2) the nature and scale of the development itself, most significantly the extent of fresh bedrock excavation envisaged. When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a Phase 1 field assessment study by a professional palaeontologist is usually warranted to identify any palaeontological hotspots and make specific recommendations for any mitigation required before or during the construction phase of the development.

On the basis of the desktop and Phase 1 field assessment studies, the likely impact of the proposed development on local fossil heritage and any need for specialist mitigation are then determined. Adverse palaeontological impacts normally occur during the construction rather than the operational or decommissioning phase. Phase 2 mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) may be required (a) in the pre-construction phase where important fossils are already exposed at or near the land surface and / or (b) during the construction phase when fresh fossiliferous bedrock has been exposed by excavations. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority, *i.e.* SAHRA for the Northern Cape (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za). It should be emphasized that, *providing appropriate mitigation is carried out*, the majority of developments involving bedrock excavation can make a *positive* contribution to our understanding of local palaeontological heritage.

3. ASSUMPTIONS & LIMITATIONS

The accuracy and reliability of palaeontological specialist studies as components of heritage impact assessments are generally limited by the following constraints:

1. Inadequate database for fossil heritage for much of the RSA, given the large size of the country and the small number of professional palaeontologists carrying out fieldwork here. Most development study areas have never been surveyed by a palaeontologist.

2. Variable accuracy of geological maps which underpin these desktop studies. For large areas of terrain these maps are largely based on aerial photographs alone, without ground-truthing. The maps generally depict only significant ("mappable") bedrock units as well as major areas of superficial "drift" deposits (alluvium, colluvium) but for most regions give little or no idea of the level of bedrock outcrop, depth of superficial cover (soil *etc*), degree of bedrock weathering or levels of small-scale tectonic deformation, such as cleavage. All of these factors may have a major influence on the impact significance of a given development on fossil heritage and can only be reliably assessed in the field.

3. Inadequate sheet explanations for geological maps, with little or no attention paid to palaeontological issues in many cases, including poor locality information;

4. The extensive relevant palaeontological "grey literature" - in the form of unpublished university theses, impact studies and other reports (*e.g*. of commercial mining companies) - that is not readily available for desktop studies;

5. Absence of a comprehensive computerized database of fossil collections in major RSA institutions which can be consulted for impact studies. A Karoo fossil vertebrate database is now accessible for impact study work.

In the case of palaeontological desktop studies without supporting Phase 1 field assessments these limitations may variously lead to either:

(a) *underestimation* of the palaeontological significance of a given study area due to ignorance of significant recorded or unrecorded fossils preserved there, or

(b) *overestimation* of the palaeontological sensitivity of a study area, for example when originally rich fossil assemblages inferred from geological maps have in fact been destroyed by tectonism or weathering, or are buried beneath a thick mantle of unfossiliferous "drift" (soil, alluvium *etc*).

Since most areas of the RSA have not been studied palaeontologically, a palaeontological desktop study usually entails *inferring* the presence of buried fossil heritage within the study area from relevant fossil data collected from similar or the same rock units elsewhere, sometimes at localities far away. Where substantial exposures of bedrocks or potentially fossiliferous superficial sediments are present in the study area, the reliability of a palaeontological impact assessment may be significantly enhanced through field assessment by a professional palaeontologist.

In the case of the Boegoeberg Hydo Power Station and associated transmission line study area a major limitation for fossil heritage studies is the paucity of previous specialist palaeontological studies in the region as a whole. There is no summary of palaeontological data from the 1: 250 000 Prieska sheet area since the relevant sheet explanation has never been published.

4. GEOLOGICAL OUTLINE OF THE STUDY AREA

The Boegoeberg hydropower project study area lies within the Lower Vaal and Orange Rivers geomorphic province of Partridge *et al.* (2010). The existing Boegoeberg Dam at *c*. 885 m amsl lies across a SE- to NW-flowing section of the Orange River flanked by arid terrain with low rocky hills and ridges (Figs. 1 & 2). The site is situated *c*. 17 km east of the N10 Upington – Prieska tar road. An area of relict Kalahari sand dunes, trending WNW-ESE, can be seen on satellite images just 2.3 km to the west. The proposed 132 kV transmission line route follows existing tracks that run southwards across topographically subdued, arid, rocky to gravelly terrain west of the Orange River. This region is dissected by dendritic ephemeral stream systems as well as the Marydale River, a west bank tributary of the Orange, in the southern part of the study area. The existing Fibre Substation lies close to irrigated lands on the northern side of the R383, some 36 km due south of Boegoeberg Dam.

The geology of the Boegoeberg study region is outlined on the north-western corner of 1: 250 000 sheet map 2922 Prieska (Fig. 5) (*N.B.* An explanation to this sheet has not yet been published). The northern and central portions of the region are largely underlain by Precambrian (Late Archaean to Middle Proterozoic) sediments, metasediments and volcanic rocks along the western margin of the ancient Kaapvaal Craton. Three major Precambrian rock successions are mapped here (See stratigraphic table in Fig. 4). Late Archaean (*c*. 2.7 Ga = billion years old) volcanics of the **Ventersdorp Supergroup** (**Zeekoebaart Formation**, Rz) comprise andesitic lavas and tuffs (ashes) with minor interbeds of marble. The Ventersdorp rocks are overlain with an unconformable or faulted contact by marine carbonates of the **Campbell Rand Subgroup** (Ghaap Group, **Transvaal Supergroup** Vgd) that were deposited on the western edge of the Kaapvaal Craton (Griqualand West Basin) in Late Archaean times, some 2.56 billion years ago (Erikkson *et al.* 2006). Finally, in Early Proterozoic times (*c*. 1.9 Ga) the varied succession of shallow marine shelf to fluvial continental sediments of the **Olifantshoek Supergroup** were deposited unconformably on the older Precambrian basement rocks. Some 100 million years or so later, the Olifantshoek sedimentary rocks were deformed and thrust south-eastwards onto the edge of the Kaapvaal Craton as a result of continental collision events (probably between the Congo and Kaapvaal Cratons) to form part of the Ubendian Belt (Kheis Orogeny; Moen 2006, McCarthy & Rubidge 2005). Olifantshoek Supergroup sediments (Ml, Mb, Mdi, Mf in Fig. 5) dominate the terrain around and immediately to the south of the Boegoeberg Dam area, to the southeast of the major Dabep Fault that defined the contact with the Namaqua-Natal basement rocks to the west (Moen 2006, his figs. 1 & 2; see also structural study of the study region by Altermann & Hälbich 1990).

The southern portion of the study region is underlain by granitoid rocks of the ancient Archaean basement, mapped as the **Skalkseput Granite** (Rs in Fig. 5). These last rocks form part of the Marydale – Prieska granite-greenstone terane on the southwestern edge of the Kaapvaal Craton and have been dated to between 3 and 2.7 Ga (Robb *et al.* 2006). Since they are entirely unfossiliferous, they won't be treated further here.

The Precambrian bedrocks are mantled in many areas by a range of much younger **superficial deposits**. These include most notably Quaternary aeolian sands of the **Gordonia Formation** (Qg, **Kalahari Group**) as well as various alluvial sediments (gravels, sands, silts) associated with the major drainage systems such as the Orange and Marydale Rivers *plus* smaller ephemeral stream beds. Relict patches of older terrace or pediment gravels ("High Level Gravels") are not mapped along this stretch of the Orange River, however. Other (unmapped) superficial deposits that are indeed present include rocky colluvium (scree), sheetwash and downwasted surface gravels, and residual soils on the valley slopes and mountainous areas. Most of these younger deposits are probably Quaternary to Recent in age.

