PALAEONTOLOGICAL IMPACT ASSESSMENT: DESKTOP STUDY

PROPOSED GROOTPOORT PHOTOVOLTAIC SOLAR ENERGY FACILITY NEAR LUCKHOFF, FREE STATE PROVINCE

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1. EXECUTIVE SUMMARY

Pele Green Energy (Pty) Ltd Is proposing to develop a photovoltaic (PV) solar energy facility of up to 100 MW photovoltaic generation capacity as well as associated infrastructure on the Farm Grootpoort 168, Registration Division Fauresmith (Letsemeng Local Municipality), Free State. The total footprint of the project, including supporting infrastructure on site, will be approximately 250 hectares.

The study area is situated on the northern side of the Gariep River some 15.5 km southwest of the small town of Luckhoff. It is underlain by (1) potentially fossiliferous basinal sediments of the marine to lacustrine Tierberg Formation (Ecca Group, Karoo Supergroup) of Middle Permian age that are locally intruded by (2) unfossiliferous Early Jurassic igneous rocks of the Karoo Dolerite suite. The Tierberg mudrocks are very poorly exposed due to the pervasive cover by Late Caenozoic superficial sediments (calcrete, soils, surface gravels, alluvium *etc*). The Ecca mudrocks in this region of the Karoo are frequently weathered and extensively calcretised near-surface. Well-exposed bedding planes that might reveal fossil material are rarely seen. The numerous large concretions of rusty-brown iron carbonate and silicified mudstone encountered at some horizons within the Tierberg succession are usually unfossiliferous; complex stromatolite-like features seen within them are not of biological origin. Baking by dolerite intrusion has probably further compromised fossil preservation within the Ecca mudrocks. The overlying superficial deposits are generally of low palaeontologically sensitivity, although local concentrations of mammalian bones and teeth as well as trace fossils may occur here. Widespread dispersed surface gravels within the study area are probably dominated by hornfels (baked mudrock), dolerite, reworked Ecca concretionary material and calcrete. They may contain rare fragments of reworked petrified wood (*cf* Almond 2015).

No significant fossil heritage resources have been recorded within the Grootpoort Photovoltaic Solar Energy Facility study area. The area is inferred to be of low sensitivity in terms of palaeontological heritage and no sensitive or no-go areas have been identified within it during the present desktop assessment. The proposed solar energy facility is of LOW (negative) impact significance with respect to palaeontological heritage resources. Cumulative impacts associated with the Grootpoort Photovoltaic Solar Energy Facility are probably low. There are no fatal flaws in the Grootpoort Photovoltaic Solar Energy Facility development proposal as far as fossil heritage is concerned. The no-go alternative is of neutral significance for palaeontology. Providing that the recommendations outlined below for palaeontological monitoring and mitigation are followed through, there are no objections on palaeontological heritage grounds to authorisation of this alternative energy project.

Pending the potential discovery of significant new fossil remains during development - notably fossil vertebrate bones & teeth - no further specialist palaeontological studies or mitigation are considered necessary for this project.

In the case of any significant fossil finds during construction (*e.g.* vertebrate teeth, bones, burrows, petrified wood, shells), these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to 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), so that appropriate mitigation (*i.e.* recording, sampling or collection) by a palaeontological specialist can be considered and implemented.

These recommendations should be incorporated into the Environmental Management Plan (EMP) for this alternative energy development.

2. INTRODUCTION & BRIEF

The company Pele Green Energy (Pty) Ltd Is proposing to develop a photovoltaic (PV) solar energy facility of up to 100 MW photovoltaic generation capacity as well as associated infrastructure on the Farm Grootpoort 168, Registration Division Fauresmith (Letsemeng Local Municipality), Free State. The total footprint of the project, including supporting infrastructure on site, will approximately be 250 hectares. The study site, situated on the northern side of the Gariep River some 15.5 km southwest of the small town of Luckhoff (Fig. 1), is currently used for sheep and cattle grazing.

The main infrastructure components of the proposed development that are of relevance to the present palaeontological heritage assessment include the following:

- Solar arrays of PV panels and foundations (cement pillars / slabs / metal screws);
- Wiring to central inverters, with cables to be buried underground;
- On-site substation;
- Connection to the Eskom grid (probably to the existing Canal Substation) *via* an overhead 132 kV transmission line with a 36 m wide servitude;
- Internal access roads (4 m wide), using existing tracks where possible;
- On-site control facility with basic services such as water and electricity and an approximate footprint of 500 m²;
- Security fencing.

