PALAEONTOLOGICAL SPECIALIST STUDY: COMBINED DESKTOP AND FIELD-BASED ASSESSMENTS

PROPOSED PHOTOVOLTAIC (SOLAR) ENERGY FACILITIES ON DU PLESSIS DAM FARM NEAR DE AAR, NORTHERN CAPE

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

July 2013

1. SUMMARY

Mulilo Renewable Energy (Pty) Ltd (Mulilo) is proposing to construct three 75 MW alternating current (AC) photovoltaic (PV) solar energy facilities on Du Plessis Dam Farm (Remainder of Farm 179), situated on the north-eastern outskirts of the town of De Aar, Northern Cape Province. The total extent of the proposed solar energy facilities would be approximately 859 ha. An alternative proposal entails the construction of a single 400 MW PV facility with an area of *c*. 1069 hectares on Du Plessis Dam 179.

The potentially fossiliferous sediments of the Ecca Group (Karoo Supergroup) that underlie the Du Plessis Dam Farm study area are almost entirely mantled in a thick layer of superficial deposits of probable Pleistocene to Recent age. The upper Ecca Group bedrocks in the De Aar area contain sparse to locally common petrified wood as well as low diversity trace fossil assemblages typical of the Waterford Formation, rather than the Tierberg Formation as mapped. Based on field assessment their palaeontological sensitivity is rated as low. The Ecca bedrocks are extensively intruded and baked by the Karoo Dolerite Suite. These Early Jurassic igneous rocks are unfossiliferous. The diverse superficial deposits in the study region, including various soils, gravels and – at least in some areas - a well-developed calcrete hardpan, are also of low palaeontological sensitivity as a whole. Calcretized rhizoliths (root casts) and possible invertebrate burrows of probable Quaternary age were observed during field studies just to the south of the Du Plessis Dam Farm. Well-preserved but small fragments of reworked Permian silicified fossil wood are recorded widely from subsurface and surface gravels overlying Ecca bedrock in the study area.

Potential impacts on fossil heritage of the proposed solar facility developments are confined to the development footprint and are only anticipated during the construction phase. As far as fossil heritage is concerned, the impact significance of both the preferred and alternative layouts is considered to be LOW (with or without mitigation) for the following reasons:

- The Karoo Supergroup bedrocks here are deeply weathered, locally calcretised and baked, and for the most part only sparsely fossiliferous;
- The development footprints for proposed PV solar energy facility sites are small and largely underlain by superficial deposits of low palaeontological sensitivity;
- Significant fossil material (*e.g.* fossil wood, vertebrate remains) at or near surface level is most likely only very sparsely distributed within the study area; and
- Extensive, deep bedrock excavations are not envisaged during the construction phase.

There is no preference on fossil heritage grounds for the preferred (Alternative 1) *versus* alternative (Alternative 2) layouts or technologies for the Du Plessis Dam solar energy facility developments. The "no go" alternative to the proposed solar plant developments would have a neutral (zero magnitude) impact significance on fossil heritage resources. Alternative transmission

line connections to De Aar Substation would both be of very low impact significance. There is no preference on palaeontological heritage grounds for conventional PV *versus* CPV technology. Likewise there is unlikely to be any significant difference in impact significance between single axis *versus* fixed axis tracking technology.

A substantial number of other alternative energy projects – including both wind energy and solar energy facilities – have been proposed for the De Aar area (*cf* 2010b, 2011, 2012a, 2012b, 2012c). Given the generally low palaeontological sensitivity of the Karoo Supergroup bedrocks and Pleistocene to Recent superficial sediments in the De Aar region as a whole, the cumulative impact of these developments is considered to be of LOW significance, however.

It is recommended that:

- The ECO responsible for the development should be aware of the possibility of important fossils (*e.g.* petrified wood, mammalian bones, teeth) being present or unearthed on site and should monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;
- In the case of any significant fossil finds (*e.g.* fossil wood, vertebrate teeth, bones, burrows, petrified wood) during construction, these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to 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) so that any appropriate mitigation (*i.e.* fossil recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer's expense; and
- These recommendations should be incorporated into the EMP for the Du Plessis Dam Farm solar energy facilities.

The palaeontologist involved 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).

2. INTRODUCTION & BRIEF

The company Mulilo Renewable Energy (Pty) Ltd (Mulilo) is proposing to construct three 75 MW alternating current (AC) photovoltaic (PV) solar energy facilties on Du Plessis Dam Farm (Remainder of Farm 179), situated on the north-eastern outskirts of the town of De Aar, Northern Cape Province (DEA REF. NOS. 14/12/16/3/3/2/454 to 456) (Figs. 1 & 3, Table 2.1). The total extent of the three proposed solar energy facilities (Alternative 1 layout) would be approximately 859 ha.

A 19.9 MW solar energy facility (PV1) on Du Plessis Dam Farm has already received environmental authorization from the Department of Environmental Affairs (DEA) on 28 September 2012. A 132 kV overhead transmission line (6.1 km) connecting the approved site to the existing Eskom infrastructure was also approved in the EA dated 28 September 2012. The area previously approved for PV1 (approximately 64 ha) will be included in the proposed layouts for the additional PV facilities as an attempt to maximize the generation capacity of the farm.

An alternative proposal (Alternative 2 layout) entails the construction of a single 400 MW PV facility on Du Plessis Dam 179 with an area of c. 1069 hectares (Fig. 3). The layout for this alternative was developed by extending and combining the proposed 75MW facilities.

Table 2.1: Footprints, capacities and coordinates of the three proposed PV solar energy facilities on Du Plessis Dam (Alternative 1, preferred layout)

Plant	Footprint (ha)	Capacity (MW)	Co-ordinates (middle point)
PV2	169	75	30°38'11.38"S; 24° 4'22.75"E
PV3	212	75	30°37'53.03"S; 24° 3'28.26"E
PV4	374	75	30°37'27.44"S; 24° 2'31.14"E

Each of the proposed PV solar energy facilities would consist of the following key components:

- **Solar energy facility:** numerous arrays of PV panels and associated support infrastructure to generate up to 75 MW AC per facility for Alternative 1 and up to 400MW for Alternative 2. The PV panel frame supports are fixed on top of steel piles. Due the occurrence of dolerite and siltstone bedrock on site at shallow depths, the steel piles would be embedded into a concrete pile. However, the final design of the foundations will depend on the geotechnical conditions of the site which will be determined at a later stage;

- **Transmission lines:** The three onsite substations envisaged would feed into a central onsite substation *via* onsite overhead 132kV transmission lines (Fig. 3);
- **Substations:** An onsite 132 kV, 3 bay central substation;
- **Boundary fence:** a fence around each 75 MW PV facility for health, safety and security reasons.

It is also proposed that the following infrastructure be shared among the three PV faclities to limit the impact on the surrounding environment, as well as to reduce costs:

- **Central substation:** One central 132 kV substation and connection to the Eskom grid. This central substation will connect the PV plants with Eskom's De Aar Substation *via* either an existing overhead 132 kV Eskom line or the previously authorised 132 kV overhead transmission line directly to De Aar substation (Fig. 3);
- **Roads:** A main access road from the R48 (6 m wide and 6.8 km long) and internal access roads for servicing and maintenance of the site (existing roads will be used where possible);
- **Water supply infrastructure:** It is proposed that potable water will be obtained from the Emthanjeni Municipality *via* an underground municipal pipeline (5 km long) from the nearest municipal supply point and will be contained onsite in a jo-jo tank;
- **Stormwater infrastructure:** Including drainage channels, berms, detention areas and kinetic energy dissipaters; and
- **Buildings:** Buildings would probably include onsite substations, a connection building, control building, guard cabin and solar resource measuring substation.

Proposed additional infrastructure will include the following components:

- A single **laydown area** that would be used during the construction phases of the proposed PV solar energy facilities;
- **Septic tanks** to be constructed at the site offices; and
- The natural water flow of the site will be interrupted by the proposed roads, and therefore **stormwater infrastructure** will be required to facilitate surface water flow and to prevent erosion.

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), as amended, on behalf of Mulilo.

Given the presence of exposures of potentially fossiliferous Karoo Supergroup sediments within the study area, a combined desktop and field-based palaeontological assessment for the project has been commissioned by Aurecon in accordance with the requirements of the National Heritage Resources Act, 1999 (Act No. 25 of 1999) (NHRA). The terms of reference for this study, which builds on the earlier combined desktop and field-based palaeontological heritage assessment for the PV1 site (Almond 2012a), as defined by Aurecon, are briefly as follows:

To undertake a Palaeontology Impact Assessment of the site in accordance with the requirements of Section 38(3) of the NHRA which would include:

- Conducting a detailed desk-top level investigation to identify all palaeontological significant geological units in the proposed development areas;
- Undertaking field work, if necessary, to verify results of desktop investigation;
- Documenting (GPS coordinates and map) all sites, objects and structures identified on the candidate sites;
- Submitting the relevant application form, as required by the South African Heritage Resources Agency and Northern Cape Provincial Heritage (Boswa ya Kapa Bokone);
- Compilation of a report which would include:

(1) Identification of palaeontologically significant sites within the proposed development areas;
(2) Assessment of the sensitivity and significance of palaeontological resource of the site;
(3) Evaluation of the potential impacts of construction, operation and maintenance of the proposed development on palaeontological resources, in terms of the scale of impact (local, regional, national), magnitude of impact (low, medium or high) and the duration of the impact (construction, up to 10 years after construction (medium term), more than 10 years after construction (long term));
(4) Assessment of cumulative impacts;
(5) Recommendation of mitigation measures to ameliorate any negative impacts on areas of palaeontological importance;
(6) The preparation of a heritage resources management plan which includes recommendations on the management of the objects, sites or features, and also guidelines on procedures to be implemented if previously unidentified palaeontological resources are uncovered during later developments in the area;
(7) Consideration of relevant guidelines.

Cognisance must be taken of the Department of Environmental Affairs and Development Planning guideline: “Guideline for involving heritage specialists in EIA processes”.

2.1. Project implications for palaeontological heritage & relevant legislation

The proposed solar energy facilities on Du Plessis Dam Farm are located in an area of the Main Karoo Basin of South Africa that is underlain by potentially fossiliferous sedimentary rocks of the Karoo Supergroup that are of Permian age. The construction phase of the development will entail excavations into the superficial sediment cover (soils, alluvial gravels *etc*) and perhaps also into the underlying potentially fossiliferous bedrock. These notably include excavations for the PV panel support structures, buried cables, internal access roads, any new power line pylons and associated infrastructure. All these developments may adversely affect potential fossil heritage 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 PV solar energy facilities will not involve further adverse impacts on palaeontological heritage, however.

The extent of the proposed development (over 5000 m^2) falls within the requirements for a Heritage Impact Assessment (HIA) as required by Section 38 (Heritage Resources Management) of the NHRA. The various categories of heritage resources recognised as part of the National Estate in Section 3 of the Heritage Resources Act include, among others:

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

Minimum standards for the palaeontological component of heritage impact assessment reports have recently been developed by South African Heritage Resources Agency (S (2013).

