PALAEONTOLOGICAL SPECIALIST STUDY: COMBINED DESKTOP AND FIELD-BASED ASSESSMENTS

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

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1. SUMMARY

Mulilo Renewable Energy (Pty) Ltd is proposing to construct a series of three photovoltaic solar power generation facilities with a total combined capacity of 275 MC on the outskirts of De Aar, Northern Cape Province: De Aar PV2 (Farm Paarde Valley), PV3 (Farm Badenhorst Dam) and PV4 (Farm Annex Du Plessis).

The potentially fossiliferous sediments of the Late Palaeozoic Karoo Supergroup (Ecca and Beaufort Groups) that underlie the three study areas are almost entirely mantled in a thick layer of superficial deposits of probable Pleistocene to Recent age. These include various soils, gravels and – at least in some areas - a very well-developed calcrete hardpan. The upper Ecca Group bedrocks in the De Aar area contain locally abundant fossil wood (of palaeontological interest for dating and palaeoenvironmental studies), as well as low diversity trace fossil assemblages typical of the Waterford Formation, rather than the Tierberg Formation as mapped.

No fossils were observed within the Lower Beaufort Group rocks that are only exposed in the southern portion of the PV3 study area. Trace fossils, silicified wood and rare vertebrate remains (therapsids) of the Middle Permian *Pristerognathus* Assemblage Zone have recently been recorded from this succession in the De Aar area. Extensive dolerite sills and dykes of the Early Jurassic Karoo Dolerite Suite are entirely unfossiliferous, as are rare intrusive kimberlite pipe rocks of Cretaceous age.

The diverse superficial deposits within the three study areas (*e.g.* soils, gravels, alluvium, calcrete hardpans) as a whole are of low palaeontological sensitivity. Calcretized rhizoliths (root casts) of probable Quaternary age were observed during field studies. Reworked fossil wood material of Ecca provenance was also recorded and probably occurs widely within subsurface and surface gravels within all three study areas.

Fossils exposed at the surface or underground may be damaged, disturbed or sealed-in during the construction phase of the three proposed solar energy facilities near De Aar. However these developments are all inferred to be of LOW overall significance in terms of palaeontological heritage resource conservation because:

- The potentially fossiliferous Karoo Supergroup rocks within the development footprints (solar panel arrays, transmission lines, roads and other infrastructure) are generally buried beneath a thick mantle of fossil-poor superficial sediments (soils, gravels, calcretes);

- The Karoo Supergroup rocks are extensively disrupted by near-surface secondary calcrete formation. In many cases they have suffered baking during dolerite magma intrusion, further compromising their fossil heritage;

- The solar energy facilities each have a small footprint while extensive, deep bedrock excavations are not envisaged for this sort of alternative energy development.

The two alternative layouts for each of the three proposed PV solar energy facility near De Aar are of equivalent, low impact significance in fossil heritage terms. The construction of new access roads and transmission lines in this region are likewise considered to be of low significance as far as fossil heritage is concerned.

Given the low overall palaeontological sensitivity of the region around De Aar, and the widespread occurrence elsewhere in the Great Karoo of the fossils so far recorded there, the successive or concurrent development of all three PV sites near De Aar that have been proposed by Mulilo Renewable Energy (Pty) Ltd does not pose a significant cumulative impact on local fossil heritage.

In view of the overall low significance of the proposed development on palaeontological heritage resources, it is concluded that no further palaeontological heritage studies or specialist mitigation are required for these three PV projects, pending the exposure of any substantial fossil remains (*e.g.* vertebrate bones and teeth, large blocks of petrified wood) during the construction phase. The ECO responsible for these developments should be alerted to the possibility of fossil remains being found on the surface or exposed by fresh excavations during construction. Should substantial fossil remains be discovered during construction, these should be safeguarded (preferably *in situ*) and the ECO should alert SAHRA so that appropriate mitigation (*e.g.* recording, sampling or collection) can be taken by a professional palaeontologist.

The specialist involved would require a collection permit from SAHRA. Fossil material must be curated in an approved repository (*e.g.* museum or university collection) and all fieldwork and reports should meet the minimum standards for palaeontological impact studies developed by SAHRA.

These recommendations should be incorporated into the EMP for the three PV developments.

2. INTRODUCTION & BRIEF

The company Mulilo Renewable Energy (Pty) Ltd is proposing to construct a series of three photovoltaic solar power generation facilities, De Aar PV2, PV3 and PV4, with a total combined capacity of 275 MC on the outskirts of De Aar, Northern Cape Province (Figs. 1 & 2, Table 1). Two alternative sites for each project are being considered; these are shown in Fig. 2. The solar power developments will also entail construction of new transmission lines from the solar power facility to the De Aar main municipal substation / Hydra substation as well as the upgrading and construction of short sections of gravel road. The type of solar panel used as well as their mountings have yet to be decided.

The present combined desktop and field-based assessment report concerns the PV2 project on Paarde Valley Farm 145 just north of De Aar, the PV3 project on Badenhorst Dam Farm (De Aar 180 on 1: 50 000 map 3024CA De Aar) on the south-eastern outskirts of De Aar, and the PV4 project on farm Du Plessis Dam 179 to the northeast of town. The capacity and footprints of the preferred as well as the alternative layouts of the three solar energy facilities are shown in Table 1.

This study forms part of the comprehensive EIA process for the PV2 and PV3 developments as well as a Basic Assessment process for the PV4 development that are being co-ordinated by Aurecon South Africa (Pty) Ltd, George. In accordance with the National Heritage Resources Act, 1999, a palaeontological heritage assessment is required as part of a Heritage Impact Assessment for these projects since their development footprints overlie potentially fossiliferous Palaeozoic rocks of the Karoo Supergroup (Ecca and Beaufort Groups). 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
- palaeontological objects and material, meteorites and rare geological specimens

Table 1: Summary of the three solar energy facilities near De Aar proposed by Mulilo Renewable Energy (Pty) Ltd (Table kindly provided by Aurecon, George).