Preparation of the site will involve levelling of some areas as well as vegetation clearance. Water for the proposed development will probably be obtained from ground water resources, alternatively from either a nearby canal or from the municipality.

The Interim Comment for the proposed development issued by SAHRA (Case ID: 905922, letter of April 2016) notes that:

> *The PalaeoSensitivity Map on SAHRIS indicates high palaeontological sensitivity for the proposed area and a desktop assessment is required to be conducted and submitted before SAHRA comments further on the case. No activities regarding the development may commence without a final comment from SAHRA.*

The required Environmental Impact Assessment process associated with the proposed Grootpoort Photovoltaic Solar Energy Facility near Luckhoff, including the present desktop palaeontological heritage assessment, is being co-ordinated on behalf of the developer by Environamics (Contact details: Ms Marelie Griesel. Environamics. Postal Address: PO Box 6484, Baillie Park, 2526, RSA. Telephone: 018-290 8228 (w) 086 762 8336 (f). Electronic Mail: marelie@environamics.co.za).

2.1. Legislative context for palaeontological assessment studies

The present desktop palaeontological heritage report falls under Sections 35 and 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999), and it will also inform the Environmental Management Programme for this project.

The various categories of heritage resources recognised as part of the National Estate in Section 3 of the National Heritage Resources Act 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 (PIAs) have been published by SAHRA (2013).