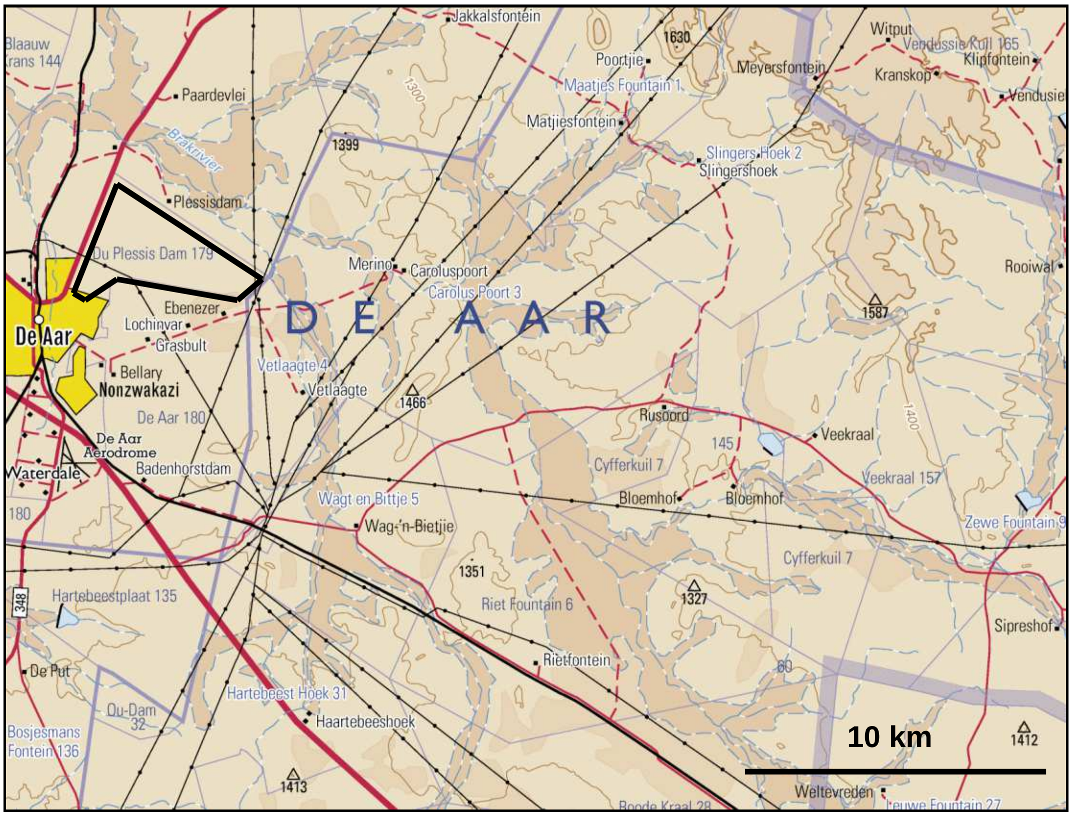
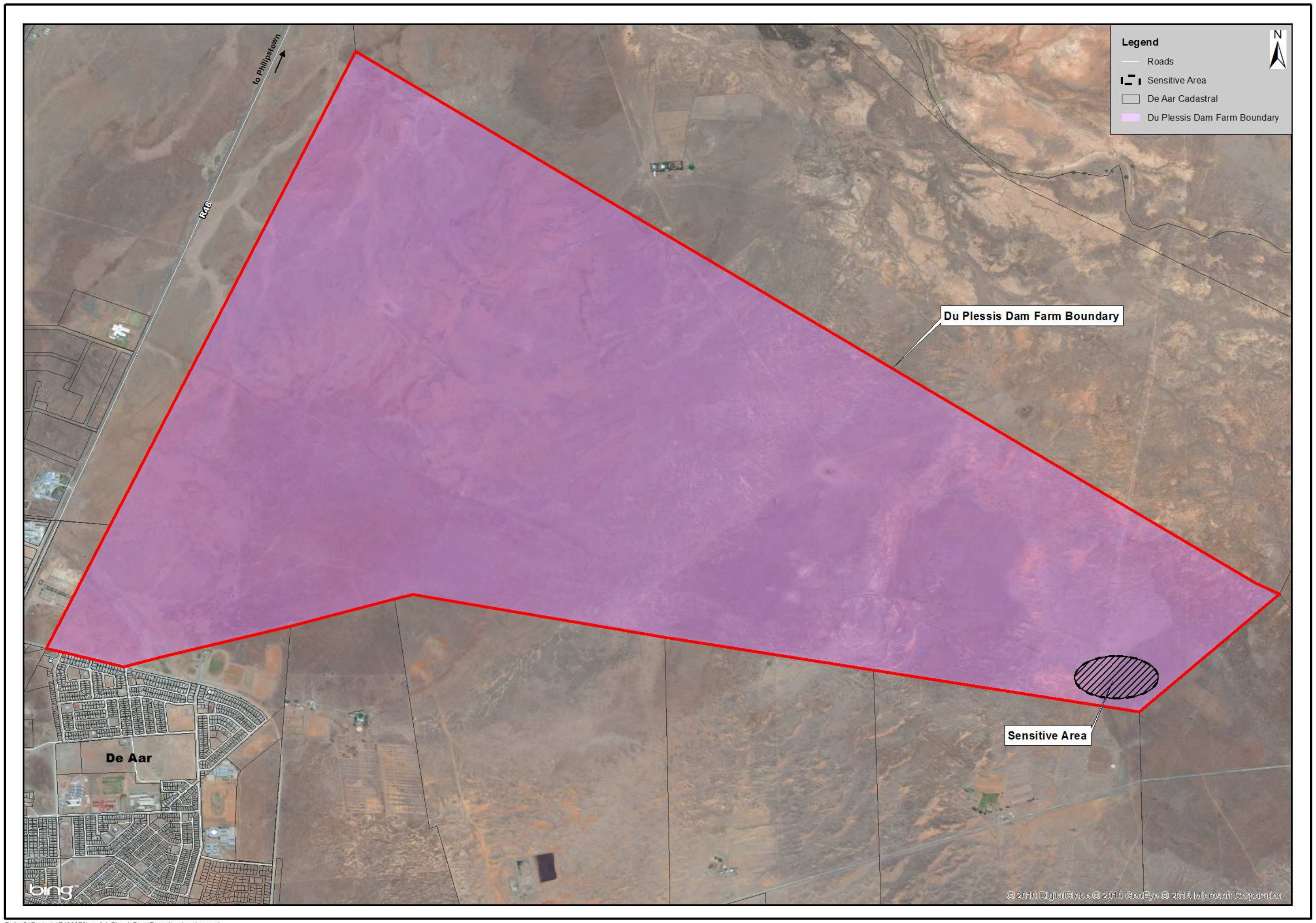


Fig. 1. Extract from 1: 250 000 topographical sheet 3024 Colesberg showing the location (black polygon) of the proposed solar energy facility study area on farm Du Plessis Dam 179 on the northeastern outskirts of De Aar.



Path: S:\Projects\E109378\mxd\duPlessisDam\Report\pv1_paleo.mxd

Fig. 2. Google Earth© satellite image of the Du Plessis Dam 179 study area to the northeast of De Aar (yellow polygon) showing *vlaktes* underlain by Ecca Group mudrocks to the north and east with rusty-brown dolerite intrusions and doleritic gravels in the southwest. Fossil wood fragments are common within surface gravels within the red dotted area, but are also occur widely elsewhere within the study area. The intermittent-flowing Brakrivier is seen to the northwest. Scale bar (yellow line) = *c.* 2 km.

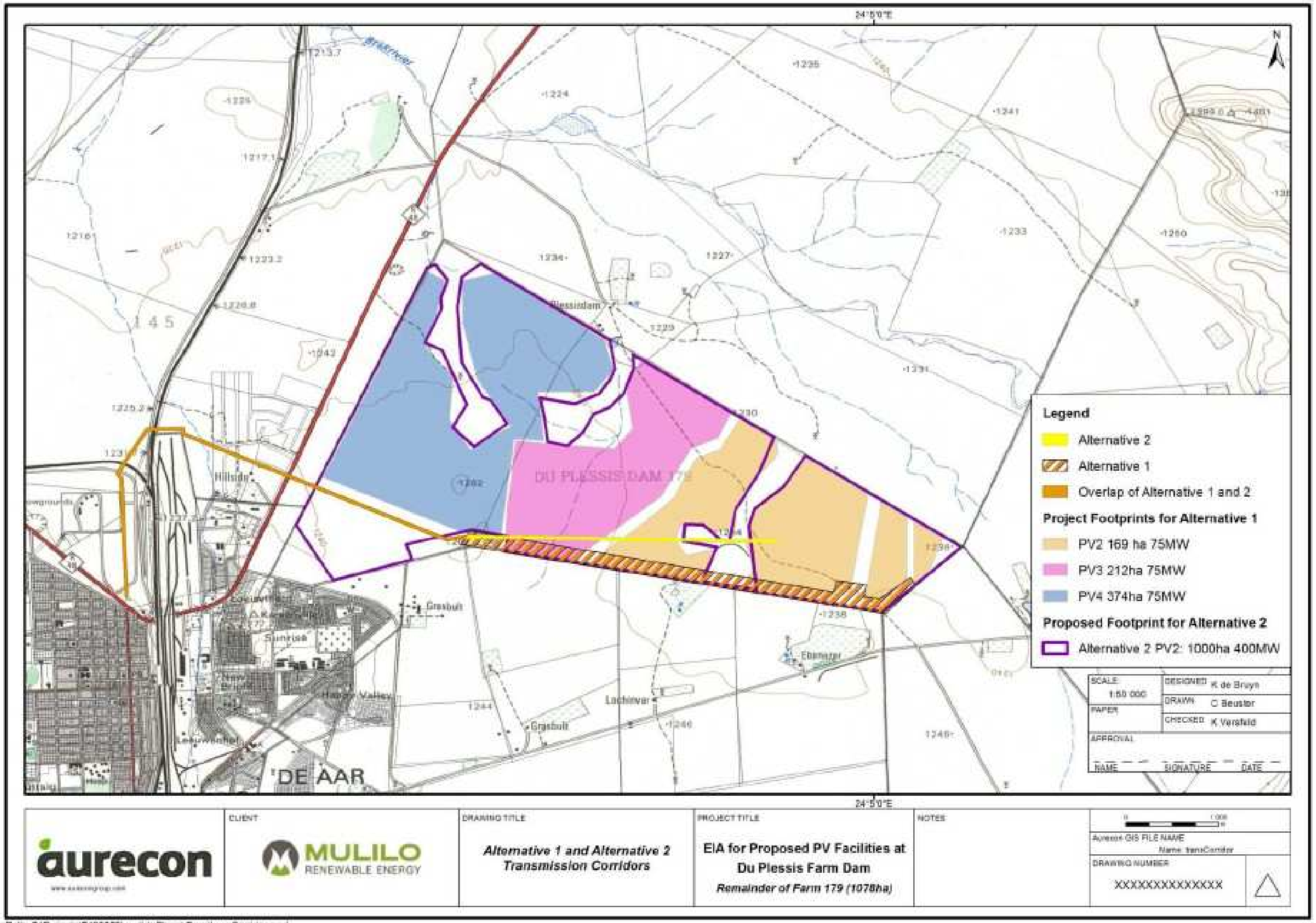


Fig. 3. Map showing alternative layouts for the proposed PV solar energy facilities on Du Plessis Dam 179, to the northeast of De Aar, Northern Cape, as well as alternative options for the transmission line connection to the De Aar main municipal substation (Image abstracted from the Draft Scoping Report of April 2013 produced by Aurecon South Africa (Pty) Ltd).