Site (name)	Megawatts (MW)	Layout alternatives (MW)	Footprint (ha)	NEMA Process	Short name
Paarde Valley Farm 30º37’11.55”S 23º59’57.90”E	75	75	225	EIA	**De Aar PV2**
Badenhorst Dam Farm 30º40”36.29”S 24º03”19.49”E	75	75	225	EIA	**De Aar PV3**
Annex Du Plessis Dam Farm 30º37’48.77”S 24º03’43.32”E	19	19	64	BA	**De Aar PV4**

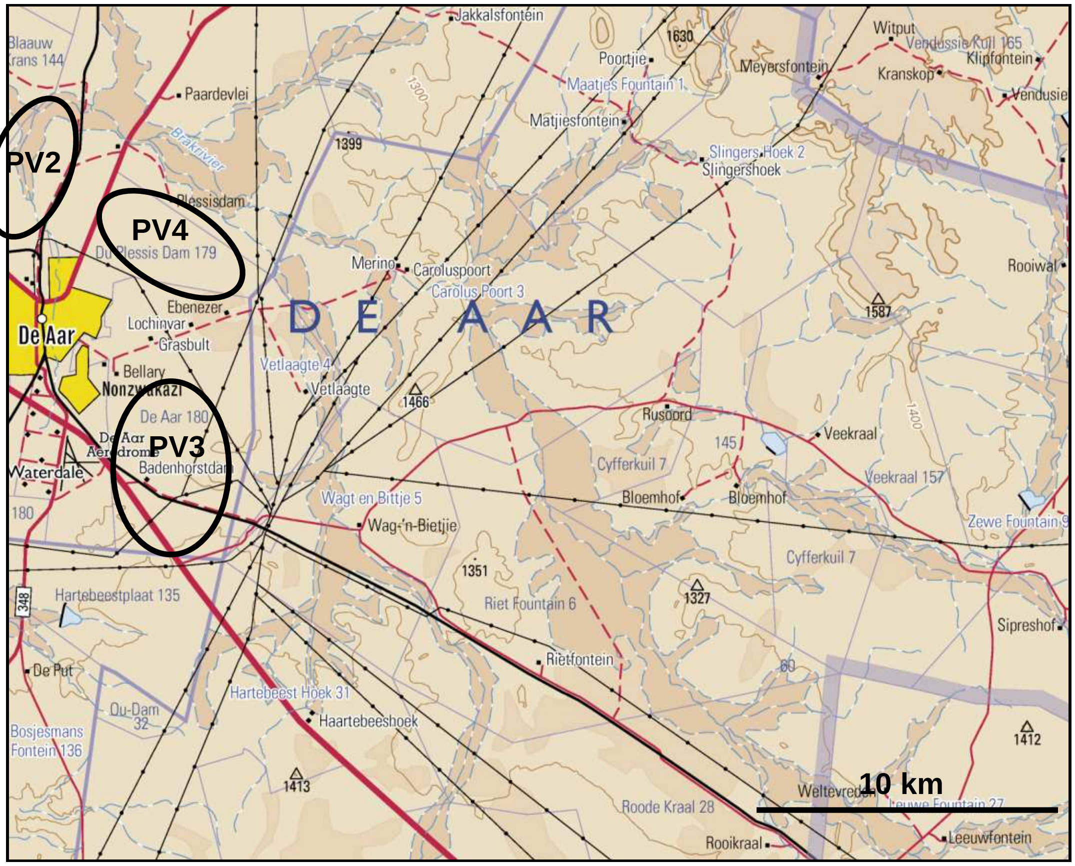

Fig. 1. Extract from 1: 250 000 topographical sheet 3024 Colesberg showing the approximate location the three solar energy facilities on the outskirts of De Aar (PV2, PV3, PV4) that have been proposed by Mulilo Renewable Energy (Pty) Ltd (See also Fig. 2).

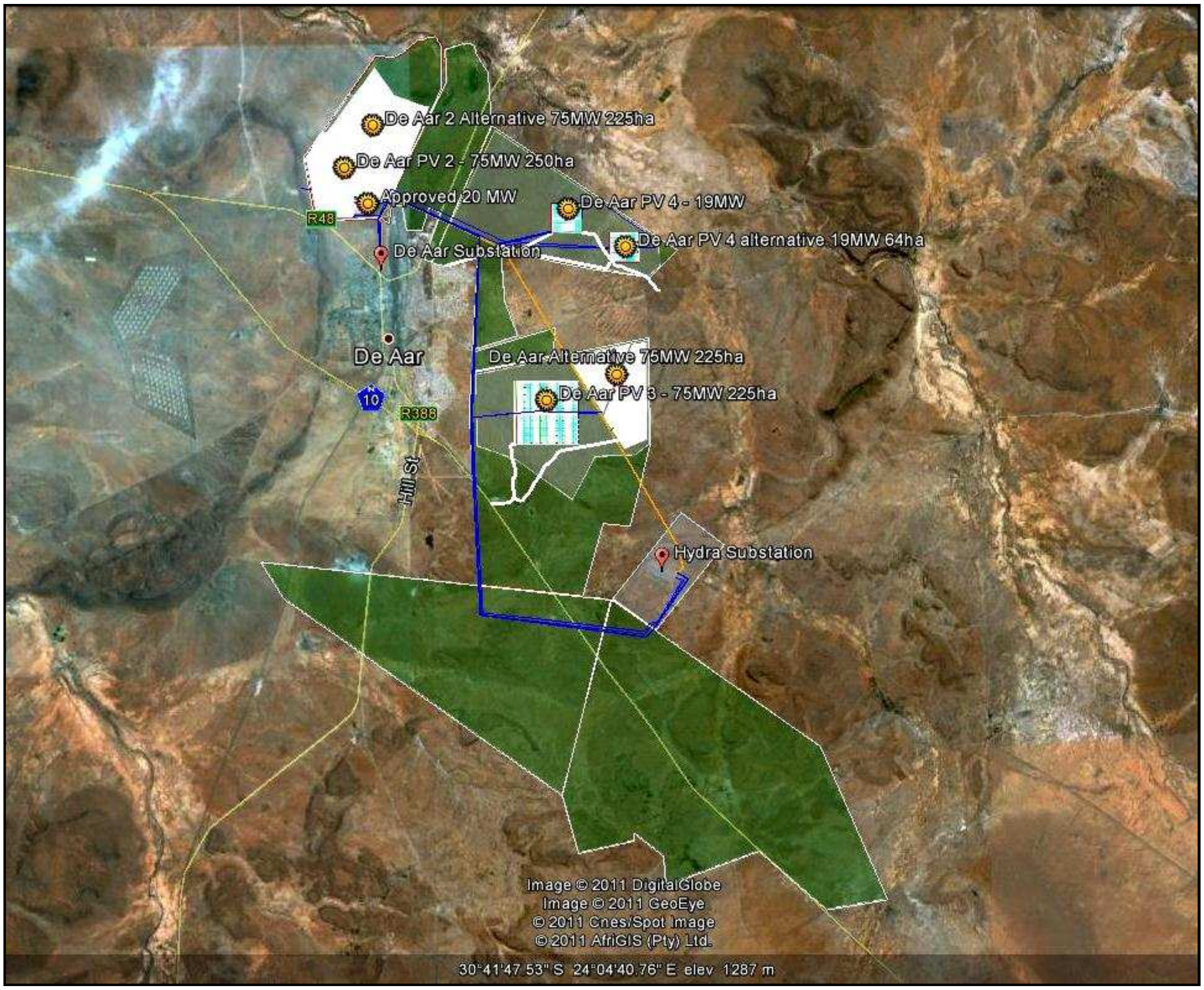

Fig. 2. Google Earth satellite image of the area east of De Aar, Northern Cape, showing location of the three separate photovoltaic solar energy facilities proposed by Mulilio Renewable Energy (Pty) Ltd, PV2, PV3 and PV4, with alternative sites and transmission line routes (blue) also indicated.