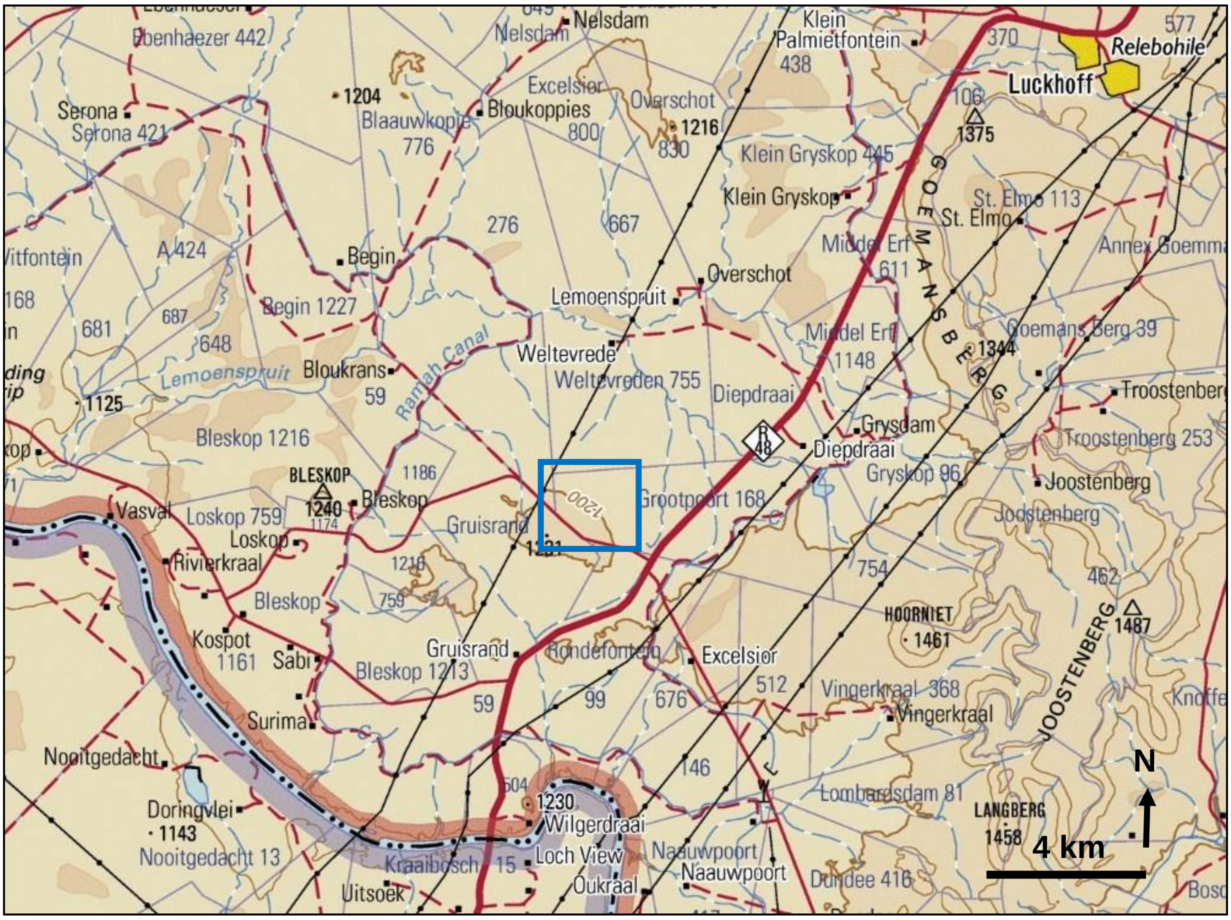

Fig. 1. Extract from 1: 250 000 topographical sheet 2924 Koffiefontein (Courtesy of the Chief Directorate: National Geo-spatial Information, Mowbray) showing the approximate location (blue rectangle) of the study area for the proposed Grootpoort Photovoltaic Solar Energy Facility on the farm Grootpoort 168, situated *c*. 15.5 km to the southwest of Luckhoff, Free State.

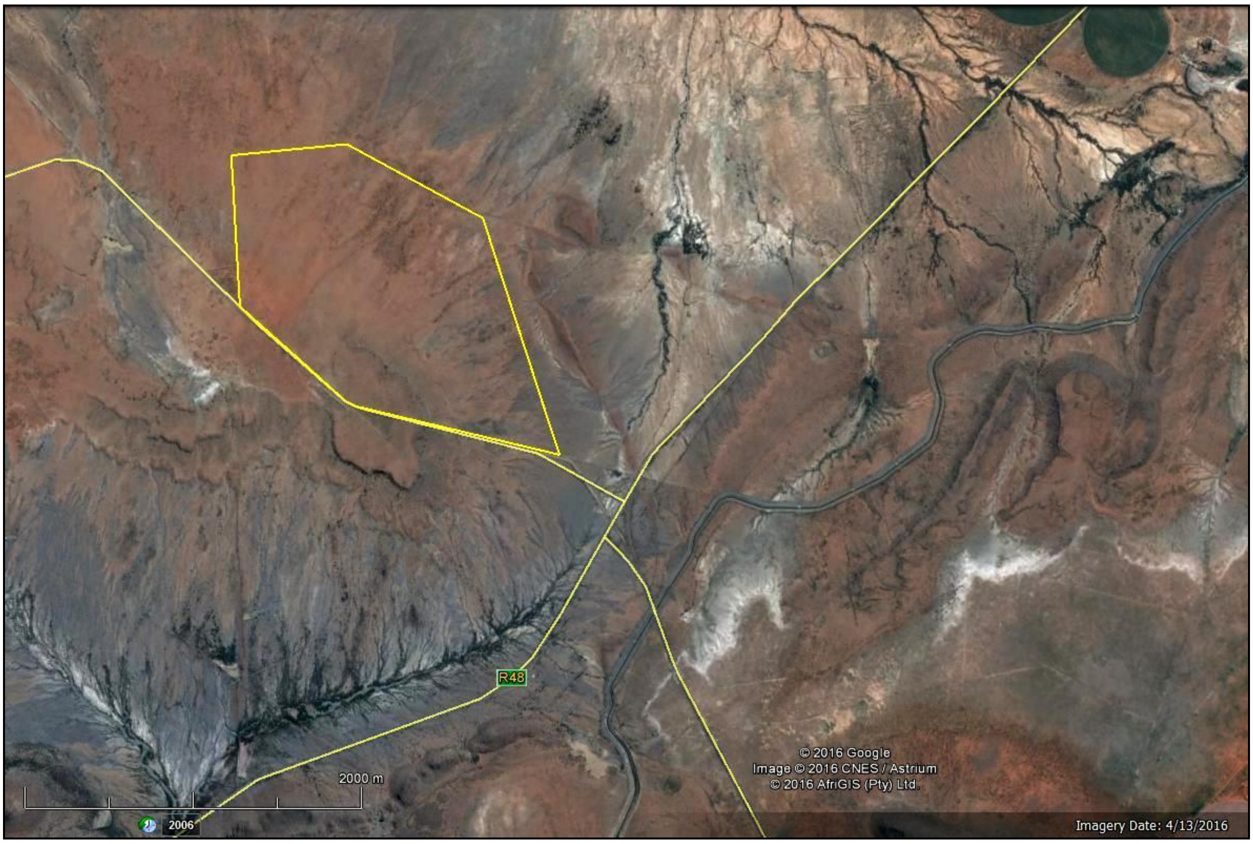

Fig. 2. Google earth© Satellite image of the study area for the proposed Grootpoort Photovoltaic Solar Energy Facility near Luckhoff, Free State (yellow polygon). Grey areas indicate exposures of Tierberg Formation (Ecca Group) mudrocks while orange-brown areas are probably mantled with colluvial / alluvial and sheetwash gravels. Note the prominent-weathering, flat-topped dolerite sill on the southern margin of the study area.