In the following section of the report the various sedimentary rock units mapped within the Boegooeberg study area (Fig. 5) are briefly reviewed. A short summary of their geology, age, known fossil heritage and inferred palaeontological sensitivity is presented in Table 1 (data largely based on

Almond & Pether 2008). The location of these rock units within the stratigraphic column for South Africa is shown in Fig. 4. They include a wide range of sedimentary and igneous rocks ranging in age from Late Archaean Proterozoic (*c*. 2.7 Ga = billion years old) to Recent. The igneous rocks (*e.g.* granites, lavas, dolerite) are entirely unfossiliferous while a high proportion of the sedimentary rocks are of low palaeontological sensitivity (Section 5).

4.1. Ventersdorp Supergroup

The **Ventersdorp Supergroup** represents a major episode of igneous extrusion (LIP = Large Igneous Province) that is associated with fracturing of the Kaapvaal Craton some 2.7 Ga (billion years) ago. The basal lava pile termed the Klipriviersberg Group - mainly basaltic lavas welling up in fissure eruptions, totalling up to two kilometres thick and 100 000 km^2 in extent - accumulated over a comparatively short period of some six million years (McCarthy & Rubidge 2005). The overlying **Platberg Group** and equivalents (*e.g.* **Seekoebaart Formation**) comprise a range of felsic to mafic volcanic rocks, including lavas and pyroclastics, such as the porphyritic felsites and pyroclastic flows of the **Makwassie Formation** near Kimberley (Bosch 1993, Van der Westhuizen *et al.* 2006). In the Kimberley area these igneous rocks are associated with rift-related sediments, including colluvial, alluvial fan and lacustrine deposits, and are overlain by fluvial polymict conglomerates and quartzites of the **Bothaville Formation**. In the study area the Seekoebaart Formation andesitic lavas and tuffs are interbedded with minor marbles.

The central portion of the transmission line route is underlain by Ventersdorp Supergroup rocks in the Seekoebaard Formation type area (Rz). The Precambrian volcanics here are extensively mantled by Kalahari sands while limestone interbeds have been metamorphosed to marble.

4.2. Transvaal Supergroup

The 15 km-thick **Transvaal Supergroup** succession spans the time period 2.7 to 2.1 billion years ago (Late Archaean to Early Proterozoic) and comprises a wide range of relatively unmetamorphosed clastic and sedimentary as well as volcanic rocks overlying the Kaapvaal Craton. Important reviews of this key Precambrian rock succession of South Africa have been given by Tankard *et al.* (1982), Catuneanu and Eriksson (1999), Moore *et al.* (2001), and Eriksson *et al.* (1991, 1993, 2006).

The **Campbell Rand Subgroup** (previously included within the Ghaapplato Formation) is a very thick (1.6 -2.5 km) carbonate platform succession of dolomites, dolomitic limestones and cherts with minor tuffs that was deposited on the shallow submerged shelf of the Kaapvaal Craton roughly 2.6 to 2.5 Ga (billion years ago; see readable general account by McCarthy & Rubidge, pp. 112-118 and Fig. 4.10 therein). A range of shallow water facies, often forming depositional cycles reflecting sea level changes, are represented here, including stromatolitic limestones and dolomites, oolites, oncolites, laminated calcilutites, cherts and marls, with subordinate siliclastics (shales, siltstones) and minor tuffs (Eriksson *et al.* 2006).

A short sector of the transmission line route to the south of the Boegoeberg Dam traverses the Campbell Rand Subgroup carbonates (Vgd) that are undifferentiated as to formation on this part of the Prieska 1: 250 000 geology sheet. The carbonate sediments here have probably been deformed by thrusting in Late Proterozoic times (*cf* Altermann & Hälbich 1990)..

4.3. Olifantshoek Supergroup

The Olifantshoek Supergroup is a thick (> 5 km), sandstone-dominated succession of shallow marine to fluvial siliciclastic sediments and subordinate basaltic volcanics that were deposited on the passive western margin of the Kaapvaal Craton in Late Proterozoic times (*c*. 1.9 Ga = billion years ago), following a major episode of denudation (Moen 2006). Thick conglomerates as well as volcanics towards the base of the supergroup are rift-related. Continental redbeds - largely braided stream deposits - within the upper part of the Olifantshoek succession are correlated with similar facies in Limpopo (Waterberg Group) and southern Botswana. These are amongst the earliest redbeds in the rock record, reflecting the establishment of an oxygenic atmosphere on Earth.

Around 1.8 Ga the Olifantshoek rocks were deformed and thrust eastwards onto the craton margin during the Kheis Orogeny, probably as a consequence of collision between the Kaapvaal and Congo Cratons. Metamorphic grade is generally low to very low, with isoclinal folding and a penetrative foliation. The basal contact of the Olifantshoek succession over older, comparatively undeformed Transvaal Supergroup rocks is unconformable on a regional scale, but locally the contact is tectonic as a result of cratonwards thrusting. The upper contact with the Namaqua-Natal Province is also tectonic (along the Dabep Fault).

Rocks in the Boegoeberg Dam area form the southernmost part of the Olifantshoek Supergroup outcrop area (Moen 2006). Four or more rock units within the lower part of the Olifantshoek succession are represented within the present project study area:

- Heterolithic shales and quartzites, with intercalated basaltic lavas, of the **Mapedi Formation** (Ml in part), with a haematite pebble conglomerate along the regional basal unconformity;
- Shallow marine, upward-coarsening (shoaling) shale – quartzite cycles with minor conglomerate and dolomite, followed by an upper succession of upward-fining fluvial siliciclastics, all included within the **Lucknow Formation** (Ml in part). The Lucknow quartzites have recently been correlated with the Magaliesberg Formation of the Pretoria Group (Swart 1999, Evans *et al.* 2002 and refs. therein);
- Basaltic lavas (subaerial eruptions) with subordinate interbedded continental conglomerates and arenites of the **Boegoeberg Dam Formation** (Mb);
- Thick, reddish-brown cross-bedded fluvial quartzites with minor conglomerates of the **Fuller Formation** (Mf), the lowermost subunit of the **Matsap Subgroup** (Volop Group) “red bed” succession.

Small outcrop areas of intrusive **dolerite** (Mdi) of uncertain age are mapped within the Boegoeberg Dam Formation outcrop area. The proposed hydropower station footprint is largely underlain by continental red beds of the slightly younger Fuller Formation (Mf in Fig. 5).

4.4. Kalahari Group

Large sections of the Boegoeberg study area are mantled by a range of **superficial sediments** of probable Late Caenozoic (*i.e.* Late Tertiary or Neogene to Recent) age, many of which are assigned to the **Kalahari Group**. The geology of the Late Cretaceous to Recent Kalahari Group is reviewed by Thomas (1981), Dingle *et al.* (1983), Thomas & Shaw 1991, Haddon (2000) and Partridge *et al.* (2006). Large areas of unconsolidated, reddish-brown to grey aeolian (*i.e.* wind-blown) sands of the Quaternary **Gordonia Formation** (Qs) are mapped overlying Precambrain basement rocks in the central and southern portions of the study region (Fig. 5). In the Kimberley area the Gordonia dune sands consist of up to 85% quartz associated with minor feldspar, mica and a range of heavy minerals (Bosch 1993). They are considered to range in age from the Late Pliocene / Early Pleistocene to Recent, dated in part from enclosed Middle to Later Stone Age stone tools (Dingle *et* *al*., 1983, p. 291). Note that the recent extension of the Pliocene - Pleistocene boundary from 1.8Ma back to 2.588 Ma would place the Gordonia Formation almost entirely within the Pleistocene Epoch.