2.1. Approach used for this specialist palaeontological study

This palaeontological report provides an assessment of the observed or inferred palaeontological heritage within the study three areas, with recommendations for specialist palaeontological mitigation where this is considered necessary. The report is based on (1) a review of the relevant scientific literature, including recent palaeontological assessments for development projects in the De Aar region by the author and others; (2) published geological maps and accompanying sheet explanations, and (3) palaeontological field assessments carried out on 12 - 13 January 2012. 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 this rock unit. Data on fossil heritage within the Lower Beaufort Group near De Aar that was collected during the recent field assessment of a wind energy project has also been referred to here.

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps. The known fossil heritage within each rock unit is inventoried from the published scientific literature, previous palaeontological impact studies in the same region, and the author's field experience (Consultation with professional colleagues as well as examination of institutional fossil collections may play a role here, or later following scoping during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development (Provisional tabulations of palaeontological sensitivity of all formations in the Western, Eastern and Northern Cape have already been compiled by J. Almond and colleagues; *e.g.* Almond & Pether 2008). The likely impact of the proposed development on local fossil heritage is then determined on the basis of (1) the palaeontological sensitivity of the rock units concerned and (2) the nature and scale of the development itself, most notably the extent of fresh bedrock excavation envisaged. When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a field-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).

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. 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.

2.2. Assumptions & limitations

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

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

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

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

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

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

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

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

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

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

In the case of 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). Confidence levels in the conclusions presented here are in consequence moderately high.

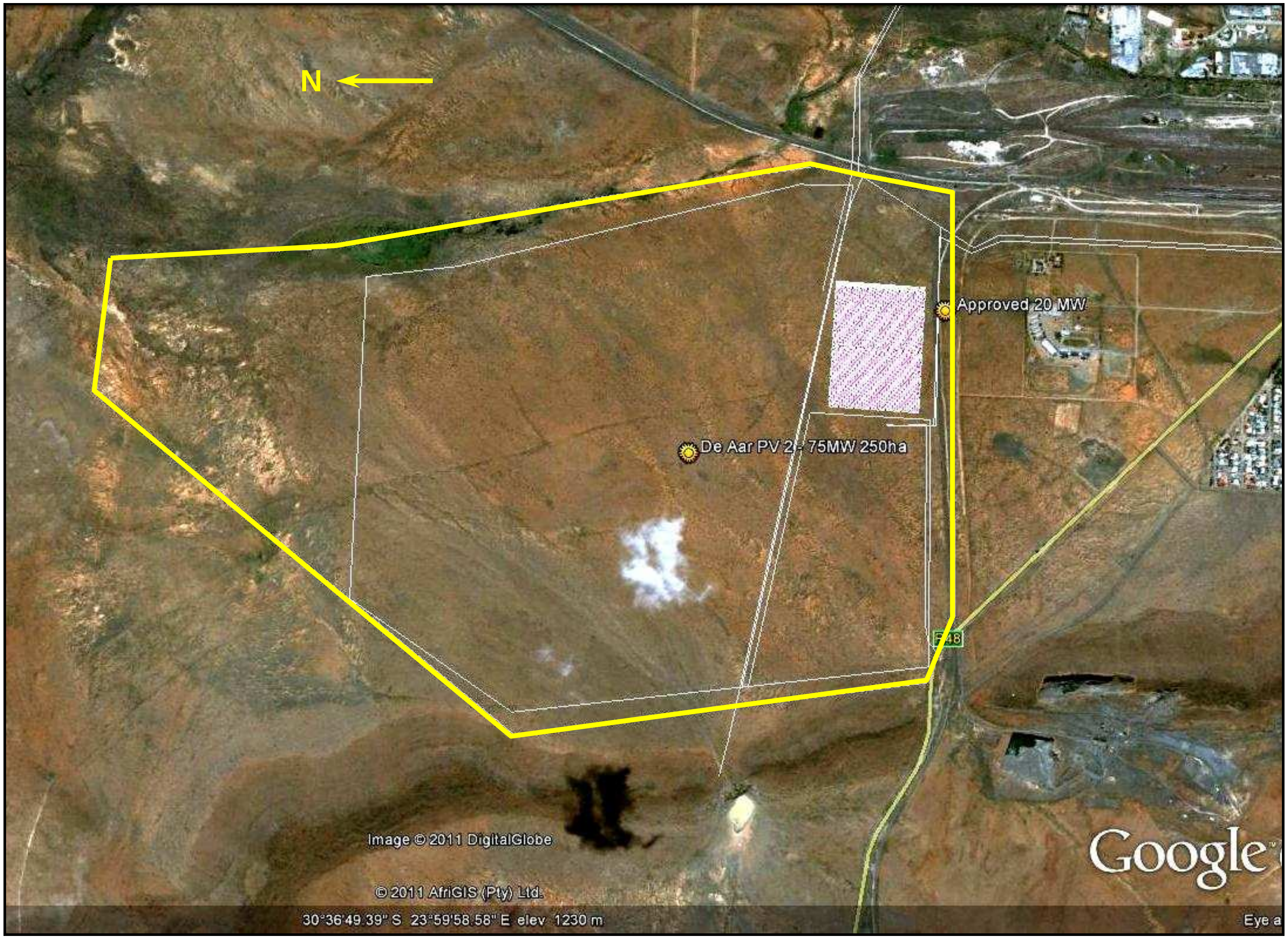

Fig. 3. Google Earth© satellite image of the PV2 study area to the north of De Aar (Paarde Valley Farm 145, yellow polygon). The pale brown *vlaktes* are underlain by Ecca Group mudrocks but almost entirely mantled by superficial deposits (pale brown soil, alluvium). Ecca Group bedrocks are exposed in the shallow stream bed along the eastern margin of the study area (a tributary of the Brakrivier drainage system). Note also the prominent dolerite dyke (rusty brown rocky ridge) running along the western edge of the study area.