2.2. General approach used for this palaeontological impact study

This PIA report provides an assessment of the observed or inferred palaeontological heritage within the broader study area, with recommendations for specialist palaeontological mitigation where this is considered necessary. The report is based on (1) a review of the relevant scientific literature, including previous palaeontological impact assessments in the area (*e.g.* Almond 2013b, 2015), (2) published geological maps and accompanying sheet explanations (*e.g.* Zawada 1992), as well as (3) the author's extensive field experience with the formations concerned and their palaeontological heritage (*e.g.* Almond & Pether 2008).

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps and satellite images. 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 scoping 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 the Western, Eastern and Northern Cape have already been compiled by J. Almond and colleagues; *e.g.* Almond & Pether 2008). The likely 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 notably the extent of fresh bedrock excavation envisaged. When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a field assessment study by a professional palaeontologist is usually warranted.

The focus of palaeontological field assessment is *not* simply to survey the development footprint or even the development area as a whole (*e.g.* farms or other parcels of land concerned in the development). Rather, the palaeontologist seeks to assess or predict the diversity, density and distribution of fossils within and beneath the study area, as well as their heritage or scientific interest. This is primarily achieved through a careful field examination of one or more representative exposures of all the sedimentary rock units present (*N.B.* Metamorphic and igneous rocks rarely contain fossils). The best rock exposures are generally those that are easily accessible, extensive, fresh (*i.e.* unweathered) and include a large fraction of the stratigraphic unit concerned (*e.g.* formation). These exposures may be natural or artificial and include, for example, rocky outcrops in stream or river banks, cliffs, quarries, dams, dongas, open building excavations or road and railway cuttings. Uncemented superficial deposits, such as alluvium, scree or wind-blown sands, may occasionally contain fossils and should also be included in the field study where they are well-represented in the study area. It is normal practice for impact palaeontologists to collect representative, well-localized (*e.g.* GPS and stratigraphic data) samples of fossil material during field assessment studies. In order to do so, a fossil collection permit from SAHRA is required and all fossil material collected must be properly curated within an approved repository (usually a museum or university collection).

Note that while fossil localities recorded during field work within the study area itself are obviously highly relevant, most fossil heritage here is embedded within rocks beneath the land surface or obscured by surface deposits (soil, alluvium *etc*) and by vegetation cover. In many cases where levels of fresh (*i.e.* unweathered) bedrock exposure are low, the hidden fossil resources have to be *inferred* from palaeontological observations made from better exposures of the same formations elsewhere in the region but outside the immediate study area. Therefore a palaeontologist might reasonably spend far *more* time examining road cuts and borrow pits close to, but outside, the study area than within the study area itself. Field data from localities even further afield (*e.g.* an adjacent province) may also be adduced to build up a realistic picture of the likely fossil heritage within the study area.

On the basis of the desktop and field 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. Mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological and taphonomic data) – is usually most effective 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, SAHRA (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.

2.3. Assumptions and 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 present study area near Luckhoff in the Free State preservation of potentially fossiliferous bedrocks is favoured by the semi-arid climate but bedrock exposure is very limited indeed due to cover by extensive superficial deposits (*e.g.* alluvium, soils, surface gravels), especially in areas of low relief, as well as by *bossieveld* vegetation. The conclusions reached in the present desktop study are largely based on a previous field-based palaeontological heritage study for a similar project located just to the south of the Gariep River (Almond 2015).

3. GEOLOGICAL BACKGROUND

The study area on Farm Grootpoort 168 near Luckhoff, Free State, comprises predominantly flat-lying terrain situated some 6 km or more to the north of the Orange / Gariep River (Fig. 2). The R48 road to Luckhoff runs just to the southeast. The semi-arid terrain within the study area lies at 1180 to 1230 m amsl with a gentle slope towards the NE and SE. A low rocky area (dolerite sill) lies along the southern boundary. The area to the north drains into the Lemoenspruit drainage system, a tributary of the Gariep.