4.5. Alluvium and other Late Caenozoic superficial sediments

A wide spectrum of superficial sediments of probable Quaternary to Recent age, as listed above, are generally not mapped separately on the 1: 250 000 geological map of the study area (Fig. 5). Bands of Quaternary to recent alluvium are indicated along either side of the Orange River to the south of the Boegoeberg Dam. The absence of older, Quaternary to Late Tertiary terrace or pediment gravels here is significant from a palaeontological sensitivity viewpoint since similar sediments are known for their important fossil mammal and petrified woods elsewhere along the Orange River (Partridge *et al.* 2006). The colluvial and alluvial deposits may be extensively calcretised (*i.e.* cemented with pedogenic limestone), especially in the neighbourhood of dolerite intrusions.

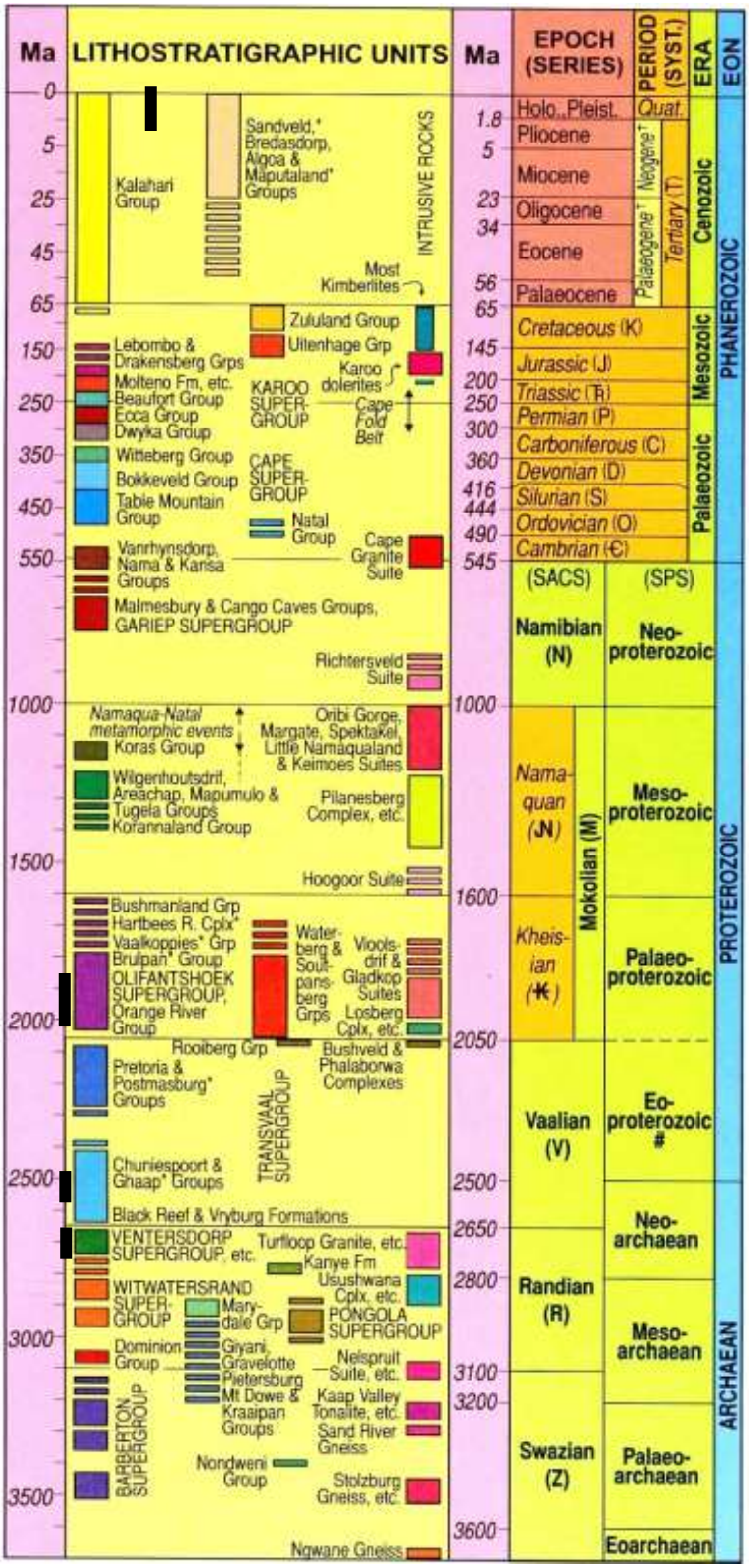

Fig. 4. Stratigraphic column for southern Africa showing the main sedimentary / volcanic rock units represented within the Boegoeberg hydropower study area, Northern Cape Province (thick vertical black lines) (Modified from Johnson *et al.* 2006). These include the Archaean to Proterozoic Ventersdorp Supergroup, Ghaap Group and Olifantshoek Supergroup rocks as well as a range of Late Caenozoic superficial sediments (scree, alluvium, Kalahari sands *etc*). Archaean basement granites of ill-defined Randian age are not indicated separately here.

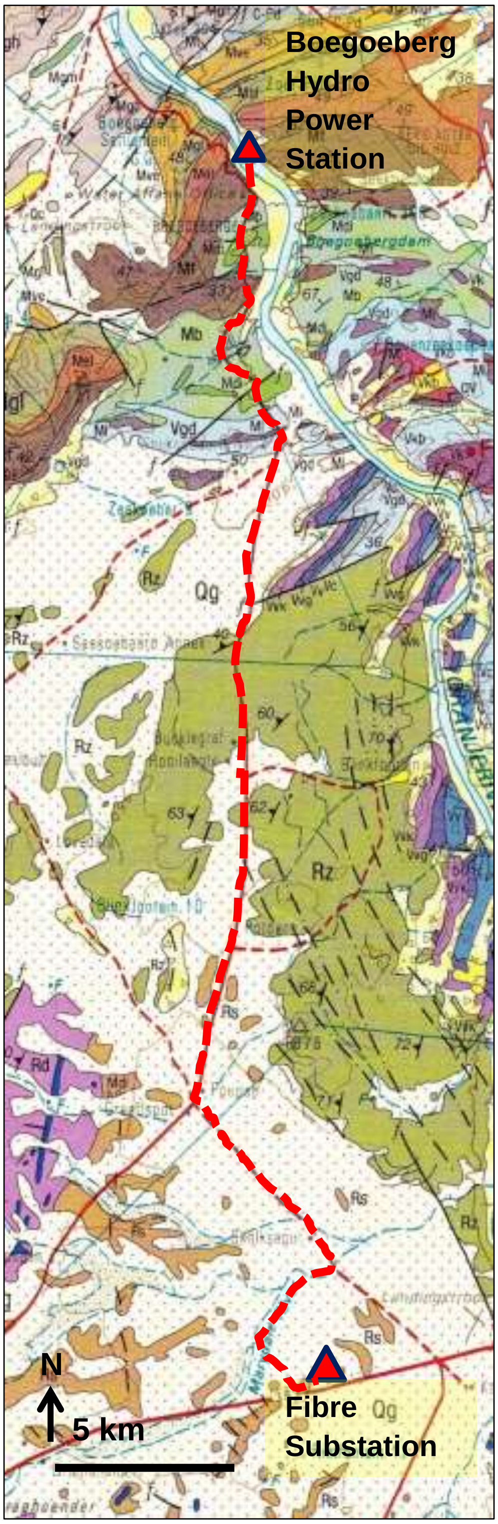

Fig. 5. Extract from 1: 250 000 geology sheet 2922 Prieska (Council for Geoscience, Pretoria) showing approximate location of the proposed Boegoeberg Hydro Power Station on the Orange River, *c*. 26 km SE of Groblershoop, Northern Cape, and the 132 kV transmission line connection to the existing Fibre Substation (red dashed line). The main rock units mapped along the various corridors are listed below:

1. GRANITE BASEMENT ROCKS

Rs (orange) = Skalkseput Granite

2. VENTERSDORP GROUP

Rz (olive green) = Zeekoebaart Formation

3. TRANSVAAL SUPERGROUP (GHAAP GROUP)

Vgd (pale blue) = CAMPBELL RAND SUBGROUP (Undifferentiated)

4. OLIFANTSHOEK SUPERGROUP

Mf (brown) = Fuller Formation (Matsap Subgroup)

Mb (pale green) = Boeberg Dam Fm

Ml (purple) = Lucknow / Mapedi Formations

Mdi (middle green) = diabase / dolerite intrusions (post-Olifantshoek age)

5. KALAHARI GROUP

Qg (pale yellow + red stipple) = Gordonia Formation ("Kalahari sands")

6. OTHER LATE CAENOZOIC SUPERFICIAL DEPOSITS

Pale yellow + flying bird symbol = alluvium (*e.g.* Orange and Marydale Rivers)

Not mapped - colluvium (scree, rubble *etc*), surface gravels, soils

5. OVERVIEW OF PALAEONTOLOGICAL HERITAGE WITHIN THE STUDY AREA

Fossil biotas recorded from each of the main sedimentary rock units mapped within the Boegoeberg hydropower project study area are briefly reviewed below and summarized in Table 1, where an indication of the palaeontological sensitivity of each rock unit is also given (Based on Almond & Pether 2008). The quality of fossil preservation may compromised in some areas due to near-surface weathering, tectonic deformation as well as baking by igneous intrusions. The basement granites in the southern part of the study area are completely unfossiliferous and therefore will not be considered further here.

Note that the Precambrian bedrocks within the study area are dated at between 2.7 and 1.9 Ga (billion years old), well before the evolution of macroscopic multicellular organisms (*cf* McCarthy & Rubidge 2005). However, macroscopic and microscopic fossils of microbial (*e.g.* cyanobacterial) origin may be present here.

5.1. Fossils within the Ventersdorp Supergroup

Domical stromatolites (microbial mounds) are recorded from shallow water lacustrine calcarenites within the volcano-sedimentary succession of the Rietgat Formation at the top of the Platberg Group, Ventersdorp Supergroup (Schopf 2006, Van der Westhuizen *et al.* 2006). The overlying predominantly siliciclastic Bothaville Formation contains conical stromatolites (Schopf 2006). Carbonate sediments are not reported in association with the Allanridge Formation lavas at the top of the Ventersdorp Supergroup.

To the authors knowledge, no fossils have been reported from sedimentary intercalations within the Zeekoebaart Formation that is represented within the study area. The original limestone interbeds (possibly lacustrine) have been subsequently recrystallized to form marbles. Preservation of biogenic structures such as stromatolites is unlikely, but not impossible, under these circumstances.

5.2. Fossils within the Campbell Rand Subgroup

The shallow shelf and intertidal sediments of the carbonate-dominated lower part of the **Ghaap Group** (*i.e.* **Schmidtsdrif** and **Campbell Rand Subgroups**) are well known for their rich fossil biota of stromatolites or microbially-generated, finely-laminated sheets, mounds and branching structures. Some stromatolite occurrences on the Ghaap Plateau of the Northern Cape are spectacularly well-preserved (*e.g.* Boetsap locality northeast of Daniëlskuil figured by McCarthy & Rubidge 2005, Eriksson *et al.* 2006). Detailed studies of these 2.6-2.5 Ga carbonate sediments and their stromatolitic biotas have been presented by Young (1932), Beukes (1980, 1983), Eriksson & Truswell (1974), Eriksson & Altermann (1998), Eriksson *et al* (2006), Altermann and Herbig (1991), and Altermann and Wotherspoon (1995). Some of the oldest known (2.6 Ga) fossil microbial assemblages with filaments and coccoids have been recorded from stromatolitic cherty limestones of the Lime Acres Member, Kogelbeen Formation at Lime Acres (Altermann & Schopf 1995). The oldest, Archaean stromatolite occurrences from the Ghaap Group have been reviewed by Schopf (2006, with full references therein). The Tsineng Formation at the top of the Campbell Rand carbonate succession has yielded both stromatolites (previously assigned to the Tsineng Member of the Gamohaan Formation) as well as filamentous microfossils named *Siphonophycus* (Klein *et al.*1987, Altermann & Schopf 1995).

Only a small outcrop area of Campbell Rand carbonates is present in the Boegoeberg study area and it is possible that these sediments have been deformed during the Late Proterozoic Kheis orogenic event. Significant impacts on fossil heritage (*e.g.* stromatolites) within these rocks is unlikely in the case of the proposed transmission line development.

5.3. Fossils within the Olifantshoek Supergroup

To the author's knowledge, there are no macro- or micro-fossil remains recorded from the Early Proterozoic Olifantshoek Supergroup of the Northern Cape so far. However, exceptionally stromatolites and organic-walled microfossils *might* be preserved within marine carbonate and pelitic (mudrock) facies of the lowermost Olifantshoek Supergroup (*i.e.* Mapedi and Lucknow Formations) as well as possible shallow marine shales of the Top Dog Formation towards the top of the succession (Volop Group). Tectonic deformation (isoclinal folding, cleavage) and low grade regional metamorphism during the Kheis Orogeny may well have compromised fossil preservation in most outcrop areas of the Olifantshoek Supergroup, however.

Quartzite-rich shallow marine beds of the Lucknow Formation have been correlated by some authors with the Magaliesberg Formation of the Pretoria Group (Transvaal Supergroup, Transvaal Basin) (Swart 1999, Evans *et al.* 2002 and refs. therein). This is of note because of the abundant evidence for Early Proterozoic microbial mat structures, presumably generated in the photoc zone, which has recently been reported within the shallow water arenites of the latter succession (Parizot *et al.* 2005, Bosch & Eriksson 2008). Some of the sedimentary structures generated by the microbial mats have a complex structure that is very reminiscent of invertebrate burrows, and indeed they have occasionally been given fossil names elsewhere (*e.g. Manchuriophycus / Rhysonetron*) (See Eriksson *et al.* 2007, Seilacher 2007). It is possible that similar microbial mat structures may eventually turn up in less deformed portions of the Lucknow Formation outcrop area.

Pisolitic laterites within the Gamagara Formation, correlated with the Mapedi Formation at the base of the Olifantshoek Supergroup (Moen 2006), have been interpreted as evidence for a highly oxygenated atmosphere, possible hot and humid climates and possibly even as evidence for terrestrial life in Early Proterozoic times (Gutzmer & Beukes 1998, Evans *et al.* 2002, Beukes *et al.* 2002). These last authors also support a correlation of the Gamagara / Mapedi Formations with the pre-Bushveld succession of the Pretoria Group (Transvaal Group).