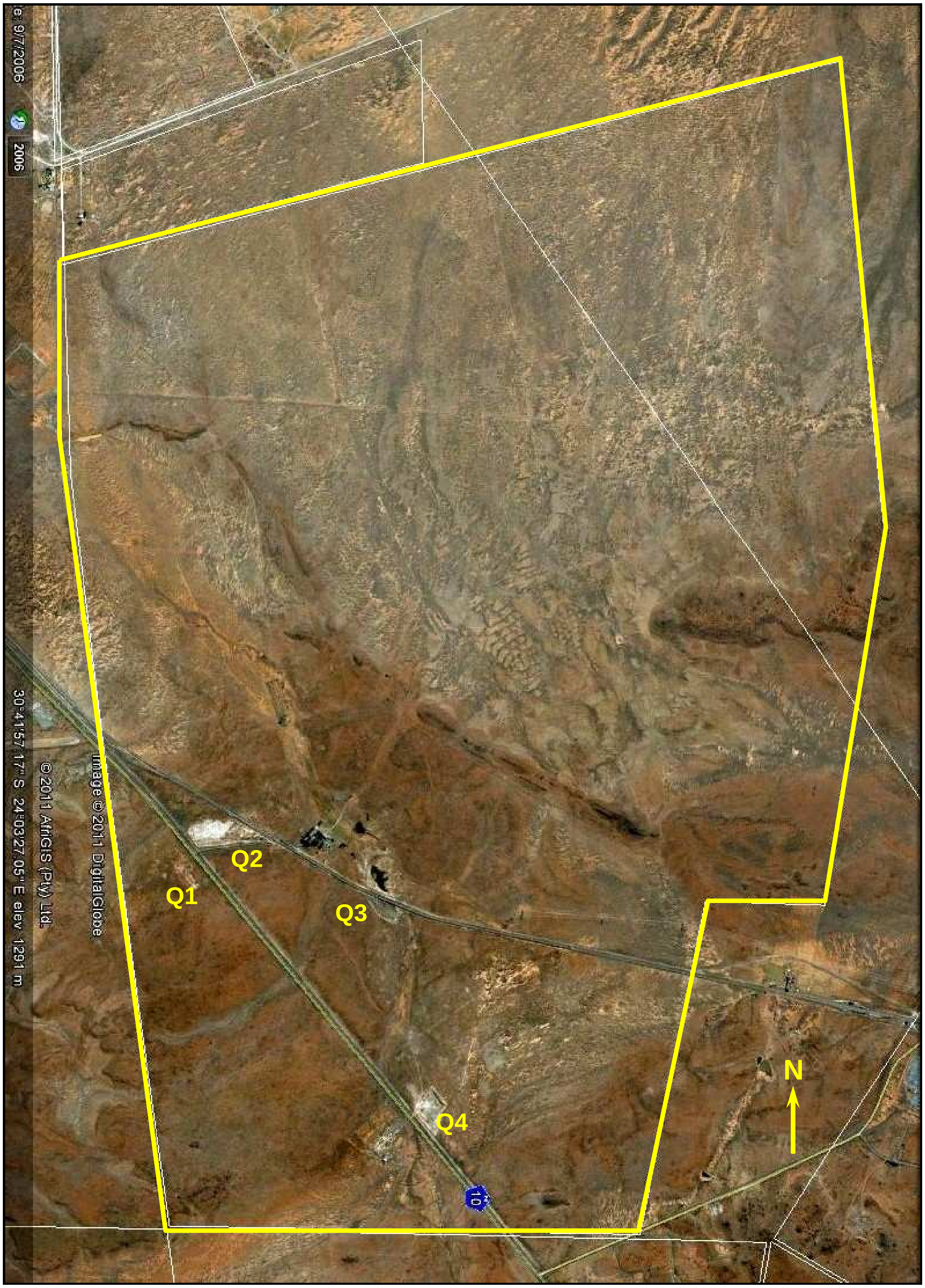

Fig. 4. Google Earth© satellite image of the PV3 study area to the southeast of De Aar (Farm De Aar 180, yellow polygon) showing *vlaktes* underlain by Ecca Group mudrocks to the north and rusty-brown dolerite intrusions and doleritic gravels overlying Lower Beaufort Group sediments in the south. Quarry sites visited during fieldwork labled Q1 to Q4.