The geology of the study area is outlined on 1: 250 000 geology sheet 2924 Koffiefontein (Council for Geoscience, Pretoria) (Fig. 3), with an accompanying short sheet explanation by Zawada (1992). The study area lies within the northern margins of the Main Karoo Basin and is largely underlain by sedimentary bedrocks of the Permian **Ecca Group** (Karoo Supergroup), notably by dark basinal shales of the **Tierberg Formation** (Pt). These are extensively mantled by Late Caenozoic superficial sediments such as doleritic colluvium, alluvium, surface gravels, soils and sheetwash.

The Tierberg Formation is a thick, recessive-weathering, mudrock-dominated succession consisting predominantly of dark, often brown to grey, well-laminated, carbonaceous shales with subordinate thin, fine-grained sandstones (Prinsloo 1989, Le Roux 1993, Viljoen 2005, Johnson *et al*., 2006). The Tierberg shales are Early to Middle 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 *in* Macey *et al.* 2011). Thin coarsening-upwards cycles occur towards the top of the formation with local evidence of soft-sediment deformation, ripples and common calcareous concretions. Thin water-lain tuffs (volcanic ash layers) are also known. 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 often baked to a dark grey hornfels with a reddish-brown crust (Prinsloo 1989). Tierberg Formation exposures some 20 km south of the present study area, on the southern side of the Gariep, have been briefly described in a previous palaeontological heritage assessment by Almond (2015). The Karoo Supergroup sedimentary bedrocks within the broader region are largely undeformed, with low, subhorizontal bedding dips except perhaps in the immediate vicinity of igneous intrusions. Exposure levels of the Tierberg mudrocks are generally poor due to the low topographic relief and extensive cover by superficial calcrete, alluvium, soils and surface downwasted or sheetwash gravels. Extensive bedding planes – a prime focus for fossil recording – are usually very rare.

The Tierberg mudrocks in the Grootpoort study area are extensively intruded by dolerites of the **Karoo Dolerite Suite** (Jd). These form part of a suite 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, Cole *et al.* 2004). 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. Close to the margins of the intrusions the country mudrocks have been thermally metamorphosed or baked to form tough, splintery hornfels. A dolerite sill is mapped on the southern edge of the study area (rocky elevation in satellite images; Fig. 2) and a dolerite dyke runs roughly west-east through the area.

Various types of **superficial deposits** of Late Caenozoic (Miocene / Pliocene to Recent) age occur widely throughout the Karoo study region (*e.g.* Holmes & Marker 1995, Cole *et al.* 2004, Partridge *et al.* 2006, Almond 2013b, Almond 2015). They include pedocretes (*e.g*. calcretes), colluvial slope deposits, down-wasted and sheetwash surface gravels, river alluvium, wind-blown sands as well as spring and pan sediments and soils. This mantle of superficial deposits obscures the Palaeozoic and Mesozoic bedrock geology in most parts of the Grootpoort study area, as seen from satellite images (Fig. 2) as well as field photos (*cf* Van Schalkwyk 2015). Furthermore, deep chemical weathering in the Late Cretaceous to Tertiary interval has probably converted some of the near-surface Ecca rocks to *in situ* weathered saprolite. Useful geological overviews of talus deposits, alluvium and calcrete occurrences in a semi-arid Karoo region are given by Cole *et al.* (2004).