2.2. Approach used for this specialist palaeontological study

This report provides an assessment of the observed or inferred palaeontological heritage within the De Aar study area, with recommendations for any specialist palaeontological mitigation where this is considered necessary. The report is based on (1) a review of the relevant scientific literature, (2) geological maps, (3) several previous palaeontological heritage assessments for alternative energy developments in the De Aar region (*e.g.* Almond 2010b, 2011, 2012a, 2012b, 2012c); (4) two one-day field assessments of the study area carried out on 12-13 January, 2012 (see Almond 2012a) and again on 1 June, 2013.

Because the level of natural rock exposure within the flat-lying study areas was generally very poor, the far better exposed stratotype section of the main rock units involved (Tierberg and Waterford Formations) on the farm Swartkoppies, some 47 km north-east of De Aar, was also inspected for fossil remains associated with these formations. Data on fossil heritage within the Ecca and Lower Beaufort Groups near De Aar that was collected during the recent field assessment of a wind energy project has also been referred to here (See Almond 2012c).

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 Northern Cape have been compiled by 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-based assessment by a professional palaeontologist is usually warranted.

The focus of the field-based assessment work 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, and 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 scoping 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 scoping studies. All fossil material collected must be properly curated within an approved repository (usually a museum or university collection).

Before fieldwork commenced, a preliminary screening of satellite images and 1: 50 000 maps of the De Aar study area was conducted to identify sites of potentially good bedrock exposure to be examined in the field (See, for example, Fig. 2). The sites included both natural exposures (*e.g.* stream beds, steep escarpment slopes, gullies) as well as artificial exposures such as dams, borrow pits and quarries.

Note that while fossil localities recorded during fieldwork 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 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. Mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) – is usually most effective during the construction phase when fresh fossiliferous bedrock has been exposed by excavations, although pre-construction recording of surface-exposed material may sometimes be more appropriate. 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, Cape Town). 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 & 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 south African 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 South Africa 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 palaeontological field studies in the De Aar region, the main limitations are:

- Very extensive intrusion of the potentially fossiliferous Karoo Supergroup bedrocks by dolerite. Weathered dolerite colluvium (scree) and sheetwash blanket most of the hill slopes in the area, *i.e.* the very regions where fossiliferous bedrocks are usually exposed;
- High levels of bedrock cover by thick alluvial and colluvial soils as well as extensive calcrete hardpans;
- Conflicting views among geologists concerning the stratigraphic subdivision and palaeoenvironmental interpretation of the Ecca – Beaufort transition rocks in the De Aar / Philipstown area.

These limitations were in part addressed through palaeontological surveying of a much larger area beyond the boundaries of the present solar energy facility study area itself (*e.g.* as part of an impact study for a nearby wind energy development; Almond 2012c). Confidence levels in the conclusions presented here are in consequence moderately high.

3. GEOLOGICAL CONTEXT

The geology of the Du Plessis Dam PV study area near De Aar is outlined on the 1: 250 000 geology sheet 3024 Colesberg (Le Roux 1993) (Fig. 4). In this section of the report the geology of the study site is briefly described first, followed by a more detailed, illustrated account of each major rock unit represented here.

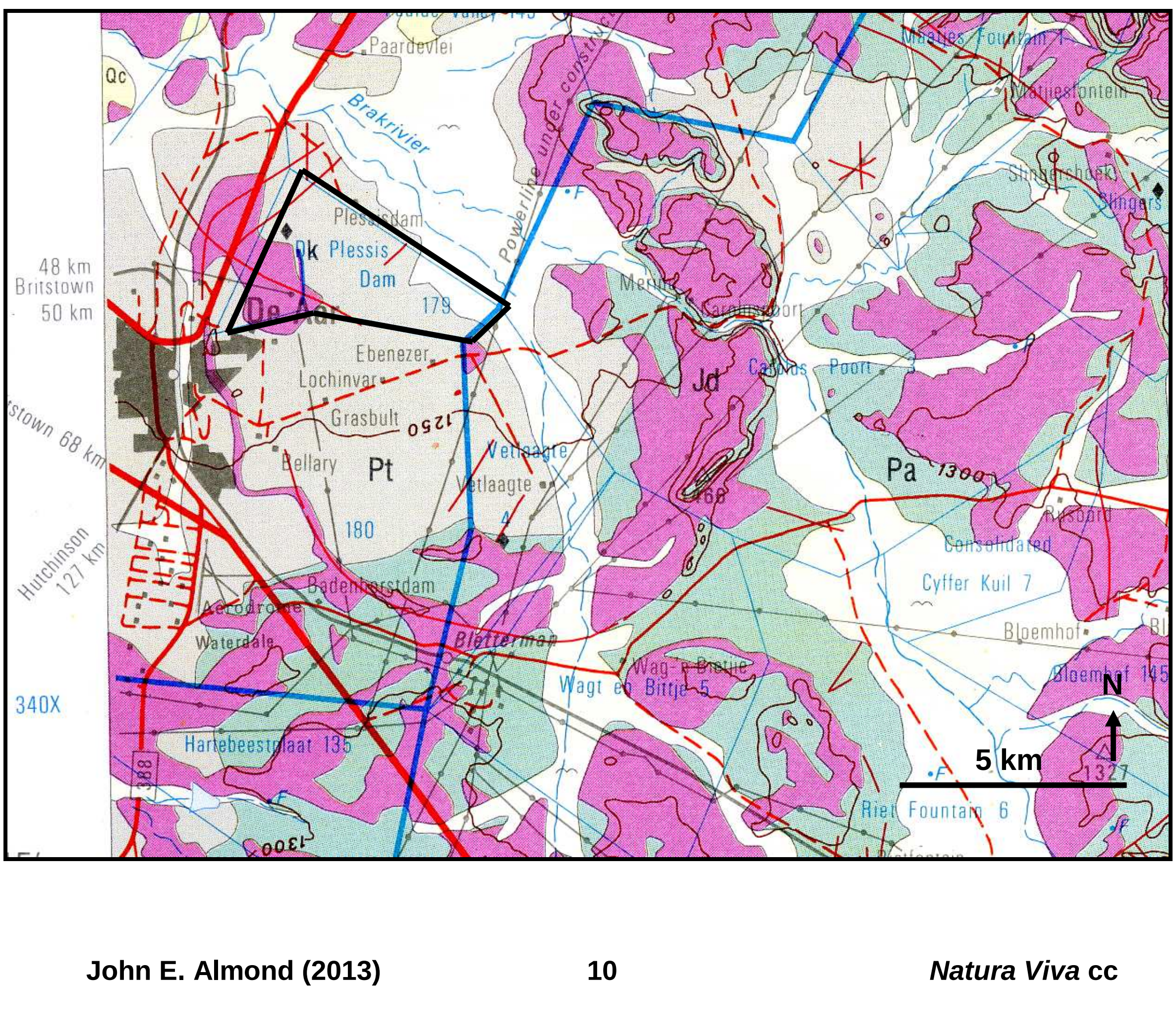


Fig. 4. Geological map of the region east of De Aar, Northern Cape, showing the approximate boundary of the Du Plessis Dam PV solar energy facility study area near De Aar (Abstracted from 1: 250 000 geology sheet 3024 Colesberg, Council for Geoscience, Pretoria).

The following rock units are mapped within or close to the PV study areas:

grey (Pt) = Tierberg / Waterford Formation (Ecca Group)
pale green (Pa) = Adelaide Subgroup (Lower Beaufort Group)
pink (Jd) = intrusive dykes and sills of the Karoo Dolerite Suite
dark yellow (T-Qc) = Neogene to Quaternary calcretes
white = Quaternary to Recent superficial deposits (alluvium, colluvium *etc*)
small black diamond symbol = Kimberlite pipe

The Farm Du Plessis Dam 179 study area is a relatively featureless, flat-lying piece of land on the east side of the De Aar to Philipstown tar road (R48). It is situated at around 1230-1260 m above mean sea level (amsl) between the Brak River drainage system in the northeast and De Aar in the southwest. The area is almost entirely covered with reddish-brown alluvial soils with sparse karroid *bossieveld* vegetation and abundant grass in summer (Fig. 5). Levels of bedrock exposure are very low. There are numerous surface scatters of fine downwasted surface gravels (mainly dolerite, hornfels, quartzite and ferruginous carbonate clasts), frequently reworked by sheetwash processes. Sizeable areas of bare orange-brown soil without surface gravels are common in the eastern sector. Where soils are comparatively thin, as in the south-eastern corner of the property (dotted area in Fig. 2), dark Ecca mudrocks with thin-bedded, pale sandstones and occasional ferruginous limestone concretions are observed.

The study area is largely underlain by mudrocks and sandstones of the upper Ecca Group that are intruded by Jurassic dolerites, especially but not exclusively in the southwest. There is also an isolated kimberlite pipe mapped close to the R48, but as usual this does not have an obvious surface expression. According to the 1: 250 000 geological map the study area is largely underlain by sediments of the **Tierberg Formation** (Ecca Group) (Fig. 4). However, as argued below (Section 3.1), in the author's opinion these rocks rather belong to the **Waterford Formation** at the top of the Ecca Group succession. The great majority of the Ecca and dolerite outcrop area is obscured by superficial sediments of probable Pleistocene to Holocene age, as well as by abundant karroid shrub and grassy vegetation (Fig 5).

Fig. 5. General view of the well-vegetated Du Plessis Dam 179 study area looking towards the east. Note the low relief and negligible bedrock exposure here.

3.1. Upper Ecca Group

The **Tierberg Formation** (**Pt**) (Ecca Group, Karoo Supergroup) is a recessive-weathering, mudrock-dominated succession – predominantly consisting of dark, 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 Lower to Mid Permian in age and were deposited in a range of offshore, quiet water environments below wave base. These include basin plain, distal turbidite fan and distal prodelta settings in ascending order (Viljoen 2005, Almond 2008a). Thin coarsening-upwards cycles occur towards the top of the formation with local evidence of soft-sediment deformation, ripples and common calcareous concretions. A restricted, brackish water environment is reconstructed for the Ecca Basin at this time. Close to the contact with Karoo dolerite intrusions the Tierberg mudrocks are baked to a dark grey hornfels with a reddish-brown crust or patina (Prinsloo 1989).