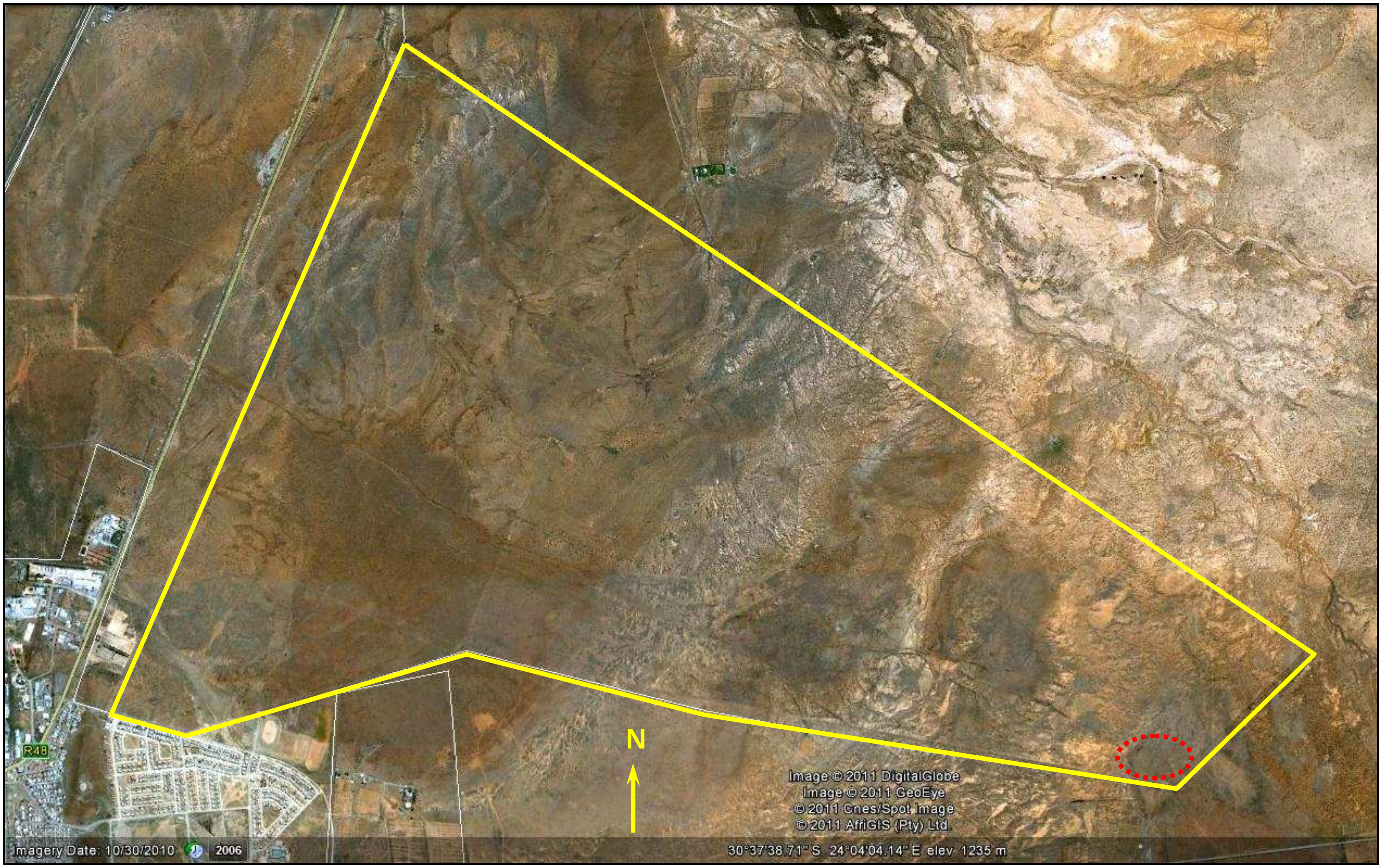

Fig. 5. Google Earth© satellite image of the PV4 study area to the northeast of De Aar (Farm Du Plessis Dam 179, yellow polygon) showing *vlaktes* underlain by Ecca Group mudrocks to the north and east with rusty-brown dolerite intrusions and doleritic gravels in the southwest. Fossil wood fragments are common within surface gravels within the red dotted area, but are also found elsewhere. The intermittent-flowing Brakrivier is seen to the northwest.

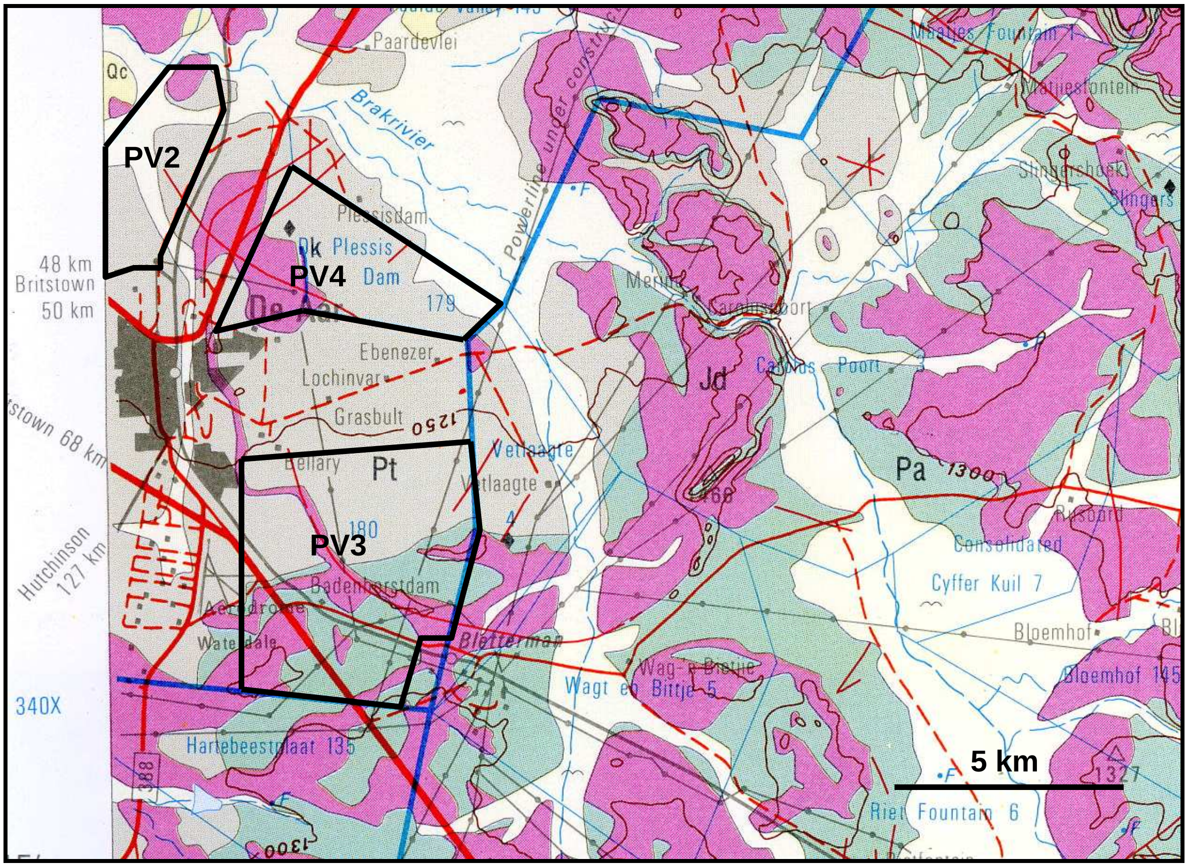

Fig. 6. Geological map of the region east of De Aar, Northern Cape, showing approximate boundaries of the three solar energy facility study areas, PV2, PV3 and PV4 (Abstracted from 1: 250 000 geology sheet 3024 Colesberg, Council for Geoscience, Pretoria).

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

grey (Pt) = Tierberg Formation (Ecca Group) (*NB* According to the author these sediments should rather be assigned to the Waterford Formation following recent fieldwork in the study area – see discussion in text)

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 (PV4 study area)

3. GEOLOGICAL BACKGROUND

The geology of the three Mulilo Renewable Energy PV study areas near De Aar is outlined on the 1: 250 000 geology sheet 3024 Colesberg (Le Roux 1993) (Fig. 6) . The geology of each study site is briefly described first (Sections 3.1 to 3.3) followed by a more detailed, illustrated account of each major rock unit represented here (Sections 3.4 to 3.8).

3.1. PV2 study area

The PV2 study area on the northern outskirts of De Aar (Farm Paarde Valley 145) is bordered by the railway lines from De Aar to Britstown and Kimberley along the southern and eastern margins respectively. The area is topographically very subdued, with elevations of between 1210 to 1225m amsl. (Fig.7). A prominent dolerite ridge runs just outside the western edge (traversed by a westward-flowing small stream) while small northwards-flowing tributaries of the Brakrivier drainage system run along the eastern edge and through the central portion of the area. The northernmost portion is also covered by alluvial deposits of the Brakrivier system (pale in satellite images, Fig. 3).