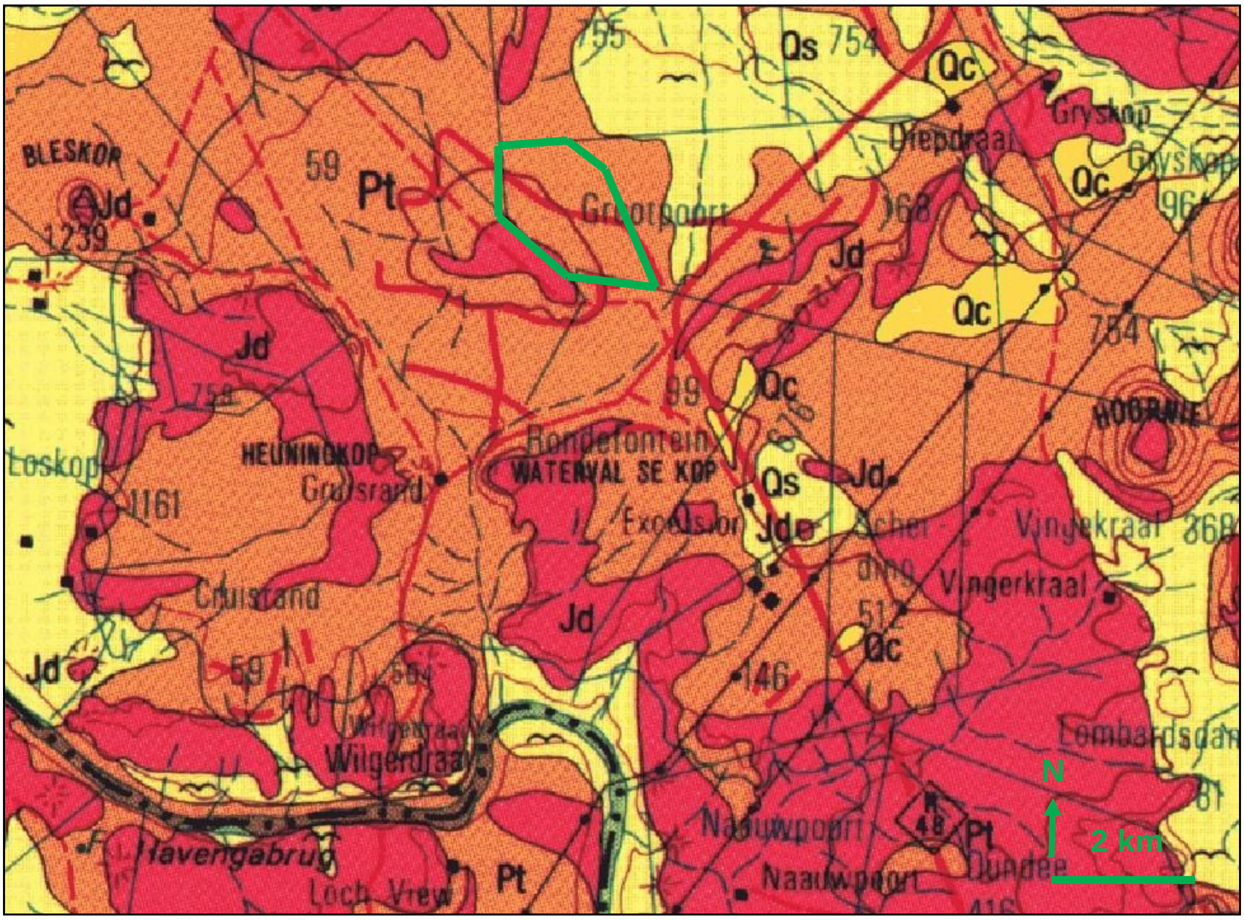

Fig. 3. Extracts from the 1: 250 000 geology sheet 2924 Koffiefontein showing the geology of the Grootpoort Solar Photovoltaic Energy development facility near Luckhoff Free State (blue polygon) (Council for Geoscience, Pretoria). The main rock units represented within the broader study region are:

1. KAROO SUPERGROUP (ECCA GROUP)

Tierberg Formation (Pt, orange)

2. KAROO DOLERITE SUITE

Dolerite sills and dykes (J-d, red)

3. LATE CAENOZOIC SUPERFICIAL SEDIMENTS

Stream and river alluvium (pale yellow with flying bird symbol), calcrete hardpans (Qc, dark yellow), aeolian sand (Qs, pale yellow)

4. PALAEONTOLOGICAL HERITAGE

The fossil heritage within each of the major sedimentary rock units that are represented within the Grootpoort study area has been summarized in previous desktop and field-based palaeontological studies by the author (*e.g.* Almond 2013b, 2015). The dolerite outcrops in 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.

4.1. Fossil heritage within the Tierberg Formation

The fossil record of the Tierberg Formation in the Loeriesfontein sheet area and elsewhere within the Main Karoo Basin has been reviewed in detail by Almond *in* Macey *et al.* (2011). Rare body fossil records include disarticulated microvertebrates (*e.g.* 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 succession (*e.g.* 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 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 (*e.g.*distal turbidites, prodeltaic sandstones) within more heterolithic successions. A modest range of ten or so different ichnogenera have been recorded from the Tierberg Formation (*e.g.* Abel 1935, Anderson 1974, 1976, Wickens 1980, 1984, 1994, 1996, Prinsloo 1989, De Beer *et al*., 2002, Viljoen 2005, Almond *in* Macey *et al.* (2011)). 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 narrow (< 1cm) *Cruziana carbonaria* 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 (*e.g.* 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 (3-4 cm), 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 (*e.g.* 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.