5.4. Fossils within the Kalahari Group and alluvium

The fossil record of the **Kalahari Group** is generally sparse and low in diversity. The **Gordonia Formation** dune sands were mainly active during cold, drier intervals of the Pleistocene Epoch that were inimical to most forms of life, apart from hardy, desert-adapted species. Porous dune sands are not generally conducive to fossil preservation. However, mummification of soft tissues may play a role here and migrating lime-rich groundwaters derived from the underlying bedrocks (including, for example, dolerite) may lead to the rapid calcretisation of organic structures such as burrows and root casts. Occasional terrestrial fossil remains that might be expected within this unit include calcretized rhizoliths (root casts) and termitaria (*e.g. Hodotermes*, the harvester termite), ostrich egg shells (*Struthio*) and shells of land snails (*e.g. Trigonephrus*) (Almond 2008, Almond & Pether 2008). Other fossil groups such as freshwater bivalves and gastropods (*e.g. Corbula, Unio*) and snails, ostracods (seed shrimps), charophytes (stonewort algae), diatoms (microscopic algae within siliceous shells) and stromatolites (laminated microbial limestones) are associated with local watercourses and pans. Microfossils such as diatoms may be blown by wind into nearby dune sands (Du Toit 1954, Dingle *et al*., 1983). These Kalahari fossils (or subfossils) can be expected to occur sporadically but widely, and the overall palaeontological sensitivity of the Gordonia Formation is therefore considered to be low. Underlying calcretes of the **Mokolanen Formation** might also contain trace fossils such as rhizoliths, termite and other insect burrows, or even mammalian trackways. Mammalian bones, teeth and horn cores (also tortoise remains, and fish, amphibian or even crocodiles in wetter depositional settings such as pans) may be expected occasionally expected within Kalahari Group sediments and calcretes, notably those associated with ancient, Plio-Pleistocene alluvial gravels.

Most of the other Late Caenozoic superficial sediments (colluvial rubble, surface gravels, residual soils *etc*) within the study area are of very low palaeontological sensitivity. The diverse superficial deposits within the South African interior have been comparatively neglected in palaeontological terms. However, sediments associated with ancient drainage systems, springs and pans in particular may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals as well as remains of reptiles like tortoises (*e.g.* 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, Brink & Rossouw 2000, Rossouw 2006). Other late Caenozoic fossil biotas that may occur within these superficial deposits include non-marine molluscs (bivalves, gastropods), ostrich egg shells, trace fossils (*e.g.* calcretised termitaria, coprolites, invertebrate burrows, rhizocretions), and plant material such as peats or palynomorphs (pollens) in organic-rich alluvial horizons 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. Ancient solution hollows within extensive calcrete hardpans may have acted as animal traps in the past. As with coastal and interior limestones, they might occasionally contain mammalian bones and teeth (perhaps associated with hyaena dens) or invertebrate remains such as snail shells.

The occurrence of significant fossil remains within the Kalahari Group and other Late Caenozoic superficial sediments is usually localized and fairly unpredictable. The fossils concerned may be of widespread occurrence. In general, the palaeontological sensitivity of such young terrestrial sediments is low.

Table 1. Fossil heritage previously recorded within the main sedimentary rock successions (groups, supergroups) cropping out within the Boegoeberg Dam hydropower development footprint, Northern Cape

MAJOR GEOLOGICAL UNIT	FORMATION, ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
LATE CAENOZOIC TERRESTRIAL DEPOSITS OF THE INTERIOR (Qs, T-Qc) (Most too small to be indicated on 1: 250 000 geological maps)	Fluvial, pan, lake and terrestrial sediments, including diatomite (diatom deposits), pedocretes (*e.g.* calcrete), spring tufa / travertine, cave deposits, peats, colluvium, aeolian sands and soils, surface gravels including downwasted rubble MOSTLY QUATERNARY TO HOLOCENE (Possible peak formation 2.6-2.5 Ma)	Bones and teeth of wide range of mammals (*e.g.* mastodont proboscideans, rhinos, bovids, horses, micromammals), reptiles (crocodiles, tortoises), ostrich egg shells, fish, freshwater and terrestrial molluscs (unionid bivalves, gastropods), crabs, trace fossils (*e.g.* termitaria, horizontal invertebrate burrows, stone artefacts), petrified wood, leaves, rhizoliths, diatom floras, peats and palynomorphs.	GENERALLY LOW (BUT LOCALLY HIGH) Scattered records, many poorly studied and of uncertain age	Monotoring of deeper excavations (> 1m) for fossils (*e.g.* mammalian bones, teeth, freshwater shells, petrified wood) by ECO. Any substantial fossil finds to be reported by ECO to SAHRA.

OLIFANTSHOEK SUPERGROUP		Predominantly continental "red beds" (fluvial sediments), subordinate shallow marine siliciclastic metasediments (low metamorphic grade), lavas, carbonates	*Possibility* of stromatolites, microfossils in marine units *e.g.* Lucknow Formation carbonates (Ml), Top Dog Formation shales (Mt)	GENERALLY LOW BUT LOCALLY HIGH WHERE WELL-DEVELOPED STROMATOLITE HORIZONS ARE DEVELOPED	Monotoring of deeper excavations (> 1m) for fossils (*e.g.* stromatolites in carbonate sediments) by ECO. Any substantial fossil finds made during development to be reported by ECO to SAHRA.
TRANSVAAL SUPERGROUP	GHAAP GROUP Campbell Rand Subgroup of Grqiualand West Basin	Predomiantly carbonates (limestone / dolomite) with minorsiliciclastics and chert bands Late Archaean / Early Proterozoic *c.* 2.56 Ga	Range of shallow marine and lacustrine stromatolites (some v. large), oolites, pisolites in carbonates, Filamentous and coccoid organic-walled microfossils (*e.g.* cyanobacteria) in siliciclastics / carbonates	GENERALLY LOW BUT LOCALLY HIGH WHERE WELL-DEVELOPED STROMATOLITE HORIZONS ARE DEVELOPED	Monotoring of deeper excavations (> 1m) for fossils (*e.g.* stromatolites in carbonate sediments) by ECO. Any substantial fossil finds made during development to be reported by ECO to SAHRA.
VENTERSDORP SUPERGROUP	PLATBERG GROUP (Rz) (undifferentiated)	Volcanic lavas, tuffs interbedded with metasediments (fluvial & lacustrine siliciclastics, chert, dolomite) Neoarchaean (Randian) *c.* 2.7 Ga	Important early occurrences of lacustrine stromatolites (microbial mounds), including conical and branching forms, as well as ooids recorded from carbonate subunits. Possible organic-walled microfossils associated with microbial stromatolites.	GENERALLY LOW VOLCANIC ROCKS) BUT LOCALLY HIGH WHERE CARBONATE ROCKS ARE PRESENT	Monotoring of deeper excavations (> 1m) for fossils (*e.g.* stromatolites in carbonate sediments) by ECO. Any substantial fossil finds made during development to be reported by ECO to SAHRA.

6. IMPACT ASSESSMENT

In this section of the report potential impacts on fossil heritage within the Boegoeberg hydropower development footprint are assessed. The impact significance of the various alternative proposals for the development briefly addressed.