According to the 1: 250 000 geological map the PV2 study area is largely underlain by sediments of the Tierberg Formation (Ecca Group) (Fig. 6). However, as argued below (Section 3.4), in the author's opinion these rocks rather belong to the Waterford Formation. They are intruded in the northern sector of the study area by Jurassic dolerites. 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. Ecca bedrocks are well exposed, however, in the bed of the small stream along the eastern edge of the PV2 area; good vertical sections through the overlying drift deposits can also be seen here.

The latter include coarse alluvial gravels directly overlying bedrock that are largely composed of angular, platy clasts of Ecca sandstone and mudrocks showing well-developed current imbrication (Fig. 18). These subsurface gravels are sometimes highly calcretised. Hardpan calcretes were encountered in test pits in the study area (Geotechnical Report by Van Rooyen 2010). They are overlain by thick (often over one meter), semi-consolidated alluvial deposits with an extensive network of calcrete veins; this older alluvium is probably Pleistocene in age. It is overlain in turn by less well-consolidated, orange-brown younger soils (probably Holocene) which are locally capped by fine, polymict alluvial gravels. In many areas sheetwash-reworked surface gravels occur, dominated by resistant clasts of hornfels, sandstone and dolerite.

3.2. PV3 study area

The PV3 study area (Farm De Aar 180, Fig. 4) comprises largely flat-lying, semi-arid terrain between 1200 – 1300m amsl on the south-eastern outskirts of De Aar that is covered with sparse karroid vegetation and grass (Fig. 8). The farm De Aar 180 spans the N10 tar road from De Aar to Hanover as well as the De Aar – Noupoort railway line. Low rocky dolerite ridges traverse the central region and there are a couple of very shallow, intermittent-flowing water courses in the west. The area is also crossed by several electrical transmission lines from the Hydra Substation located just south-east of the development area. A number of small quarries penetrating to the Karoo Supergroup bedrock are situated close to the N10 and railway line in the southern portion of the farm, but not in the PV3 development footprint area (Q1 to Q4 in Fig. 4).

As mapped on the 1: 250 000 Colesberg geology sheet (Fig. 6), the northern half of the PV3 study area is largely underlain by dark basinal mudrocks of the Tierberg Formation (Pt) mantled with a thin cover of brown soils, alluvial and sheet wash gravels that appear greyish in satellite images (Fig. 4). The southern portion of the study is underlain by fluvial Lower Beaufort Group sediments of the Adelaide Subgroup (Pa). The latter in particular are extensively intruded by Early Jurassic dolerite sills (Jd) and a narrow, sinuous dolerite dyke extends SE-NW across the study area towards De Aar. These intrusions weather out at surface as low rocky ridges and *koppies* that show up in rusty-brown colours in satellite images. They have baked (thermally metamorphosed) the adjacent Karoo Supergroup mudrocks to hornfels, and any sandstones to quartzites. Dolerite colluvial rubble extends well beyond the intrusions themselves to blanket adjacent slopes and *vlaktes*.

Fig. 7. View towards the NE across the PV2 study area north of De Aar (Farm Paarde Valley 145) showing low relief, high vegetation and soil cover with occasional shallow streams.

Fig. 8. Flat terrain blanketed by soil and grassy karroid vegetation in northern part of the PV 3 study area, view towards the southeast.

3.3. PV4 study area

The PV4 study area (Farm Du Plessis Dam 179, Fig. 4) 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 1230-1260m amsl between the Brakrivier 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 vegetation and abundant grass in summer (Fig. 9). There are numerous surface scatters of downwasted surface gravels (mainly dolerite, hornfels, quartzite clasts), reworked by sheetwash processes (Fig. 23). It is likely that buried gravel lenticles and layers are present at the bedrock / soil interface in many areas, as seen in the PV3 study area. Likewise subsurface calcrete hardpans were not observed during the brief field survey, but are almost certainly present in many areas, especially overlying the dolerite outcrop area.

The PV4 study area is largely underlain by mudrocks and sandstones of the upper Ecca Group that are intruded by Jurassic dolerites in the southwest (Fig. 6). There is also an isolated kimberlite pipe close to the R48, but as usual this does not have an obvious surface expression.

Where soils are comparatively thin, as in the south-eastern corner of the property (dotted area in Fig. 4), dark Ecca mudrocks with thin-bedded, pale sandstones and occasional ferruginous limestone concretions are observed (Fig. 13). These rocks probably belong to the Waterford Formation of the Ecca Group, and not the Tierberg Formation as shown on the geological map (See discussion below, Section 3.4).

Fig. 9. General view of the PV4 study area (Du Plessis Dam 179) looking towards the east. Note low relief and negligible bedrock exposure.

3.4. 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). They tend 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 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. 6) and the key SACS publication by Viljoen (2005).

Good exposures of typical Carnarvon-type facies of the Waterford Formation are seen in riverine exposures in study area PV2. 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 (Fig. 10). Locally the grey, thin-bedded Ecca mudrocks underlying the sandstones are also exposed in the river banks (Fig. 11).

With the exception of occasional concentrations of excavated blocks of dark grey to grey-green mudrocks and sandstones, for example associated with geotechnical test pits, farm tracks and shallow dams, Ecca Group sediments are not exposed in the northern sector of the PV3 study area (Fig. 12). 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. Likewise Ecca Group exposures in the PV4 study site are very limited in extent (Fig. 13).

Fig. 10. Good exposure of tabular Waterford Formation sandstones in a river bed along the eastern edge of the PV2 study area (Hammer = 30 cm). Note thick cover of reddish-brown alluvial soils in the background.

Fig. 11. Small exposure of greyish Ecca mudrocks and thin sandstones in stream bank on eastern part of PV2 (Hammer = 30 cm).

Fig. 12. Excavated blocks of Ecca Group mudrocks and sandstones near shallow dam in northern part of PV3 study area (Hammer = 30 cm).

Fig. 13. Limited exposure of dark Ecca mudrocks and thin sandstones in the south-eastern corner of the PV4 study area (dotted ellipse in Fig. 5).