It should be noted here that the stratigraphic as well as palaeoenvironmental interpretation of the Ecca / Beaufort boundary rocks in the De Aar – Philipstown area is more complex and unresolved than that suggested by the brief treatment in the Britstown sheet explanation by Le Roux (1993). For mapping purposes, the base of the first prominent-weathering sandstone within the Ecca / Beaufort boundary succession has been taken as the base of the Beaufort Group in this region (ibid., p. 4, following Nel 1977). The marine / lacustrine, uppermost Ecca Group rocks here, though mapped as offshore / basinal Tierberg Formation, have in fact many features in common with the shallow shelf, storm-dominated, sandstone-rich facies seen at the top of the Ecca succession in the Carnarvon area to the west. These uppermost Ecca Group rocks were previously assigned to the **Carnarvon Formation** that has since been incorporated into the **Waterford Formation** (*e.g.* Johnson *et al.* 2006). The uppermost Ecca succession here tends to be more sandstone-rich than the overlying Beaufort Group. The "Carnarvon Facies" is characterised by upward-coarsening, yellowish-weathering, sandstone-rich successions containing storm-generated hummocky cross-stratification and wave ripples, large ferruginous carbonate concretions (*koffieklip*), ball-and-pillow load structures, and pervasive low intensity bioturbation by low diversity trace fossil assemblages. The latter have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Siebrits 1987, Prinsloo 1989, Rust *et al.* 1991 and references therein). Petrified wood and other plant remains (*e.g.* leaf compressions) are locally abundant. The inshore shelf (shoreface) Carnarvon facies rocks have a gradational lower contact with the underlying offshore Tierberg mudrocks and are in turn conformably overlain by continental (subaerial), fluvial sediments of the Lower Beaufort Group. For the purpose of the present fossil heritage study, the upper Ecca Group sediments within the study area are assigned to the Waterford Formation, despite their attribution to the Tierberg Formation on the published 1: 250 000 geological map (Fig. 4) and the key SACS publication by Viljoen (2005). It is possible that the Tierberg / Waterford (*i.e.* offshore basin to prodelta) transition is represented in this region.

Good exposures of typical Carnarvon-type facies of the Waterford Formation are seen in several shallow riverine exposures in the De Aar region (*e.g.* Almond 2012a, 2012b, 2012c). They include tabular-bedded, well-jointed sandstones with wave rippled tops, well-developed low angle cross-lamination (hummocky cross-stratification), abundant bioturbation, convolute lamination (dewatering or load structures) and occasional large *koffieklip* ferruginous carbonate concretions. Locally the grey, thin-bedded Ecca mudrocks underlying the sandstones are also exposed in the river banks.

Ecca Group sediments are not at all well exposed in the Du Plessis Dam Farm study area. Here the Karoo Supergroup bedrocks are almost entirely mantled with shallow to deep silty to sandy soils of brownish to orange-brown hues, with rare patches of downwasted surface gravels (sandstone, mudrock, hornfels, quartzite, dolerite) and cream-coloured reworked calcrete. Rare exposures of Ecca rocks attributable to the Waterford Formation include baked, laminated and vuggy buff sandstones showing soft-sediment deformation features and ferruginous carbonate concretions at Locs. 257, 259 and 273. Extensive shallow stream exposures of grey mudrocks and buff sandstones are observed at Loc. 267 (Figs. 7 & 13), while patches of flaggy, brittle (baked) sandstone float blocks were observed at Locs. 268 and 270. Dark grey tabular-bedded mudrocks in the roadside gully section at Loc. 271 (Fig. 6) resemble Tierberg Formation basinal facies (as mapped).

Fig. 6. Roadside gully exposure of thin-bedded, baked, dark-grey mudrocks containing flattened horizontal burrows (Loc. 271).

Fig. 7. Shallow streamside exposure of tabular Ecca Group sandstones and grey mudrocks, Loc. 267 (Hammer = 30 cm).

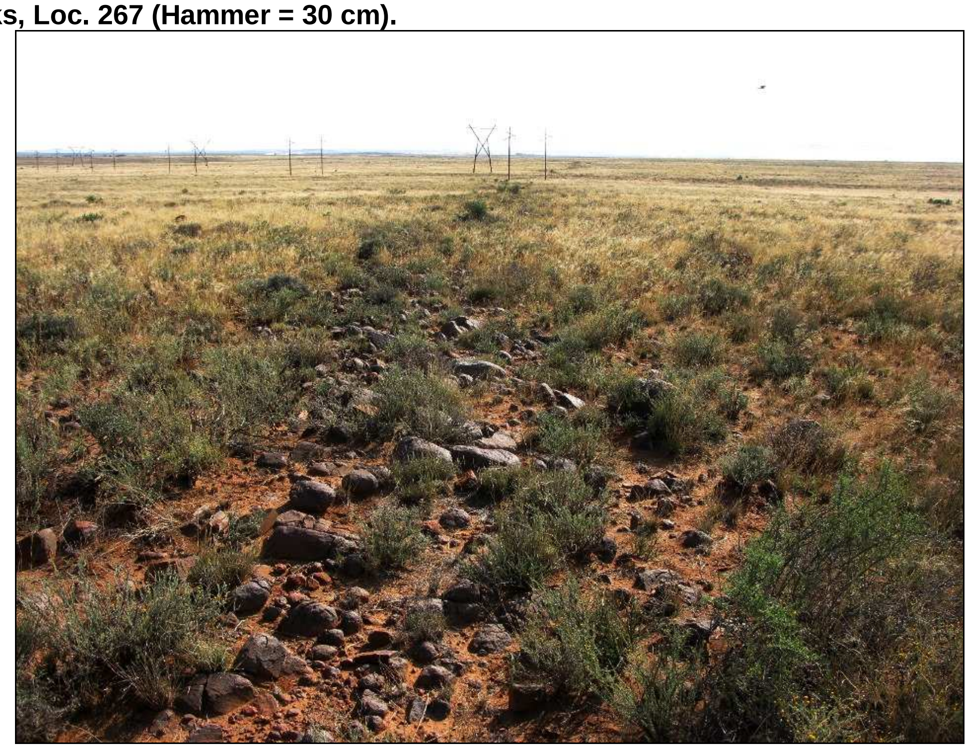


Fig. 8. A linear zone of dolerite boulders at Loc. 263 is the surface expression of a dolerite dyke.

Fig. 9. Concentration of boulder-sized dolerite corestones surrounded by orange-brown ferruginous soils, Loc. 266.

3.2. Karoo Dolerites

The Karoo Dolerite Suite (Jd) is an extensive network of basic igneous bodies (dykes, sills) that were intruded into sediments of the Main Karoo Basin in the Early Jurassic Period, about 183 million years ago (Duncan & Marsh 2006). These dolerites form part of the Karoo Igneous Province of Southern Africa that developed in response to crustal doming and stretching preceding the break-up of Gondwana. Hard cappings of blocky, reddish-brown to rusty-weathering dolerite are a very typical feature of the flat-topped koppies in the Great Karoo region. As seen from geological maps (Fig. 4), extensive dolerite intrusion of both the upper Ecca Group as well as the Lower Beaufort Group rocks is observed in the De Aar region. The country rocks adjacent to the intrusions have often been extensively baked or thermally metamorphosed. Mudrocks are altered to flinty hornfels ("lydianite" of some authors), while sandstones are metamorphosed to resistant-weathering, siliceous quartzites. The Karoo rocks within the thermal aureole of the dolerite intrusions are also often chemically altered; they tend to be silicified, more brittle and contain numerous irregular vugs (cavities) lined or infilled with secondary minerals.

Bouldery ridges and low koppies of well-jointed, masonry-like dolerite, as well as zones of dolerite corestones emerging from the soil, are well seen in western portion of the Du Plessis Dam Farm study area (Figs. 8 & 9). Thick calcrete development overlying deeply-weathered dolerite (corestones, onionskin weathering etc) is seen in several quarries to the south of the Du Plessis Dam study area (Almond 2012b) and may be developed in the subsurface here as well.

3.3. Kimberlite pipes

Numerous **kimberlite pipes** of Jurassic to Cretaceous age intrude the Karoo Supergroup rocks north of Victoria West, including several examples to the east of De Aar. They are variously assigned to the Victoria West and Group II Provinces (Skinner & Truswell 2006) and do not contain diamonds. According to Le Roux (1993) the ultramafic kimberlite pipe rocks in the Colesberg sheet area are highly weathered with no obvious surface expression. They can usually be located only on the basis of characteristic mineral assemblages (garnet, phlogopite mica) found in ant heaps, termite mounds and prospecting holes. The only mapped example within the present study areas comprises one example close to the western edge of Du Plessis Dam Farm (diamond symbol in map Fig. 4). Kimberlite rocks are unfossiliferous, although rich Cretaceous to Paleocene fossil assemblages may be found in associated crater lake facies (not present here).

3.4. Superficial deposits

Quaternary to Recent superficial deposits ("drift") cover all but the steepest slopes of the Karoo *koppies* as well as most of the plains at their feet, including dry river courses such as the Brak River in the broader De Aar study region. Various types of superficial deposits of geologically young, Late Caenozoic (Miocene / Pliocene to Recent) age (< 5 Ma) occur throughout the Great Karoo region (Prinsloo 1989, Le Roux 1993, with more extensive discussion in Holmes & Marker 1995, Cole *et al.* 2004, Partridge *et al*. 2006). They include pedocretes (*e.g.* calcretes), colluvial slope deposits (dolerite, sandstone and hornfels scree *etc*), sandy, gravelly and bouldery river alluvium, as well as spring and pan sediments. These colluvial and alluvial deposits may be extensively calcretised (*i.e.* cemented with soil limestone), especially in the neighbourhood of dolerite intrusions.

Thin (usually < 1 m) horizons of fine to coarse, angular gravels mantle the Palaeozoic and Mesozoc bedrocks over much of the study area. Gravel clasts mostly consist of locally-derived Ecca Group sandstones, mudrocks, hornfels, quartzite, ferruginous carbonate nodule fragments and silicified wood as well as weathered to fresh dolerite, including small to large rounded dolerite corestone boulders. In areas with a well-developed calcrete hardpan the surface gravels are rich in reworked calcrete clasts (Loc. 272) (Fig. 12). Buried gravel lenticles and layers are present at the bedrock / soil interface in many areas, as seen elsewhere in the De Aar area.
Unconsolidated orange-brown to brown surface soils up to several dm thick, locally overlying Ecca bedrocks or a calcrete hardpan, may be of alluvial, sheet wash or even in part aeolian origin (Fig. 13). These superficial soils are probably Holocene in age. They contain, or are locally overlain by, fine to coarse downwasted surface gravels, concentrated by downwasting and sheetwash processes (Figs. 10 to 12).

Fig. 10. Reddish-brown soils with downwasted surface gravels, Du Plessis Dam Farm study area.

Fig. 11. Reworking of finer-grained surface gravels by sheetwash processes, Loc. 260 (Hammer = 30 cm).