The development footprint of the proposed Boegoeberg Hydro Power Station and associated 132 kV transmission line overlie areas of the Northern Cape Province that are underlain by potentially fossilifous sedimentary rocks of Precambrian, and younger, Tertiary or Quaternary age (Sections 4 & 5). The construction phase of the development may entail surface clearance and substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock, notably for pipelines, canals, ponds, as well as transmission line tower installations. In addition, sizeable areas of bedrock may be sealed-in or sterilized by infrastructure such as construction camps as well as new gravel roads. All these developments may adversely affect fossil heritage preserved at or beneath the surface of the ground within the study area by destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good. Once constructed, the operational and decommissioning phases of the hydropower station and transmission line developments are unlikely to involve further adverse impacts on palaeontological heritage, however.

In general, the destruction, damage or disturbance out of context of fossils preserved at the ground surface or below ground that may occur during construction represents a *negative* impact that is limited to the development footprint (*site specific*). Such impacts can usually be mitigated but cannot be fully rectified (*i.e. long term, irreversible*). Some of the sedimentary formations represented within the study area (*e.g.* Campbell Rand Subgroup, Gordonia Formation) contain fossils of some sort, so impacts on fossil heritage are *probable*. However, because of (1) the generally sparse occurrence of fossils within all the bedrock units concerned here as well as within the overlying superficial sediments (windblown sands, soil, alluvium, colluvium *etc*) in addition to (2) moderately high levels of deformation (folding, cleavage) of the bedrocks, the magnitude of these impacts is conservatively rated as *very low*. Confidence levels in this assessment are rates as *unsure* because of the lack of palaeontological field data from the study area.

No areas or sites of exceptional fossil heritage sensitivity or significance have been identified within the Boegoeberg project study area. The footprint of the Boegoeberg Hydropower Station, where substantial excavations are anticipated, is underlain by deformed Precambrian sedimentary bedrocks of the Olifantshoek Supergroup that are not known to contain fossil remains. It is also noted that potentially fossiliferous ancient river gravels are *not* mapped along this section of the Orange River. The majority of the transmission line corridor from the Boegoeberg Dam site to the Fibre Substation traverses bedrocks of very low to zero palaeontological sensitivity - mainly Precambrian lavas of the Ventersdorp Group and ancient basement granites. Precambrian marine sediments of the Campbell Rand Subgroup that might contain fossil stromatolites (microbial mounds) are crossed by the transmission line some 7 km south of the dam site but these rocks are probably tectonically deformed and only a small outcrop area is concerned here. Much of the southern portion of the transmission line route is underlain by Pleistocene aeolian sands of the Gordonia Formation that are at most sparsely fossiliferous. Any fossils or subfossils encountered here are likely to be of widespread occurrence (*i.e.* not unique to the study area).

There are no fatal flaws in the Boegoeberg Dam Hydropower Station development proposal as far as fossil heritage is concerned. Due to (1) the general scarcity of fossil remains within the bedrocks and superficial deposits represented here, (2) the moderately high levels of bedrock deformation, (3) the comparatively small development footprints, as well as (4) the extensive superficial sediment cover mapped within the study area, the overall impact significance of the construction phase of the proposed hydropower plant and associated powerline is assessed as LOW with regard to palaeontological heritage resources. This applies equally to all site layout and transmission line route alternatives under consideration since the anticipated impacts in all cases will be very similar. The “no-go” option (*i.e.* no hydropower station development) will have a neutral impact on fossil heritage resources. The operational and decommissioning phases of the hydropower plant facilities will not involve further significant adverse or other impacts on palaeontological heritage.

Should significant new fossil remains be discovered before or during construction and reported by the responsible ECO to the responsible heritage management authority (SAHRA) for professional recording and collection, as recommended below, the overall impact significance of the project following mitigation would remain LOW. Residual negative impacts from loss of fossil heritage would be partially offset by an improved palaeontological database as a direct result of appropriate mitigation. This is a *positive* outcome because any new, well-recorded and suitably curated fossil material from this palaeontologically under-recorded region would constitute a useful addition to our scientific understanding of the fossil heritage here.

7. RECOMMENDATIONS FOR THE ENVIRONMENTAL MANAGEMENT PROGRAMME

Given the low impact significance of all the proposed Boegoeberg Dam hydropower plant development as far as palaeontological heritage is concerned, no further specialist palaeontological heritage studies or mitigation are considered necessary for this project, pending the discovery or exposure of any substantial new fossil remains (*e.g.* well-preserved stromatolites, vertebrate bones and teeth) during construction.

During the construction phase all substantial bedrock excavations should be generally monitored for fossil remains by the responsible Environmental Control Officer (ECO). In particular, the ECO should be alerted to the possibility of fluvial gravels containing transported, disarticulated bones and teeth of fossil mammals. Should significant fossil remains such as vertebrate bones and teeth, shells, plant-rich fossil lenses or dense fossil burrow assemblages be exposed during construction, the Environmental Control Officer should safeguard these, preferably *in situ*, and alert the South African Heritage Resources Agency, SAHRA (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za) as soon as possible so that appropriate action can be taken by a professional palaeontologist at the developer’s expense. Mitigation would normally involve the scientific recording and judicious sampling or collection of fossil material as well as associated geological data (*e.g.* stratigraphy, sedimentology, taphonomy).

These mitigation recommendations should be incorporated into the Environmental Management Programme (EMP) for the Boegoeberg Dam hydropower station development.

Provided that the recommended mitigation measures are carried through, it is likely that any potentially negative impacts of the proposed development on local fossil resources will be substantially reduced and, furthermore, they will partially offset by the *positive* impact represented by increased understanding of the palaeontological heritage of the Northern Cape.

Please note that:

- All South African fossil heritage is protected by law (South African Heritage Resources Act, 1999) and fossils cannot be collected, damaged or disturbed without a permit from SAHRA or the relevant Provincial Heritage Resources Agency;

- The palaeontologist concerned with mitigation work will need a valid fossil collection permit from SAHRA and any material collected would have to be curated in an approved depository (*e.g.* museum or university collection);

- All palaeontological specialist work should conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording fossil collection and curation, final report) should adhere as far as possible to the minimum standards for Phase 2 palaeontological studies recently developed by SAHRA (2013).

Table 2: Assessment of impacts on palaeontological heritage of the proposed Boegoeberg Dam Hydropower Station and associated transmission line, Northern Cape (construction phase).

Key impacts	Nomitigation /Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase of the hydropower station and associated transmission line	No mitigation	Local	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
	Mitigation	Local	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.

8. CONCLUSIONS & RECOMMENDATIONS

The development footprints of the proposed Boegoeberg Hydropower Station and associated 132 kV transmission line overlie igneous and sedimentary rocks of Precambrian and much younger, Tertiary or Quaternary age. The main Precambrian bedrock units concerned are basement granites (Skalkseput Granite), Precambrian volcanics of the Venterdorp Group, marine carbonate sediments of the Campbelll Rand Subgroup (Transvaal Supergroup) and a spectrum of shallow marine to fluvial sediments and igneous rocks of the Olifantshoek Supergroup. Late Caenozoic superficial sediments within the development footprint mainly comprise alluvium along the River Orange and more minor watercourses, surface gravels, rubbly colluvium (*e.g.* scree) and aeolian sands of the Gordonia Formation (Kalahari Group).