3.5. Lower Beaufort Group

The **Adelaide Subgroup** (**Pa**) (Lower Beaufort Group, Karoo Supergroup) was deposited by large-scale meandering river systems flowing northwards from the youthful Cape Fold Belt across the extensive floodplains of the ancient Karoo Basin (Smith 1980, Rubidge 1995, Johnson *et al*. 2006). The sediments mainly comprise fine-grained overbank mudrocks with subordinate lenticular channel sandstones. These last commonly have a basal conglomeratic lag of rolled mudflake pellets and calcrete nodules, the latter reflecting the prevailing semi-arid climates in Middle to Late Permian times. Small, often transient playa lakes were also present on the floodplain. In the Britstown – Williston - Colesberg sheet areas the Lower Beaufort succession consists largely of blocky-weathering, blue-grey and reddish floodplain mudrocks, showing occasional mudcracks. There are also subordinate siltstones, fine-grained, lenticular, current cross-bedded channel sandstones, flat-laminated crevasse-splay sandstones, and occasional playa lake deposits (Prinsloo, 1989, Viljoen 1989, Le Roux 1993). Carbonate concretions, including ferruginous *koffieklip*, as well as calcrete nodules (pedogenic limestones) and silicified gypsum rosettes ("desert roses") are common.

The precise stratigraphic assignment of the Lower Beaufort Group sediments east of De Aar is unresolved. According to the most recent fossil biozonation map of the Beaufort Group (Van der Walt *et al*. 2010) the sediments here are assigned to the *Pristerognathus* Assemblage Zone that characterises the uppermost Abrahamskraal Formation *plus* the Poortjie Member of the Teekloof Formation west of longitude 24º East, as well as the uppermost Koonap Formation and basal Middleton Formation to the east (Rubidge 1995). De Aar is situated on the (arbitrary) cut-off line between these two stratigraphic schemes. The lowermost Beaufort Group rocks in the region to the east of town contain numerous, closely-spaced sandstones with a yellowish hue, resembling in this respect the Poortjie Member recognised in the western part of the Karoo Basin. An assignation of these rocks to the **Poortjie Member** is supported (but not yet confirmed) by the sparse fossil vertebrate remains recently recorded here (Almond, unpublished observations 2012).

Compared with the underlying Abrahamskraal rocks, the Teekloof Formation has a generally higher proportion of sandstones while reddish mudrocks are more abundant here. Multi-storied sandstones are common in the basal arenaceous Poortjie Member. Thin, impersistent lenses of pinkish "cherts" are probably altered volcanic ashes (Johnson & Keyser 1979, Theron 1983, Smith & Keyser 1995, Rubidge *et al.* 2010). Several economically interesting uranium ore deposits occur within the Poortjie Member in association with brown-weathering, ferruginous channel sandstones ("koffieklip") and transported plant material. Interesting accounts of the sedimentology and palaeontology of the Poortjie Member are given by Stear (1978) as well as by Cole and Smith (2008). The Poortjie Member has a thickness of some 200m while the entire Teekloof succession is *c*. 1000m thick (Cole *et al.* 1990, Cole & Voster 1999). Recent, unpublished radiometric dating of zircons from tuff layers within the Poortjie Member gives an age of 261.3 Ma (Rubidge *et al.* 2010 and pers. comm. 2010), placing this stratigraphic unit within the Gaudalupian Epoch (late Middle Permian). Previously the Poortjie Member was considered to be earliest Late Permian or Lopingian in age (*cf* Smith & Keyser 1995, Rubidge 2005).

Lower Beaufort Group rocks are exposed within several quarries in the southern portion of the De Aar 180 study area (but outside the footprint of proposed solar energy facility) (Q1 to Q4 in Fig. 4). They comprise grey-green mudrocks interbedded with tabular, thin to medium bedded greenish sandstones or wackes with occasional large (meter-sized) ferruginous calcareous concretions (*koffieklip*). Wave-rippled upper bedding planes are seen locally (Fig. 15), perhaps related to playa lakes (Alternatively, these rippled rocks may belong to the storm-influenced Carnarvon facies of the uppermost Ecca).

Fig. 14. SE-dipping dark mudrocks and thin sandstones of the Lower Beaufort Group exposed in small quarry near the N10, PV3 study area (Q4 in Fig. 4). Note also dolerite dyke beneath hammer (Hammer = 30 cm).

Fig. 15. Wave-rippled upper surface of Lower Beaufort Group sandstone bed in quarry exposure, southwestern part of PV3 study area (Q2 in Fig. 4).

Fig. 16. Small-scale folding in Lower Beaufort Group sediments, possibly due to extensive near-surface secondary calcrete deposition, small quarry in southwestern part of PV3 study area (Q2 in Fig. 4).

The Beaufort Group mudrocks and sandstones exposed near-surface are often disrupted to a depth of several meters by a dense network of calcrete veins. Whereas Karoo Supergroup rocks in the De Aar region are normally flat-lying, reflecting the absence of tectonic disturbance here, those seen in Fig. 16 show well-spaced small-scale folds. This phenomenon of buckling and heaving of Karoo beds is probably a geologically recent (probably Pleistocene) process consequent on stresses induced by extensive secondary mineralization by calcrete, causing both vertical and horizontal expansion of the rock column. Past expression of sandstone anticlinal hinge axes as surface ridges has promoted erosion of mudrocks in intervening synclines and development here of a thick calcrete packet. SE-dipping Beaufort mudrocks and thin sandstones are exposed in a small quarry close to the N10 (note small dolerite dyke here; Fig. 14).

3.6. 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. 6), 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.

Rocky ridges and low koppies of well-jointed, masonry-like dolerite, as well as zones of dolerite corestones emerging from the soil, are seen in central portion of the PV3 study area (Fig. 17). Thick calcrete development overlying deeply-weathered dolerite (corestones, onionskin weathering *etc*) is seen in several quarries to the south (Fig. 19).

Fig. 17. Well-jointed outcrop of large dolerite intrusion in central part of PV3 study area, viewed from the south.

3.7. 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 PV4 (diamond symbol in map Fig. 6). Kimberlite rocks are unfossiliferous, although rich Cretaceous to Paleocene fossil assemblages may be found in associated crater lake facies (not present here).

3.8. 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 Brakrivier 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 < 1m) horizons of coarse, angular gravels mantle the Palaeozoic bedrocks over much of the study area, as seen in several quarry and riverine exposures (Fig. 18). Gravel clasts mostly consist of locally-derived Beaufort Group sandstones, hornfels and quartzite as well as weathered to fresh dolerite, including large rounded dolerite corestone boulders. The highly porous gravel layers may be preferentially calcretised. Locally diamictite-like slurries of calcretised gravels and sand (breccio-conglomerates) are developed; these probably represent debris flows into local depressions in the pre-Holocene landscape. Apparently cross-bedded gritty deposits of weathered dolerite "grus" are found between the dolerite bedrock and calcrete capping (Q3 in Fig. 4). These may be stream-reworked coarsely granular dolerite material ("*sabunga*") or perhaps *in situ* onion-skin weathered dolerite layers.