Apart from very rare fragments of petrified wood reworked into the overlying surface gravels, no fossils were recorded directly from the Tierberg Formation just to the south of the Gariep by Almond (2015). Complex ribbed structures frequently seen within ferruginous carbonate concretions are abiogenic cone-in-cone structures and not true fossils; they are often mistaken for fossil stromatolites (microbial mounds). The concretions appear to be late diagenetic in origin and no macroscopic fossil remains have been observed within them (although various microfossils might be preserved here). The Tierberg Formation mudrocks are poorly exposed at surface within the Grootpoort study area, as judged from satellite images as well as field photos, and they are at least in part metamorphosed by dolerite intrusions. It is concluded that the overall palaeontological sensitivity of the Ecca Group bedrocks here is low.

4.2. Fossil heritage within the Late Caenozoic 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 (*e.g.* calcretised termitaria, coprolites), and plant remains such as peats or palynomorphs (pollens, spores) in organic-rich alluvial horizons (Scott 2000) and siliceous 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). Stone artefacts of Pleistocene and younger age may additionally prove useful in constraining the age of superficial deposits such as gravelly alluvium within which they are occasionally embedded.

A previous palaeontological heritage field study of an area just south of the Gariep by Almond (2015) suggests that the superficial sediments overlying the Ecca Group here are of low palaeontological sensitivity.

5. IMPACT ASSESSMENT

The potential impact of the proposed Grootpoort Photovoltaic Solar Energy Facility near Luckhoff on local fossil heritage resources is briefly evaluated in Table 1 below. This assessment applies only to the construction phase of the PV solar development since further impacts on fossil heritage during the planning, operational and decommissioning phases of the facility are not anticipated. The assessment applies to all key infrastructure as described in Section 2 situated within the study area that is shown in Figs. 2 and 3, *i.e.* solar panel arrays, underground cables, access roads, on-site substation and control facility, 132 kV transmission lines and associated infrastructure.

The destruction, damage or disturbance out of context of legally-protected fossils preserved at the ground surface or below ground that may occur during construction of the solar energy facility entail direct *negative* impacts to palaeontological heritage resources that are confined to the development footprint (*site*). These impacts can often be mitigated but cannot be fully rectified (*i.e.* they are *permanent*). All of the sedimentary formations represented within the study area contain fossils of some sort, so impacts of some sort on fossil heritage are unavoidable, but the probability of impacts on scientifically-important fossil remains is rated as *unlikely*. Most (but *not* all) of the fossils concerned are probably of widespread occurrence within the outcrop areas of the formations represented here; the likelihood of loss of *unique or rare* fossil heritage is therefore low. Because of the generally sparse occurrence of scientifically-important, well-preserved, unique or rare fossil material within the bedrock formations concerned here as well as within the overlying superficial sediments (soil, alluvium, colluvium *etc*), the severity or intensity of these impacts is conservatively rated as *low*.

As a consequence of (1) the paucity of irreplaceable, unique or rare fossil remains within the development footprint, as well as (2) the extensive superficial sediment cover overlying most potentially-fossiliferous bedrocks within the study area, the overall impact significance of the construction phase of the proposed PV solar energy project is assessed as LOW (negative). This assessment applies to all planned infrastructure within the study area and applies equally to all technology alternatives under consideration. There are therefore no preferences on palaeontological heritage grounds for any particular infrastructure layout or technology alternative among the various options under consideration.

No significant further impacts on fossil heritage are anticipated during the planning, operational and decommissioning phases of the solar energy facility. The no-go alternative (*i.e.* no development) will have a neutral impact on palaeontological heritage.

There are no fatal flaws in the Grootpoort Photovoltaic Solar Energy Facility development proposal as far as fossil heritage is concerned. Providing that the proposed recommendations for palaeontological monitoring and mitigation outlined below are followed through, there are no objections on palaeontological heritage grounds to authorisation of this alternative energy project.

Due to the generally low levels of bedrock exposure within the study area as well as the lack of palaeontological field data from the study area, confidence levels for this palaeontological heritage assessment are only *moderate*. These conclusions are supported, however, by a previous palaeontological field assessment undertaken in the broader study region by the author (Almond 2015).

Table 1: Table 1: Assessment of impacts of the proposed Grootpoort Photovoltaic Solar Energy Facility on fossil heritage resources during the construction phase of the development (*N.B.* Significant impacts are not anticipated during the operational and decommissioning phases).