No areas or sites of exceptional fossil heritage sensitivity or significance have been identified within the Boegoeberg hydropower project study area. The footprint of the hydropower station itself, where substantial excavations are anticipated, is underlain by deformed Precambrian sedimentary bedrocks of the Olifantshoek Supergroup that are not known to contain fossil remains. It is also noted that potentially fossiliferous ancient river gravels are *not* mapped along this section of the Orange River. The majority of the transmission line corridor from the Boegoeberg Dam site to the Fibre Substation traverses bedrocks of very low to zero palaeontological sensitivity (mainly Ventersdorp Group lavas, basement granites, Kalahari sands). Campbell Rand Subgroup marine carbonates crossed by the transmission line some seven kilometres south of the dam site might contain fossil stromatolites (microbial mounds) but these rocks are probably tectonically deformed and only a small outcrop area is concerned here.

Due to (1) the general scarcity of fossil remains within the bedrocks and superficial deposits represented here, (2) the moderately high levels of bedrock deformation, (3) the comparatively small development footprints, as well as (4) the extensive superficial sediment cover mapped within the study area, the overall impact significance of the construction phase of the proposed hydropower plant and associated powerline is assessed as LOW with regard to palaeontological heritage resources. This applies equally to all site layout and transmission line route alternatives under consideration since the anticipated impacts in all cases will be very similar. The “no-go” option (i.e.no hydropower station development) will have a neutral impact on fossil heritage resources. The operational and decommissioning phases of the hydropower plant facilities will not involve further significant adverse or other impacts on palaeontological heritage.

Given the low impact significance of all the proposed PV solar plant developments as far as palaeontological heritage is concerned, no further specialist palaeontological heritage studies or mitigation are considered necessary for this project, pending the discovery or exposure of any significant new fossil remains (*e.g.* well-preserved stromatolites, vertebrate bones and teeth) during development.

During the construction phase all substantial bedrock excavations should be generally monitored for fossil remains by the responsible Environmental Control Officer. In particular, the ECO should be alerted to the possibility of fluvial gravels containing transported, disarticulated bones and teeth of fossil mammals. Should significant fossil remains such as vertebrate bones and teeth, shells, plant-rich fossil lenses or dense fossil burrow assemblages be exposed during construction, the Environmental Control Officer should safeguard these, preferably *in situ*, and alert the South African Heritage Resources Agency, SAHRA (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za) as soon as possible so that appropriate action can be taken by a professional palaeontologist at the developer’s expense. Mitigation would normally involve the scientific recording and judicious sampling or collection of fossil material as well as associated geological data (*e.g.* stratigraphy, sedimentology, taphonomy).

9. ACKNOWLEDGEMENTS

Mr Simon Clarke of Aurecon, Cape Town, is thanked for commissioning this study and for kindly providing the necessary background information.

10. REFERENCES

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

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

ALTERMANN, W. & HÄLBICH, I.W. 1990. Thrusting, folding and stratigraphy of the Ghaap Group along the southwestern margin of the Kaapval Craton. South African Journal of Geology 93, 553-566.

ALTERMANN, J. & HERBIG 1991. Tidal flats deposits of the Lower Proterozoic Campbell Group along the southwestern margin of the Kaapvaal Craton, Northern Cape province, South Africa. Journal of African Earth Science 13: 415-435.

ALTERMANN, W. & SCHOPF, J.W. 1995. Microfossils from the Neoarchaean Campbell Group, Griqualand West Sequence of the Transvaal Supergroup, and their paleoenvironmental and evolutionary implications. Precambrian Research 75, 65-90.

ALTERMANN, W. & WOTHERSPOON, J. McD. 1995. The carbonates of the Transvaal and Griqualand West sequences of the Kaapvaal craton, with special reference to the Limje Acres limestone deposit. Mineralium Deposita 30, 124-134.

AURECON. 2013. Proposed hydropower station and associated infrastructure at Boegoeberg dam on the Orange River, near Groblershoop, Northern Cape: Final Scoping Report. Report No. 8182 /109626.

BEUKES, N.J. 1980. Stratigraphie en litofasies van die Campbellrand-Subgroep van die Proterofitiese Ghaap-Group, Noord-Kaapland. Transactions of the Geological Society of South Africa 83, 141-170.

BEUKES, N.J. 1983. Stratigraphie en litofasies van die Campbellrand-Subgroep van die proterofitiese Ghaap-Groep, Noord-Kaapland. Transactions of the Geological Society of South Africa 83: 141-170.

BEUKES, N.J. 1986. The Transvaal Sequence in Griqualand West. In: Anhaeusser, C.R. & Maske, S. (Eds.) Mineral deposits of Southern Africa, Volume 1, pp. 819-828. Geological Society of South Africa.

BEUKES, N.J., DORLAND, H., GUTZMER, J., NEDACHI, M. & OHMOTO, H. 2002. Trolpical laterites, life on land, and the history of atmospheric oxygen in the Palaeoproterozoic. Geology 30, 491-494.

BOSCH, P.J.A. 1993. Die geologie van die gebied Kimberley. Explanation to 1: 250 000 geology Sheet 2824 Kimberley, 60 pp. Council for Geoscience, Pretoria.

BOSCH, P. & ERIKSSON, P. 2008. A note on two occurrences of inferred microbial mat features preserved in the c. 2.1 Ga Magaliesberg Formation (Pretoria Group, Transvaal Supergroup) sandstones, near Pretoria, South Africa. South African Journal of Geology 111, 251-262.

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.

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.

BRINK, J.S. & ROSSOUW, L. 2000. New trial excavations at the Cornelia-Uitzoek type locality. Navorsinge van die Nasionale Museum Bloemfontein 16, 141-156.

CATUNEANU, O. & ERIKSSON, P.G. 1999. The sequence stratigraphic concept and the Precambrian rock record: an example from the 2-7 – 2.1 Ga Transvaal Supergroup, Kaapvaal craton. Precambrian Research 97, 215-251.

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.

DINGLE, R.V., SIESSER, W.G. & NEWTON, A.R. 1983. Mesozoic and Tertiary geology of southern Africa. viii + 375 pp. Balkema, Rotterdam.

DU TOIT, A. 1954. The geology of South Africa. xii + 611pp, 41 pls. Oliver & Boyd, Edinburgh.

ERIKSSON, P.G. 1999. Pretoria Group. SA Committee for Stratigraphy. Catalogue of South African lithostratigraphic units 6, 29- 32. Council for Geoscience, Pretoria.

ERIKSSON, K.A. & TRUSWELL, J.F. 1973. High inheritance elongate stromatolitic mounds from the Transvaal Dolomite. Palaeontologia Africana 15, 23-28.

ERIKSSON, K.A. & TRUSWELL, J.F. 1974. Tidal flat associations from a Lower Proterozoic carbonate sequence in South Africa. Sedimentology 21: 293-309.

ERIKSSON, P.G., SCHRIEBER, U.M. & VAN DER NEUT, M. 1991. A review of the sedimentology of the Early Proterozoic Pretoria Group, Transvaal Sequence, South Africa: implications for tectonic setting. Journal of African Earth Sciences (and the Middle East) 13, 107-119.

ERIKSSON, P.G., SCHWEITZER, J.K., BOSCH, P.J.A., SCHREIBER, U.M., VAN DEVENTER, J.L. & HATTON, C.J. 1993. The Transvaal Sequence: an overview. Journal of African Earth Sciences (and the Middle East) 16, 25-51.

ERIKSSON, P.G., HATTINGH, P.J. & ALTERMANN, W. 1995. An overview of the geology of the Transvaal Sequence and Bushveld Complex, South Africa. Mineralium Deposita 30, 98-111.

ERIKSSON, P.G. & ALTERMANN, W. 1998. An overview of the geology of the Transvaal Supergroup dolomites (South Africa). Environmental Geology 36, 179-188.