Fig. 12. Surface gravels enriched in reworked calcrete together with clasts of rusty-brown patinated hornfels (some flaked) as well as rare cherty fossil wood fragments (arrowed), Loc. 272 (Hammer = 30 cm).

Fig. 13. Shallow stream exposure of Ecca Group sediments mantled by orange-brown silty soils and patchy surface gravels, Loc. 267.

4. PALAEONTOLOGICAL HERITAGE

Fossil biotas recorded from each of the main stratigraphic units mapped in the study area are briefly reviewed in this section. Bedding dips of the Karoo Supergroup sediments in the study region are generally horizontal to very shallow. Low levels of tectonic deformation and cleavage development are expected here, favouring good fossil preservation. However, extensive dolerite intrusion has compromised fossil heritage in the Karoo Supergroup sediments due to resulting thermal metamorphism. In addition, pervasive calcretisation of many near-surface bedrocks has further compromised their original fossil heritage.

4.1. Upper Ecca Group

The fossil record of the **Tierberg Formation** has been reviewed in detail by Almond (2008a). 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 (drifted leaves, petrified wood). The latter become more abundant in the upper, more proximal (prodeltaic) facies of the Tierberg (*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 has 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 2008a). These are mainly bedding parallel, epichnial and hypichnial traces, some preserved as undertracks. Penetrative, steep to subvertical burrows are rare, perhaps because the bottom sediments immediately beneath the sediment / water interface were anoxic. Most Tierberg ichnoassemblages display a low diversity and low to moderate density of traces. Apart from simple back-filled and / or lined horizontal burrows (*Planolites, Palaeophycus*) they include arthropod trackways (*Umfolozia*) and associated resting impressions (*Gluckstadtella*), undulose fish swimming trails (*Undichna*) that may have been generated by bottom-feeding palaeoniscoids, horizontal epichnial furrows (so-called *Scolicia*) often attributed to gastropods (these are also common in the co-eval Collingham Formation; Viljoen 1992, 1994), arcuate, finely striated feeding excavations of an unknown arthropod (*Vadoscavichnia*), beaded traces ("*Hormosiroidea*" or "*Neonereites*"), small sinusoidal surface traces (*Cochlichnus*), small star-shaped feeding burrows (*Stelloglyphus*) and zigzag horizontal burrows (*Beloraphe*), as well as possible narrow (< 1cm) *Cruziana* scratch burrows. The symmetrical, four-pronged trace *Broomichnium* (= *Quadrispinichna* of Anderson, 1974 and later authors) often occurs in groups of identical size (*c*. 3.5 cm 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.

As discussed previously (Section 3.1) it is considered likely that the majority of the Ecca Group rocks in the study area belong to the **Waterford Formation** rather than the Tierberg Formation as mapped. Rare fragments of poorly-preserved tetrapod bone are recorded in channel lags within the upper Waterford Formation in the Williston sheet area (Viljoen 1989) and the southern Great Karoo. These probably belong to aquatic temnospondyl amphibians ("labyrinthodonts") but large fish and terrestrial therapsids might also be represented. Scattered palaeoniscoid fish scales and fish coprolites are common in the Waterford Formation, and several genera of non-marine bivalves have been described from the southern Karoo (Bender *et al*. 1991, Cooper & Kensley 1984).

Upper delta platform facies of the Waterford Formation (including the Koedoesberg Formation of earlier authors) contain abundant, low diversity trace assemblages of the *Scoyenia* ichnofacies. They are dominated by the rope-like, horizontal and oblique burrows of the ichnogenus *Scoyenia* that has been attributed to small arthropods (possibly insects) and / or earthworms. These tubular, meniscate back-filled scratch burrows characterise intermittently moist, firm substrates such as channel and pond margins on the upper delta platform (Smith & Almond 1998, Buatois & Mángano 2004, 2007). Good examples, often associated with wave-rippled surfaces, are recorded from Waterford thin-bedded sandstones and siltstones in the Roggeveld Escarpment zone by Wickens (1984, 1996) and Viljoen (1989). Offshore delta platform facies of the Waterford Formation have very impoverished, poorly-preserved ichnofaunas due to rapid sedimentation rates with abundant soft-sediment deformation and perhaps also to fluctuating salinities.

Petrified wood and other plant material of the *Glossopteris* Flora (*e.g. Glossopteris, Phyllotheca*) is also common in the Waterford Formation (Theron 1983, Anderson & Anderson 1985, Viljoen 1989, Wickens 1984, 1996, Rubidge *et al*. 2000). Leaves and stems of arthrophytes (horsetails) such as *Schizoneura* have been observed in vertical life position. Substantial fossil logs (so-called "*Dadoxylon*") showing clearly developed seasonal growth rings are mostly permineralised with silica but partially or completely calcified material is also known (Viljoen 1989). At least two different genera of gymnospermous woods, *Prototaxoxylon* and *Australoxylon,* have been identified so far (Bamford 1999, 2004).

The storm-dominated shelf sediments of the Carnarvon-type facies of the Waterford Formation, as seen near De Aar, are typically associated with pervasive low intensity bioturbation by low diversity trace fossil assemblages. The latter have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Rust *et al.* 1991 and references therein). Good examples of these traces are illustrated by Siebrits (1987), Prinsloo (1989) and Rust *et al.* (1991). Prominent trace fossil taxa include cm-sized horizontal to oblique burrows with striated walls (*cf Palaeophycus striatus*) and vertical spreiten burrows of the ichnogenus *Teichichnus*. Possible arthropod feeding traces of the ichnogenera *Rusophycus* and *Cruziana* are also reported here. Petrified wood ("*Dadoxylon*") showing well-developed seasonal growth lines and other plant remains (*e.g.* leaf compressions) are locally abundant.

Low diversity ichoassemblages dominated by *Teichichnus*, *Palaeophycus striatus* and unidentified horizontal burrows were recorded from the tops of wave-rippled Ecca sandstones exposed in the De Aar area (Almond 2012b, 2012c). Assemblages of small- to medium-sized traces, including *Cruziana*, "*Plagiogmus*" – type strap burrows, *Teichichnus* and various other horizontal burrows, were recorded from *in situ* Ecca sandstones as well as sandstone float blocks at Locs. 262, 267, 268 and 270 (Figs. 15 to 17). Tierberg-like dark grey flaggy mudrocks at Loc. 271 also contain numerous narrow strap-shaped horizontal burrows (possibly "*Plagiogmus*") (Fig. 14).

Sheetwash and other surface gravels at the Du Plessis Dam Farm study area consistently contain small cherty fragments of silicified woods from the underlying Ecca Group bedrocks (*e.g.* Locs. 260, 272) (Figs. 12 & 19). Larger petrified wood samples also occur within subsurface gravels overlying Ecca bedrocks where these are exposed at surface, for example at Loc. 273 (Fig. 18). The woods typically show well-developed seasonal growth rings and preservation of original the original woody microstructure appears to be good; this should facilitate identification and possible dating of the samples. No other Ecca Group body fossils were observed within the study area. Reworked clasts of cherty silicified wood can be widely expected within downwasted surface or near-surface gravels, and are of widespread occurrence and locally common in the De Aar area (Almond 2012a, 2012b, 2012c).

Fig. 14. Dark grey, baked Tierberg-like Ecca mudrocks containing abundant flattened horizontal burrows up to 1 cm across, Loc. 271 (Scale in cm and mm).

Fig. 15. Greyish-buff Ecca sandstone with large flat burrow referred to the ichnogenus *Plagiogmus*, Loc. 267 (Scale in cm).

Fig. 16. Ecca sandstone float block showing sparse, low-diversity trace fossil assemblages (including small-scale *Cruziana*) on the sole surface, Loc. 262 (Scale in cm).

Fig. 17. Narrow endichnial burrow within an Ecca sandstone float block, Loc. 262 (Scale in cm and mm).

Fig. 18. Locally abundant fragments of silicified fossil wood reworked from the Ecca Group in the south-eastern corner of the Du Plessis Dam Farm study area, Loc. 273 (See dotted area on satellite image, Fig. 2)(Scale in cm).

Fig. 19. Close-up of silicified wood fragment showing detailed preservation of annual growth rings and radial arrays of xylem vessels, Loc. 272. Specimen is *c*. 3.5 cm long.

4.2. Karoo Dolerite Suite

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

4.3. Quaternary to Recent superficial deposits

The central Karoo drift deposits have been comparatively neglected in palaeontological terms. However, they may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals as well as remains of reptiles like tortoises. Good examples are the Pleistocene mammal faunas at Florisbad, Cornelia and Erfkroon in the Free State and elsewhere (Wells & Cooke 1942, Cooke 1974, Skead 1980, Klein 1984, Brink, J.S. 1987, Bousman *et al.* 1988, Bender & Brink 1992, Brink *et al*. 1995, MacRae 1999, Meadows & Watkeys 1999, Churchill *et al*. 2000 Partridge & Scott 2000, Brink & Rossouw 2000, Rossouw 2006). Other late Caenozoic fossil biotas from these superficial deposits include non-marine molluscs (bivalves, gastropods), ostrich egg shells, tortoise remains, trace fossils (*e.g.* calcretised termitaria, coprolites), and plant material such as peats or palynomorphs (pollens) in organic-rich alluvial horizons (Scott 2000) and diatoms in pan sediments. In Quaternary deposits, fossil remains may be associated with human artefacts such as stone tools and are also of archaeological interest (*e.g.* Smith 1999 and refs. therein). Ancient solution hollows within extensive calcrete hardpans such as seen here 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.

Assemblages of possible calcretized rhizoliths (solid plant root casts) up to 5 cm across as well as hollow subhorizontal root moulds and / or invertebrate burrows are exposed below the calcrete hardpan in a quarry near the N10 to the southeast of De Aar (Almond 2012a). Identifiable stone artefacts (*e.g.* MSA), useful for dating purposes, have been observed embedded within subsurface gravel horizons elsewhere in the De Aar region (*e.g.* Almond 2012c). As already mentioned in Section 4.1, reworked clasts of resistant-weathering, cherty fossil wood are locally common both in subsurface gravels as well as sheetwash gravels at the soil surface (Figs. 12, 18 & 19). No other trace or body fossils were observed within the Late Caenozoic superficial deposits of Du Plessis Dam Farm study area.