Nature of impact: Disturbance, damage, destruction or sealing-in of scientifically important fossil remains preserved at or beneath the ground surface within the development area, most notably by surface clearance and bedrock excavations during the construction phase of the solar energy facility.		
	Without mitigation	**With mitigation**
Geographical Extent	Site (1)	Site (1)
Duration	Permanent (4)	Permanent (4)
Intensity / Magnitude	Low (1)	Low (1)
Probability	Unlikely (1)	Unlikely (1)
Significance	**Negative Low (7)**	**Negative Low (7)**
Status	Negative	Negative (loss of fossils) & positive (improved fossil database following mitigation)
Reversibility	Irreversible	Irreversible
Irreplaceable loss of resources	No, since the limited fossil resources concerned are also represented outside the development area (*i.e.* not unique)	No, since the limited fossil resources concerned are also represented outside the development area (*i.e.* not unique)
Can impacts be mitigated?	Yes	Yes.
Mitigation: Monitoring of all substantial bedrock excavations for fossil remains by ECO, with reporting of substantial new palaeontological finds (notably fossil vertebrate bones & teeth) to SAHRA for possible specialist mitigation.		
Cumulative impacts: Unknown (Insufficient data on local alternative energy and other developments available) but probably low.		
Residual impacts: Negative impacts due to loss of local fossil heritage will be partially offset by *positive* impacts resulting from mitigation (*i.e.* improved palaeontological database).		

5.1. Cumulative impacts

Because of the paucity of field-based palaeontological heritage data on alternative energy or other developments within the broader study region near Luckhoff (*cf* SAHRIS website), cumulative impacts posed by these developments cannot be realistically assessed. Given the low impact significance assessed for a solar energy development underlain by very similar geology just to the south of the Gariep River (Almond 2015), it is likely that cumulative impacts associated with the Grootpoort Photovoltaic Solar Energy Facility are low.

6. SUMMARY & RECOMMENDATIONS

The study area for the proposed Grootpoort Photovoltaic Solar Energy Facility near Luckhoff is underlain by (1) potentially fossiliferous basinal sediments of the marine to lacustrine Tierberg Formation (Ecca Group, Karoo Supergroup) of Middle Permian age that are locally intruded by (2) unfossiliferous Early Jurassic igneous rocks of the Karoo Dolerite suite. The Tierberg mudrocks are very poorly exposed due to the pervasive cover by Late Caenozoic superficial sediments (calcrete, soils, surface gravels, alluvium *etc*). The Ecca mudrocks in this region of the Karoo are frequently weathered and extensively calcretised near-surface. Well-exposed bedding planes that might reveal fossil material are rarely seen. The numerous large concretions of rusty-brown iron carbonate and silicified mudstone encountered at some horizons within the Tierberg succession are usually unfossiliferous; complex stromatolite-like features seen within them are not of biological origin. Baking by dolerite intrusion has probably further compromised fossil preservation within the Ecca mudrocks. The overlying superficial deposits are generally of low palaeontologically sensitivity, although local concentrations of mammalian bones and teeth as well as trace fossils may occur here. Widespread dispersed surface gravels within the study area are probably dominated by hornfels (baked mudrock), dolerite, reworked Ecca concretionary material and calcrete. They may contain rare fragments of reworked petrified wood (*cf* Almond 2015).

No significant fossil heritage resources have been recorded within the Grootpoort Photovoltaic Solar Energy Facility study area. The area is inferred to be of low sensitivity in terms of palaeontological heritage and no sensitive or no-go areas have been identified within it during the present desktop assessment. The proposed solar energy facility is of LOW (negative) impact significance with respect to palaeontological heritage resources. Cumulative impacts associated with the Grootpoort Photovoltaic Solar Energy Facility are probably low. There are no fatal flaws in the Grootpoort Photovoltaic Solar Energy Facility development proposal as far as fossil heritage is concerned. The no-go alternative is of neutral significance for palaeontology. Providing that the recommendations outlined below for palaeontological monitoring and mitigation are followed through, there are no objections on palaeontological heritage grounds to authorisation of this alternative energy project.

Pending the potential discovery of significant new fossil remains during development - notably fossil vertebrate bones & teeth - no further specialist palaeontological studies or mitigation are considered necessary for this project.

In the case of any significant fossil finds during construction (*e.g.* vertebrate teeth, bones, burrows, petrified wood, shells), these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to 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), so that appropriate mitigation (*i.e.* recording, sampling or collection) by a palaeontological specialist can be considered and implemented.

These recommendations should be incorporated into the Environmental Management Plan (EMP) for this alternative energy development.

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9. 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, Mpumalanga, Free State, Gauteng, Limpopo and Northwest Province under the aegis of his Cape Town-based company *Natura Viva* cc. He has been 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 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.

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