ERIKSSON, P.G., ALTERMANN, W. & HARTZER, F.J. 2006. The Transvaal Supergroup and its precursors. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 237-260. Geological Society of South Africa, Marshalltown.

ERIKSSON, P.G., PORADA, H., BANERJEE, S., BOUOUGRI, E., SARKAR, S. & BUMBY, A.J. 2007. Mat-destruction features. In: Schieber, J., Bose, P.K., Eriksson, P.G., Banerjee, S., Sarkar, S., Altermann, W. and Catuneanu, O. (Eds.) Atlas of microbial mat features preserved within the clastic rock record, p. 76-105. Elsevier.

ERIKSSON, P.G., RAUTENBACH, C.J. de W., WRIGHT, D.T., BUMBY, A.J., CATUNEANU, O., MOSTERT, P. & VAN DER NEUT, M. 2009. Possible evidence for episodic epeiric marine and fluvial sedimentation (and implications for palaeoclimatic conditions), c. 2.3-1.8 Ga, Kaapvaal craton, South Africa. Palaeogeography, Palaeoclimatology, Palaeoecology 273, 153-173.

EVANS, D.A.D., BEUKES, N.J. & KIRSCHVINK, J.L. 2002. Paleomagnetism of a lateritic paleoweathering horizon and overlying Paleoproterozoic red beds from South Africa: Implications for the Kaapvaal apparent polar wander path and a confirmation of atmospheric oxygen enrichment. Journal of Geophysical Research 107, B12, 1-22.

GUTZMER, J. & BEUKES, N.J. 1998. Earliest laterites and possible evidence for terrestrial vegetation in the Early Proterozoic. Geology 26, 263-266.

HADDON, I.G. 2000. Kalahari Group sediments. In: Partridge, T.C. & Maud, R.R. (Eds.) The Cenozoic of southern Africa, pp. 173-181. Oxford University Press, Oxford.

KLEIN, C., BEUKES, N.J. & SCHOPF, J.W. 1987. Filamentous microfossils in the early Proterozoic Transvaal Supergroup: their morphology, significance, and palaeoenvironmental setting. Precambrian Research 36, 81-94.

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.

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.

MOEN, H.F.G. 2006. The Olifantshoek Supergroup. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 319-324. Geological Society of South Africa, Marshalltown.

MOORE, J.M., TSIKOS, H. & POLTEAU, S. 2001. Deconstructing the Transvaal Supergroup, South Africa: implications for Palaeoproterozoic palaeoclimate models. African Earth Sciences 33, 437-444.

PARIZOT, M., ERIKSSON, P.G., AIFA, T., SARKAR, S., BANERJEE, S., CATUNEANU, O., ALTERMANN, W., BUMBY, A.J., BORDY, E.M., VAN ROOY, J.L. & BOSHOFF, A.J. 2005. Suspected microbial mat-related crack-like sedimentary structures in the Palaeoproterozoic Magaliesberg Formation sandstones, South Africa. Precambrian Research 138, 274-296.

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.

PARTRIDGE, T.C., DOLLAR, E.S.J., MOOLMAN, J. & DOLLAR, L.H. 2010. The geomorphic provinces of South Africa, Lesotho and Swaziland: a physiographic subdivision for earth and environmental scientists. Transactions of the Royal Society of South Africa 65, 1-47.

ROBB, L.J., BRANDL, G., ANHAEUSSER, C.R. & POUJOL, M. 2006. Archaean granitoid intrusions. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 57-94. Geological Society of South Africa, Marshalltown.

ROSSOUW, L. 2006. Florisian mammal fossils from erosional gullies along the Modder River at Mitasrust Farm, Central Free State, South Africa. Navorsinge van die Nasionale Museum Bloemfontein 22, 145-162.

SCHOPF, J.W. 2006. Fossil evidence of Archaean life. Philosophical Transactions of the Royal Society of London B 361, 869-885.

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

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.

SWART, Q.D. 1999. Carbonate rocks of the Paleoproterozoic Pretoria and Postmasburg Groups, Transvaal Supergroup. Unpublished masters thesis, Rand Afrikaans University, 126 pp.

TANKARD, A.J., JACKSON, M.P.A., ERICKSSON, K.A., HOBDAY, D.K., HUNTER, D.R. & MINTER, W.E.L. 1982. Crustal evolution of Southern Africa – 3.8 billion years of earth history. xv + 523 pp. Springer Verlag, New York.

THOMAS, M.J. 1981. The geology of the Kalahari in the Northern Cape Province (Areas 2620 and 2720). Unpublished MSc thesis, University of the Orange Free State, Bloemfontein, 138 pp.

THOMAS, R.J., THOMAS, M.A. & MALHERBE, S.J. 1988. The geology of the Nossob and Twee Rivieren areas. Explanation for 1: 250 000 geology sheets 2520-2620. 17pp. Council for Geoscience, Pretoria.

THOMAS, D.S.G. & SHAW, P.A. 1991. The Kalahari environment, 284 pp. Cambridge University Press.

VAN DER WESTHUIZEN, W.A., DE BRUIYN, H. & MEINTJES, P.G. 2006. The Ventersdorp Supergroup. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 187-208. Geological Society of South Africa, Marshalltown.

VISSER, D.J.L. 1989. The geology of the Republics of South Africa, Transkei, Bophuthatswana, Venda and Ciskei and the Kingdoms of Lesotho and Swaziland. Explanation: geological map 1: 1 000 000, 491 pp. Council for Geoscience, Pretoria.

YOUNG, R.B. 1932. The occurrence of stromatolitic or algal limestones in the Campbell Rand Series, Griqualand West. Transactions of the Geological Society of South Africa 53: 29-36.

11. QUALIFICATIONS & EXPERIENCE OF THE AUTHOR

Dr John Almond has an Honours Degree in Natural Sciences (Zoology) as well as a PhD in Palaeontology from the University of Cambridge, UK. He has been awarded post-doctoral research fellowships at Cambridge University and in Germany, and has carried out palaeontological research in Europe, North America, the Middle East as well as North and South Africa. For eight years he was a scientific officer (palaeontologist) for the Geological Survey / Council for Geoscience in the RSA. His current palaeontological research focuses on fossil record of the Precambrian - Cambrian boundary and the Cape Supergroup of South Africa. He has recently written palaeontological reviews for several 1: 250 000 geological maps published by the Council for Geoscience and has contributed educational material on fossils and evolution for new school textbooks in the RSA.

Since 2002 Dr Almond has also carried out palaeontological impact assessments for developments and conservation areas in the Western, Eastern and Northern Cape under the aegis of his Cape Town-based company *Natura Viva* cc. He is a long-standing member of the Archaeology, Palaeontology and Meteorites Committee for Heritage Western Cape (HWC) and an advisor on palaeontological conservation and management issues for the Palaeontological Society of South Africa (PSSA), HWC and SAHRA. He is currently compiling technical reports on the provincial palaeontological heritage of Western, Northern and Eastern Cape for SAHRA and HWC. Dr Almond is an accredited member of PSSA and APHP (Association of Professional Heritage Practitioners – Western Cape).

Declaration of Independence

I, John E. Almond, declare that I am an independent consultant and have no business, financial, personal or other interest in the proposed development project, application or appeal in respect of which I was appointed other than fair remuneration for work performed in connection with the activity, application or appeal. There are no circumstances that compromise the objectivity of my performing such work.

Dr John E. Almond
Palaeontologist, *Natura Viva* cc