Table 4.1: Palaeontological record and sensitivity of rocks units represented in the De Aar region

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Superficial deposits (“drift”)	**Alluvium, colluvium (scree), pan sediments, surface gravels, calcrete hardpans *etc* NEOGENE / QUATERNARY TO RECENT**	**Sparse remains of mammals (bones, teeth), reptiles, ostrich egg shells, molluscs shells, trace fossils (calcretized termitaria, rhizoliths), plant remains, palynomorphs, diatoms; reworked Karoo-age silicified wood clasts and stone artefacts in surface or subsurface gravels**	**LOW**	**Any substantial fossil finds to be reported by ECO to SAHRA**
Kimberlite pipes (diamond symbol)	**Ultramafic kimberlite CRETACEOUS**	**None within pipe itself**	**ZERO**	**None**
Karoo Dolerite Suite (Jd)	**Intrusive dolerite sills & dykes EARLY JURASSIC**	**NONE**	**ZERO**	**None**
Adelaide Subgroup (Pa) BEAUFORT GROUP	**Floodplain mudrocks with lenticular channel sandstones, tabular crevasse splay sandstones, minor playa lake sediments LATE MIDDLE PERMIAN**	**Important but low diversity terrestrial vertebrate fauna (esp. therapsids) of *Pristerognathus* Assemblage Zone, petrified wood, plant remains (incl. fossil wood, leaf & stem impressions), freshwater molluscs, trace fossils (trackways, burrows, coprolites)**	**HIGH**	**Any substantial fossil finds to be reported by ECO to SAHRA**
Tierberg and Waterford Formations (Pt) ECCA GROUP	**Dark basinal, prodelta and submarine fan mudrocks with minor sandstones (Tierberg Fm) OR Storm-influenced coastal sandstones and mudrocks (Carnarvon facies of Waterford Fm) EARLY TO MIDDLE PERMIAN**	**Locally abundant trace fossils, petrified wood, plant debris, microvertebrates**	**MEDIUM**	**Any substantial fossil finds to be reported by ECO to SAHRA**

5. ASSESSMENT OF SIGNIFICANCE OF PALAEONTOLOGICAL HERITAGE IMPACTS

In this section of the report potential impacts on fossil heritage within each of the three proposed PV solar energy facility study sites on Du Plessis Dam Farm are assessed, followed by an assessment of the cumulative impacts in a local and regional context. The impact significance of the various alternative solar energy facility proposals for Du Plessis Dam Farm is then briefly addressed. Please note that the operational and decommissioning phases of the solar energy facilities will not involve further significant adverse or other impacts on palaeontological heritage.

5.1. Assessment of individual PV facilities and proposed mitigation

The inferred impact on local fossil heritage of each of the four proposed PV solar energy facility developments, - PV2 to PV4 of Alternative 1 (preferred layout) as well as the Alternative 2 layout - is analysed for the construction phase in Table 5.1 below according to the system developed by Aurecon. Given the very similar terrain and underlying geology represented within all four sites, their impact ratings are identical.

The construction phase of the proposed PV solar energy facilities will not entail very substantial (*i.e.* deep and voluminous) excavations into the superficial sediment cover (soils, surface gravels *etc*). In most cases the underlying bedrocks will not be directly impacted. Shallow excavations, including surface clearance, will be required in the case of solar panel emplacements, underground cables, new internal access roads, onsite transmission line pylons, pipelines, stormwater infrastructure, septic tanks and foundations for associated infrastructure such as on-site substations and the workshop / administration building. In addition, sizeable areas may be sealed-in or sterilized by infrastructure such as lay down areas and access roads. However, all these developments may adversely affect potential fossil heritage exposed at the ground surface or preserved below the surface within the study area by damaging, 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 PV solar energy facilities will not 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*). Most of the sedimentary formations represented within the study area 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 (soil, alluvium, colluvium *etc*) in addition to (2) the high level of weathering, calcretisation and (in some cases) baking of the bedrocks, the magnitude of these impacts is conservatively rated as *very low*.

No areas or sites of exceptional fossil heritage sensitivity or significance are identified within the Du Plessis Dam Farm study area. The fossil remains identified in this study (*viz.* low diversity trace fossil assemblages within Ecca sandstones and mudrocks, *plus* sparse, reworked silicified wood fragments within surface gravels) are of widespread occurrence within the rock units concerned (*i.e.* not unique to the study area).

There are no fatal flaws in the Du Plessis Dam Farm development proposal as far as fossil heritage is concerned. Extensive, deep bedrock excavations are not envisaged during the construction phase. Due to the general scarcity of fossil remains within the bedrocks and superficial deposits represented here, the high levels of bedrock weathering, the comparatively small development footprints, as well as the extensive superficial sediment cover observed within and close to the study area, the overall impact significance of the construction phase of all the proposed PV solar energy facilities, with or without mitigation, is assessed as LOW with regard to palaeontological heritage resources.

It should be noted that should 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 here, the overall impact significance of the project 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.

Because of the generally very low levels of bedrock exposure within the study area, and the potential on Du Plessis Dam Farm for unrecorded buried fossiliferous deposits, such as petrified wood or rare amphibian remains, confidence levels for this palaeontological heritage assessment following a two-day field assessment of representative rock exposures are only moderate (*unsure*).

Given the low impact significance of the proposed PV solar energy facilities 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 significant new fossil remains during development.

During the construction phase all substantial bedrock excavations should be monitored for fossil remains by the responsible ECO. Should significant fossil remains such as vertebrate bones and teeth, shells, plant-rich fossil lenses, sizeable petrified wood specimens or dense fossil burrow assemblages be exposed during construction, the responsible Environmental Control Officer should safeguard these, preferably *in situ*, and alert 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 Plan (EMP) for the Du Plessis Farm Dam PV solar energy facility developments.

Provided that the recommended mitigation measures are carried through, it is likely that any potentially negative impacts of the proposed solar energy facilities 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 (NHRA) 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).

5.2. Assessment of cumulative impacts

In this section the cumulative impact of the proposed PV facilties on Du Plessis Dam Farm is assessed in the context of other alternative energy projects planned or proposed for the De Aar study region.

A number of wind and solar energy projects have been proposed for the De Aar region, in addition to the Mulilo PV solar plants proposed for Du Plessis Dam Farm (See map Fig. 20 and also proposed Mulilo windfarm development on the Eastern Plateau assessed by Almond 2012c). Potential impacts on palaeontological heritage resources for several of these other projects have been assessed by the author on the basis of desktop as well as field studies (*e.g.* Almond 2010b, 2011, 2012a, 2012b, 2012c). The geology of the bedrocks as well as of the superficial deposits throughout the De Aar region is very similar as far as palaeontology is concerned and in all cases the impact significance of the proposed alternative energy developments was assessed as LOW.

The cumulative impacts of the proposed new PV solar energy facilities in terms of both local (< 10 km radius) as well as regional (> 10 km radius) fossil heritage resources is likewise assessed as LOW (Table 5.2) because of:

- The low palaeontological sensitivity of the relevant bedrocks (Ecca Group, Karoo dolerite) throughout the De Aar region;
- Weathering, calcretisation and local baking of the near-surface bedrocks, further decreasing their palaeontological sensitivity;
- The very sparse occurrence of fossils within the extensive mantle of superficial sediments (soils, gravels, calcretes *etc*) in the De Aar region; and
- The limited amount of substantial (deep, voluminous) bedrock excavations envisaged and comparatively small development footprints in the case of the solar energy facility projects in particular.

Table 5.1: Evaluation of impacts on local fossil heritage resources of proposed photovoltaic solar energy facilities on farm Du Plessis Farm Dam near De Aar – PV2, PV3 and PV4 of Alternative 1 (preferred layout) and Alternative 2 layout.

Project	Key impacts	No mitigation / Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
PV2	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	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.
PV3	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	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.
PV4	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	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.

Alternative 2	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	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.
No-go Option	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Zero	Long term	Neutral	Probable	Sure	n/a	n/a
		Mitigation	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 5.2: Evaluation of cumulative impacts on local fossil heritage resources of the proposed photovoltaic energy plants on Du Plessis Dam Farm near De Aar

	Key impacts	No mitigation /Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
Du Plessis Farm Dam	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	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.
Local extent	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	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.
	Key impacts	No mitigation /Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
Regional extent	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial

	Key impacts	No mitigation /Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
										bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.

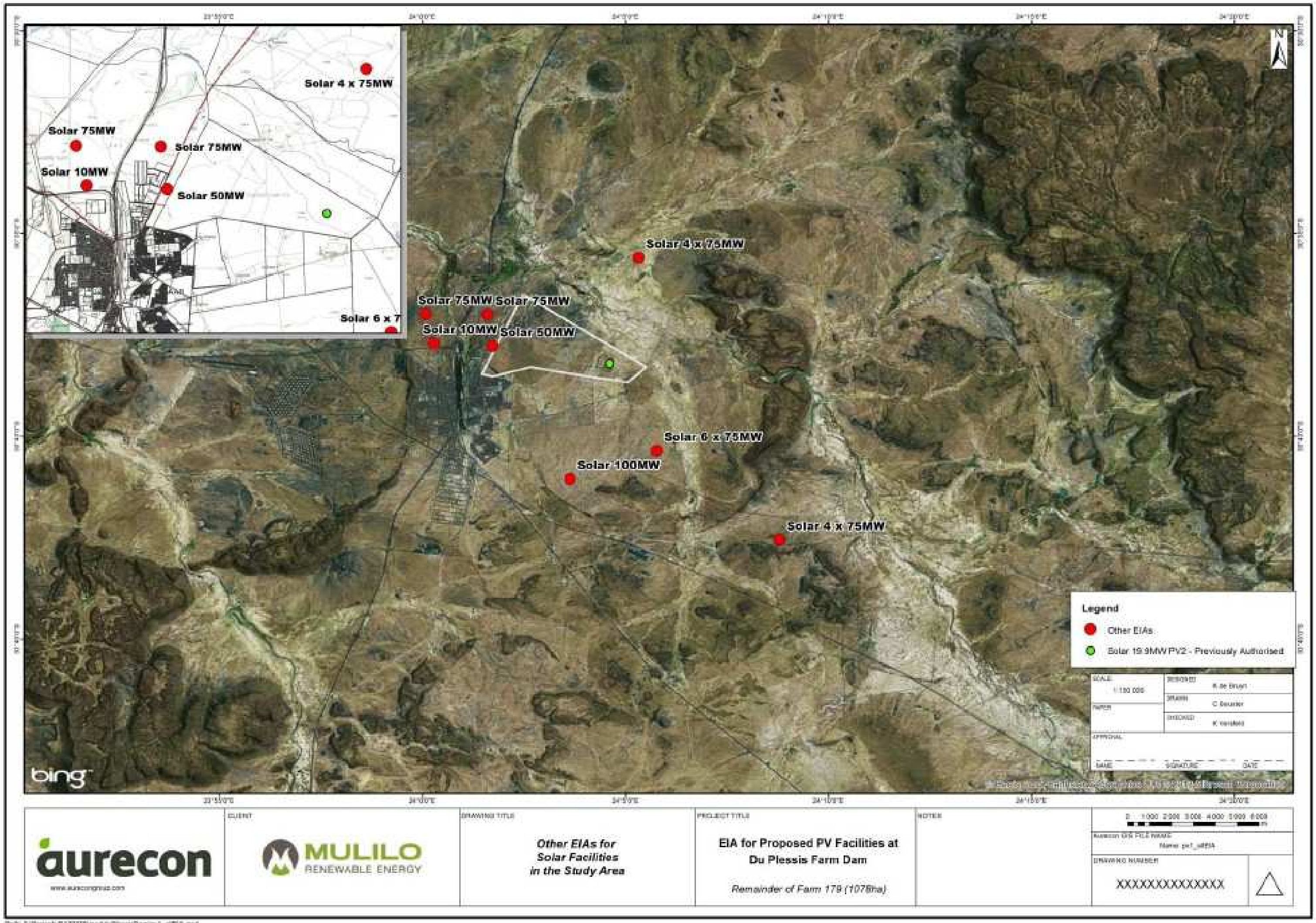


Fig. 20. Solar energy developments currently planned or proposed for the De Aar region, Northern Cape (Image abstracted by the Draft Scoping Report by Aurecon South Africa (Pty) Ltd, April 2013).

5.3. Assessment of project alternatives for Du Plessis Dam Farm

A range of project alternatives have been considered at the EIA stage for the Du Plessis Dam Farm PV solar energy facility project, as summarized in the following table (See also map Fig. 3):

Table 5.3: Project alternatives for the proposed Du Plessis Dam Farm solar energy facility development

Alternative Type	Description
Location alternatives	**One location for the proposed Du Plessis Dam Farm (Remainder of Farm 179)**
Activity alternatives	• **Solar energy generation *via* a PV plant** • **"No-go" alternative to solar energy production**
Site layout alternatives	• **Three 75 MW AC PV facilities (Layout Alternative 1)** • **One 400 MW PV facility (Layout Alternative 2)**
Technology alternatives	• **Solar panels: Conventional PV *vs.* CPV technology** • **Mounting: Single Axis *vs.* Fixed Axis PV tracking technology**
Transmission line routing	• **Two alternative transmission line corridors**

The "no go" alternative to the proposed solar plant developments would have a neutral (zero magnitude) impact significance on fossil heritage resources.

The Layout Alternative 2, comprising a single 400 MW PV facility developed by extending and combining the proposed 75 MW facilities on Du Plessis Dam Farm (Fig. 3) would have a similar, low impact significance on fossil heritage resources to that of the preferred Layout Alternative 1 (three PV sites) that is considered in more detail above.

There is no preference on palaeontological heritage grounds for conventional PV *versus* CPV technology. Likewise there is unlikely to be any significant difference in impact significance between single axis *versus* fixed axis tracking technology.

The three proposed onsite substations will be connected by overhead transmission lines to the De Aar substation. Two alternative transmission line corridors, overlapping over a distance of 5 km, are under consideration, as shown in Fig. 3. Alternative 1 is *c*. 10 km long (31 – 160 m wide) while Alternative 2 is *c*. 8 km long (31 m wide).The geology underlying both transmission line corridors is very similar to the Du Plessis Farm Dam study area and has a comparable low palaeontological sensitivity. The impact significance of both alternatives is accordingly assessed as low.

6. CONCLUSIONS & RECOMMENDATIONS

The potentially fossiliferous sediments of the Ecca Group (Karoo Supergroup) that underlie the Du Plessis Dam Farm study area are almost entirely mantled in a thick layer of superficial deposits of probable Pleistocene to Recent age. The upper Ecca Group bedrocks in the De Aar area contain sparse to locally common petrified wood as well as low diversity trace fossil assemblages typical of the Waterford Formation, rather than the Tierberg Formation as mapped. Based on field assessment their palaeontological sensitivity is rated as low. The Ecca bedrocks are extensively intruded and baked by the Karoo Dolerite Suite. These Early Jurassic igneous rocks are unfossiliferous. The diverse superficial deposits in the study region, including various soils, gravels and – at least in some areas - a well-developed calcrete hardpan, are also of low palaeontological sensitivity as a whole. Calcretized rhizoliths (root casts) and possible invertebrate burrows of probable Quaternary age were observed during field studies just to the south of the Du Plessis Dam Farm. Well-preserved but small fragments of reworked Permian silicified fossil wood are recorded widely from subsurface and surface gravels overlying Ecca bedrock in the study area.

Potential impacts on fossil heritage of the proposed solar facility developments are confined to the development footprint and are only anticipated during the construction phase. As far as fossil heritage is concerned, their impact significance is considered to be LOW for the following reasons:

- The Karoo Supergroup bedrocks here are deeply weathered, locally calcretised and baked, and for the most part only sparsely fossiliferous;
- The development footprints for proposed PV solar energy facility sites are small and largely underlain by superficial deposits of low palaeontological sensitivity;
- Significant fossil material (*e.g.* fossil wood, vertebrate remains) at or near surface level is most likely only very sparsely distributed within the study area; and
- Extensive, deep bedrock excavations are not envisaged during the construction phase.

There is no preference on fossil heritage grounds for the preferred *versus* alternative layouts or technologies for the Du Plessis Dam solar energy facility developments. The "no go" alternative to the proposed solar plant developments would have a neutral (zero magnitude) impact significance on fossil heritage resources. Alternative transmission line connections to De Aar Substation would both be of very low impact significance. There is no preference on palaeontological heritage grounds for conventional PV *versus* CPV technology. Likewise there is unlikely to be any significant difference in impact significance between single axis *versus* fixed axis tracking technology.

A substantial number of other alternative energy projects – including both wind energy and solar energy facilities – have been proposed for the De Aar area (*cf* 2010b, 2011, 2012a, 2012b, 2012c). Given the generally low palaeontological sensitivity of the Karoo Supergroup bedrocks and Pleistocene to Recent superficial sediments in the De Aar region as a whole, the cumulative impact of these developments is not considered to be of high significance, however.

It is recommended that:

- The ECO responsible for the development should be aware of the possibility of important fossils (*e.g.* petrified wood, mammalian bones, teeth) being present or unearthed on site and should monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;
- In the case of any significant fossil finds (*e.g.* fossil wood, vertebrate teeth, bones, burrows, petrified wood) during construction, these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to 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) so that any appropriate mitigation (*i.e.* fossil recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer's expense; and

- These recommendations should be incorporated into the EMP for the Du Plessis Dam Farm solar energy facilities.

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).

7. ACKNOWLEDGEMENTS

Mrs Karen van der Westhuizen and Ms Karen Versfeld of Aurecon, Cape Town, are both thanked for commissioning this study and for kindly providing the necessary background information.

8. REFERENCES

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

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

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

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

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

ALMOND, J.E. 2010a. Eskom Gamma-Omega 765kV transmission line: Phase 2 palaeontological impact assessment. Sector 1, Tanqua Karoo to Omega Substation (Western and Northern Cape Provinces), 95 pp + appendix. Natura Viva cc, Cape Town.

ALMOND, J.E. 2010b. Proposed photovoltaic power generation facility at De Aar, Northern Cape Province. Palaeontological impact assessment: desktop study, 17 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2011. Proposed Mainstream Solar Park at De Aar, Northern Cape Province. Desktop study, 17 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2012a. Proposed Mulilo Renewable Energy PV2, PV3 and PV4 photovoltaic energy facilities on Farms Paarde Valley, Badenhorst Dam and Annex Du Plessis Dam near De Aar, Northern Cape Province. Palaeontological specialist study: combined desktop and field-based assessments, 45 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2012b. Proposed solar power generation facilities on the remaining extent of the farm Vetlaagte No. 4, De Aar, Northern Cape Province. Palaeontological specialist study: combined desktop and field-based assessments, 33 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2012c. Two wind energy facilities on the Eastern Plateau near De Aar, Northern Cape Province proposed by Mulilo Renewable Energy (Pty) Ltd. Palaeontological specialist study: combined desktop and field-based assessments, 55 pp. Natura Viva cc, Cape Town.

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

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

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

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

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

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

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

BENDER, P.A. 2004. Late Permian actinopterygian (palaeoniscid) fishes from the Beaufort Group, South Africa: biostratigraphic and biogeographic implications. Bulletin 135, 84pp. Council for Geoscience, Pretoria.
BENDER, P.A., RUBIDGE, B.S., GARDINER, B.S., LOOCK. J.C. & BREMNER, A.T. 1991. The stratigraphic range of the palaeoniscoid fish Namaichthys digitata in rocks of the Karoo sequence and its palaeoenvironmental significance. South African Journal of Science 87: 468-469.
BENDER, P.A. & BRINK, J.S. 1992. A preliminary report on new large mammal fossil finds from the Cornelia-Uitzoek site. South African Journal of Science 88: 512-515.
BENTON, M.J. 2003. When life nearly died. The greatest mass extinction of them all, 336 pp. Thames & Hudson, London.
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.
BAMFORD, M. 1999. Permo-Triassic fossil woods from the South African Karoo Basin. Palaeontologia africana 35, 25-40.
BAMFORD, M.K. 2004. Diversity of woody vegetation of Gondwanan southern Africa. Gondwana Research 7, 153-164.
BRADDY, S.J. & BRIGGS, D.E.G. 2002. New Lower Permian nonmarine arthropod trace fossils from New Mexico and South Africa. Journal of Paleontology 76: 546-557.
BRINK, J.S. 1987. The archaeozoology of Florisbad, Orange Free State. Memoirs van die Nasionale Museum 24, 151 pp.
BRINK, J.S. *et al*. 1995. A new find of *Megalotragus priscus* (Alcephalini, Bovidae) from the Central Karoo, South Africa. Palaeontologia africana 32: 17-22.
BRINK, J.S. & ROSSOUW, L. 2000. New trial excavations at the Cornelia-Uitzoek type locality. Navorsinge van die Nasionale Museum Bloemfontein 16, 141-156.
BUATOIS, L. & MANGANO, M.G. 2004. Animal-substrate interactions in freshwater environments: applications of ichnology in facies and sequence stratigraphic analysis of fluvio-lacustrine successions. In: McIlroy, D. (Ed.) The application of ichnology to palaeoenvironmental and stratigraphic analysis. Geological Society, London, Special Publications 228, pp 311-333.
BUATOIS, L.A. & MÁNGANO, M.G. 2007. Invertebrate ichnology of continental freshwater environments. In: Miller, W. III (Ed.) Trace fossils: concepts, problems, prospects, pp. 285-323. Elsevier, Amsterdam.
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.
COLE, D.I., SMITH, R.M.H. & WICKENS, H. DE V. 1990. Basin-plain to fluvio-lacustrine deposits in the Permian Ecca and Lower Beaufort Groups of the Karoo Sequence. Guidebook Geocongress '90, Geological Society of South Africa, PO2, 1-83.
COLE, D.I. & VORSTER, C.J. 1999. The metallogeny of the Sutherland area, 41 pp. Council for Geoscience, Pretoria.
COLE, D.I., NEVELING, J., HATTINGH, J., CHEVALLIER, L.P., REDDERING, J.S.V. & BENDER, P.A. 2004. The geology of the Middelburg area. Explanation to 1: 250 000 geology Sheet 3124 Middelburg, 44 pp. Council for Geoscience, Pretoria.
COLE, D. & SMITH, R. 2008. Fluvial architecture of the Late Permian Beaufort Group deposits, S.W. Karoo Basin: point bars, crevasse splays, palaeosols, vertebrate fossils and uranium. Field Excursion FT02 guidebook, AAPG International Conference, Cape Town October 2008, 110 pp.
COOKE, H.B.S. 1974. The fossil mammals of Cornelia, O.F.S., South Africa. In: Butzer, K.W., Clark, J.D. & Cooke, H.B.S. (Eds.) The geology, archaeology and fossil mammals of the Cornelia Beds, O.F.S. Memoirs of the National Museum, Bloemfontein 9: 63-84.
COOPER, M.R. & KENSLEY, B. 1984. Endemic South American Permian bivalve molluscs from the Ecca of South Africa. Journal of Paleontology 58: 1360-1363.
DE BEER, C.H., GRESSE, P.G., THERON, J.N. & ALMOND, J.E. 2002. The geology of the Calvinia area. Explanation to 1: 250 000 geology Sheet 3118 Calvinia. 92 pp. Council for Geoscience, Pretoria.
COLE, D.I., NEVELING, J., HATTINGH, J., CHEVALLIER, L.P., REDDERING, J.S.V. & BENDER, P.A. 2004. The geology of the Middelburg area. Explanation to 1: 250 000 geological sheet 3124 Middelburg, 43 pp. Council for Geoscience, Pretoria.
DUNCAN, A.R. & MARSH, J.S. 2006. The Karoo Igneous Province. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 501-520. Geological Society of South Africa, Marshalltown.
HOLMES, P.J. & MARKER, M.E. 1995. Evidence for environmental change from Holocene valley fills from three central Karoo upland sites. South African Journal of Science 91: 617-620.
JOHNSON, M.R. & KEYSER, A.W. 1979. Die geologie van die gebied Beaufort-Wes. Explanation of geological Sheet 3222, 14 pp. Council for Geoscience, Pretoria.
JOHNSON, M.R., VAN VUUREN, C.J., VISSER, J.N.J., COLE, D.I., De V. WICKENS, H., CHRISTIE, A.D.M., ROBERTS, D.L. & BRANDL, G. 2006. Sedimentary rocks of the Karoo Supergroup. In: Johnson,

M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 461-499. Geological Society of South Africa, Marshalltown.
KEYSER, A.W. & SMITH, R.M.H. 1977-78. Vertebrate biozonation of the Beaufort Group with special reference to the Western Karoo Basin. Annals of the Geological Survey of South Africa 12: 1-36.
KITCHING, J.W. 1977. The distribution of the Karroo vertebrate fauna, with special reference to certain genera and the bearing of this distribution on the zoning of the Beaufort beds. Memoirs of the Bernard Price Institute for Palaeontological Research, University of the Witwatersrand, No. 1, 133 pp (incl. 15 pls).
KLEIN, R.G. 1984. The large mammals of southern Africa: Late Pliocene to Recent. In: Klein, R.G. (Ed.) Southern African prehistory and paleoenvironments, pp 107-146. Balkema, Rotterdam.
LE ROUX, F.G. 1993. Die geologie van die gebied Colesberg. Explanation to 1: 250 000 geology Sheet 3024, 12 pp. Council for Geoscience, Pretoria.
LE ROUX, F.G. & KEYSER, A.W. 1988. Die geologie van die gebied Victoria-Wes. Explanation to 1: 250 000 geology Sheet 3122, 31 pp. Council for Geoscience, Pretoria.
LUCAS, D.G. 2009. Global Middle Permian reptile mass extinction: the dinocephalian extinction event. Geological Society of America Abstracts with Programs 41, No. 7, p. 360.
MACRAE, C. 1999. Life etched in stone. Fossils of South Africa, 305 pp. The Geological Society of South Africa, Johannesburg.
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.
NEL, L. 1977. Die geologie van die gebied suid van Hopetown. Unpublished PhD thesis, University of the Free State, 171 pp.
NICOLAS, M.V. 2007. Tetrapod diversity through the Permo-Triassic Beaufort Group (Karoo Supergroup) of South Africa. Unpublished PhD thesis, University of Witwatersrand, Johannesburg.
NICOLAS, M. & RUBIDGE, B.S. 2010. Changes in Permo-Triassic terrestrial tetrapod ecological representation in the Beaufort Group (Karoo Supergroup) of South Africa. Lethaia 43, 45-59.
PARTRIDGE, T.C. & SCOTT, L. 2000. Lakes and pans. In: Partridge, T.C. & Maud, R.R. (Eds.) The Cenozoic of southern Africa, pp.145-161. Oxford University Press, Oxford.
PARTRIDGE, T.C., BOTHA, G.A. & HADDON, I.G. 2006. Cenozoic deposits of the interior. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 585-604. Geological Society of South Africa, Marshalltown.
PRINSLOO, M.C. 1989. Die geologie van die gebied Britstown. Explanation to 1: 250 000 geology Sheet 3022 Britstown, 40 pp. Council for Geoscience, Pretoria.
RETALLACK, G.J., METZGER, C.A., GREAVER, T., HOPE JAHREN, A., SMITH, R.M.H. & SHELDON, N.D. 2006. Middle – Late Permian mass extinction on land. GSA Bulletin 118, 1398-1411.

RUBIDGE, B.S. (Ed.) 1995. Biostratigraphy of the Beaufort Group (Karoo Supergroup). South African Committee for Biostratigraphy, Biostratigraphic Series No. 1., 46 pp. Council for Geoscience, Pretoria.
RUBIDGE, B.S. 2005. Re-uniting lost continents – fossil reptiles from the ancient Karoo and their wanderlust. 27th Du Toit Memorial Lecture. South African Journal of Geology 108, 135-172.
RUBIDGE, B.S., HANCOX, P.J. & CATUNEANU, O. 2000. Sequence analysis of the Ecca-Beaufort contact in the southern Karoo of South Africa. South African Journal of Geology 103, 81-96.
RUBIDGE, B.S., ERWIN, D.H., RAMEZANI, J., BOWRING, S.A. & DE KLERK, W.J. 2010. The first radiometric dates for the Beaufort Group, Karoo Supergroup of South Africa. Proceedings of the 16th conference of the Palaeontological Society of Southern Africa, Howick, August 5-8, 2010, pp. 82-83.
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.
RUST, I.C., SHONE, R.W. & SIEBRITS, L.B. 1991. Carnarvon Formasie: golf-oorheesde sedimentasie in 'n vlak Karoosee. South African Journal of Science 87, 198-202.
RYAN, P.J. 1967. Stratigraphic and palaeocurrent analysis of the Ecca Series and lowermost Beaufort Beds in the Karoo Basin of South Africa. Unpublished PhD thesis, University of the Witwatersrand, Johannesburg, 210 pp.
SCOTT, L. 2000. Pollen. In: Partridge, T.C. & Maud, R.R. (Eds.) The Cenozoic of southern Africa, pp.339-35. Oxford University Press, Oxford.
SEILACHER, A. 2007. Trace fossil analysis, xiii + 226pp. Springer Verlag, Berlin.
SIEBRITS, L.B. 1987. Die sedimentology van die Formasie Carnarvon in die omgewing van Carnarvon. Unpublished MSc thesis, University of Port Elizabeth, v + 92 pp.
SIEBRITS, L.B. 1989. Die geologie van die gebied Sakrivier. Explanation of 1: 250 000 geology sheet 3020, 19 pp. Council for Geoscience, Pretoria.
SKEAD, C.J. 1980. Historical mammal incidence in the Cape Province. Volume 1: The Western and Northern Cape. 903pp. Department of Nature and Environmental Conservation, Cape Town.
SKINNER, E.M.W. & TRUSWELL, J.F. 2006. Kimberlites. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 651-659. Geological Society of South Africa, Marshalltown.

SMITH, A.M. & ZAWADA, P.K. 1988. The Ecca-Beaufort transition zone near Philipstown, Cape Province: a marine shelf sequence. South African Journal of Geology 91, 75-82.

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

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

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

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

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

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

STEAR, W.M. 1978. Sedimentary structures related to fluctuating hydrodynamic conditions in flood plain deposits of the Beaufort Group near Beaufort West, Cape. Transactions of the Geological Society of South Africa 81, 393-399.

THERON, J.N. 1983. Die geologie van die gebied Sutherland. Explanation of 1: 250 000 geological Sheet 3220, 29 pp. Council for Geoscience, Pretoria.

VAN DER WALT M., DAY M., RUBIDGE B., COOPER A.K. & NETTERBERG I. 2010. A new GIS-based biozone map of the Beaufort Group (Karoo Supergroup), South Africa. Palaeontologia Africana, 45, 5pp.

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

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

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

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

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

VISSER, J.N.J. & LOOCK, J.C. 1974. The nature of the Ecca-Beaufort transition in the western and central Orange Free State. Transactions of the Geological Society of South Africa 77, 371-372.

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

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

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

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

WICKENS, H. DE V. 1992. Submarine fans of the Permian Ecca Group in the SW Karoo Basin, their origin and reflection on the tectonic evolution of the basin and its source areas. In: De Wit, M.J. & Ransome, I.G.D. (Eds.) Inversion tectonics of the Cape Fold Belt, Karoo and Cretaceous Basins of southern Africa, pp. 117-126. Balkema, Rotterdam.

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

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

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

APPENDIX: GPS LOCALITY DATA FOR SITES LISTED IN TEXT

All GPS readings were taken in the field using a hand-held Garmin GPSmap 60CSx instrument. The datum used is WGS 84.Only those localities mentioned in the text are listed here.

Du Plessis Dam Farm 1 June 2013

Nr	South	East	Comments
257	S30 37 05.9	E24 03 31.6	Baked Ecca sandstones showing soft sediment deformation, diagenetic nodules
258	S30 37 14.1	E24 03 36.7	Dolerite intrusion, hornfels country rocks
259	S30 37 48.0	E24 04 00.4	Ecca sediments with large ferruginous carbonate concretions
260	S30 38 06.3	E24 03 38.0	Fine sheetwash gravels with silicified wood
261	S30 37 51.2	E24 02 52.4	Dolerite dyke, bouldery surface
262	S30 37 51.2	E24 02 52.4	Ecca sandstones with trace fossils
263	S30 38 18.8	E24 02 30.9	Dolerite dyke, bouldery surface
264	S30 38 18.5	E24 02 30.9	Ditto
265	S30 38 19.5	E24 02 27.3	Low rocky dolerite exposure, corestones
266	S30 38 17.5	E24 02 04.7	Ditto
267	S30 37 40.7	E24 03 00.6	Shallow stream exposure of Ecca sediments, low diversity trace fossil assemblages
268	S30 37 32.4	E24 03 00.0	Float blocks of Ecca sandstones, trace fossils
269	S30 37 19.2	E24 02 59.3	Low rocky dolerite exposure, baked country rocks
270	S30 37 19.4	E24 02 42.7	Float blocks of Ecca sandstones, trace fossils
271	S30 37 05.3	E24 03 15.8	Dark Tierberg-like basinal mudrocks, horizontal burrows
272	S30 38 05.9	E24 04 13.3	Polymict surface gravels, well-preserved silicified wood, ferruginous carbonate concretions
273	S30 38 38.3	E24 04 59.3	Larger fragments of silicified wood in surface gravels, bioturbated Ecca sediments, ferruginous concretions