Quarry sections in the southern portion of the PV3 study area show that a large proportion of the Karoo and dolerite bedrocks are mantled with a thick (up to 4m, though often much less), irregular and variable layer of secondary calcrete (Figs. 19, 21, 22). This may be massive or multi-layered, and contains lenticular to laterally persistent horizons of gravels (quartzite, hornfels, siltstone, sandstone, dolerite). The thickest calcrete horizons probably infill depressions in the pre-Holocene landscape and are often associated directly or indirectly with weathered dolerite. For the most part they are probably Pleistocene in age. The calcrete hardpan is often cavernous weathering. Possible irregular, subvertical soil-filled zones may be solution hollows (*Makondos*, dolines), as seen in both coastal limestones as well as Precambrian carbonate rocks of the interior. Calcretes seen in the study area are very variable in character and in many or most cases are probably composite horizons that have developed in several phases over thousands or tens of thousands of years. Veins, networks and sheets of calcrete extend downwards from the main hardpan into the underlying superficial sediments or bedrock (Figs. 20, 21).

Semi-consolidated, blocky-weathering, coarse sandy and gritty deposits locally underlying the calcrete hard pan and overlying bedrock or gravel layers may be ancient alluvial soils, of possible Pleistocene age. They contain sparse coarse gravel clasts and are often permeated by a network of pale calcrete veins. Unconsolidated orange-brown to brown surface soils, overlying the calcrete hardpan, may be of alluvial, sheet wash or even in part aeolian origin. These superficial soils are probably Holocene in age. They contain, or are locally overlain by, downwasted surface gravels, concentrated by downwasting and sheetwash processes.

Fig. 18. Coarse alluvial gravels overlain by thick reddish-brown alluvial soils in a stream bank section in the PV2 study area (Hammer = 30 cm).

Fig. 19. Several meter - thick calcrete hardpan overlying weathered dolerite (in foreground) in quarry exposure close to railway line, PV3 study area (Q3 in Fig. 4).

Fig. 20. Thick calcrete hardpan forming low cliff in background, underlain by extensively calcretised grey-green mudrocks of the Lower Beaufort Group, quarry exposure in southern part of PV3 study area (Q2 in Fig. 4) (Hammer = 30 cm).

Fig. 21. Well-consolidated, calcretised older alluvial soils overlain by unconsolidated orange-brown younger soils, quarry exposure in southern part of PV3 study area (Q1 in Fig. 4) (Hammer = 30 cm).

Fig. 22. Composite, multi-layered calcrete hardpan with coarse gravel horizon adjacent to hammer, PV3 study area quarry exposure near N10 (Q4 in Fig. 4) (Hammer = 30 cm).

Fig. 23. Reddish-brown soils with downwasted surface gravels reworked by sheetwash processes, PV4 study area. These gravels often contain small cherty fragments of reworked fossil wood from the Ecca Group.

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 (*eg* 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 (*eg* Wickens 1984). Prinsloo (1989) records numerous plant impressions and unspecified "fragmentary vertebrate fossils" within fine-grained sandstones in the Britstown sheet area. Dark carbonaceous Ecca mudrocks are likely to contain palynomorphs (*e.g.* pollens, spores, acritarchs).

The commonest fossils by far in the Tierberg Formation are sparse to locally concentrated assemblages of trace fossils that are often found in association with thin event beds (*eg* distal turbidites, prodeltaic sandstones) within more heterolithic successions. A modest range of ten or so different ichnogenera have been recorded from the Tierberg Formation (*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*. 3.5cm wide) and similar orientation on the bedding plane. This trace has frequently been misinterpreted as a web-footed tetrapod or arthropod trackway (*e.g.* Van Dijk *et al*. 2002 and references therein). However, Braddy and Briggs (2002) present a convincing case that this is actually a current-orientated arthropod resting trace (cubichnion), probably made by small crustaceans that lived in schools of similar-sized individuals and orientated themselves on the seabed with respect to prevailing bottom currents. Distinctive broad (3-4cm), strap-shaped, horizontal burrows with blunt ends and a more-or-less pronounced transverse ribbing occur widely within the Tierberg mudrocks. They have been described as "fucoid structures" by earlier workers (*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 3.4.) it is considered likely that 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 ichnogenus *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 undidentified horizontal burrows were recorded from the tops of wave-rippled Ecca sandstones exposed in the stream bed running along the eastern edge of the PV2 study area (Figs. 24, 25). Sheetwash gravels in the PV4 study area consistently contain small cherty fragments of silicified woods from the underlying Ecca Group bedrocks. Larger petrified wood samples also occur within subsurface gravels overlying Ecca bedrocks where these are exposed at surface (Fig. 26). The woods typically show well-developed seasonal growth rings and preservation of original the original woody microstructure appears to be good; this would facilitate identification and possible dating of the samples. No Ecca Group body fossils were observed within the PV2 and PV3 study areas. Reworked clasts of cherty silicified wood can be expected within downwasted surface or near-surface gravels, and are of widespread occurrence and locally common in the De Aar area (Almond, recent field obs., 2010).

Fig. 24. Scattered burrows of *Teichichnus* and *Palaeophycus striatus* in Ecca Group sandstones, stream bed in study area PV2 (GPS locality 30º 37' 24.9" S, 24º 00' 47.9" E).

Fig. 25. Unidentified sinuous horizontal burrows within upper Ecca sandstones (same locality as above, PV2 study area) (Scale in cm).

Fig. 26. Locally abundant fragments of silicified fossil wood from the Ecca Group (probably Waterford Formation) in the south-eastern corner of the PV4 study area (See dotted area on satellite image, Fig. 5. GPS locality 30º 38' 38.9" S, 24º 05' 00.7" E) (Scale in cm).

4.2. Adelaide Subgroup

The overall palaeontological sensitivity of the Lower Beaufort Group sediments is high (Rubidge 1995, Almond & Pether 2008). These fluvial and lacustrine sediments have yielded one of the richest fossil records of land-dwelling plants and animals of Permo-Triassic age anywhere in the world. Well-preserved tetrapod fossils, from isolated skulls and post-cranial bones to fully articulated skeletons, are mainly found in overbank mudrocks, often in association with pedogenic calcretes (palaeosol horizons). Disarticulated, water-worn bones occur in the channel lag conglomerates and sandstones (Smith 1980, 1993). Playa lake deposits may be associated with disarticulated amphibian bones and a range of trace fossils (*e.g. Scoyenia*). Fossils embedded within metamorphosed sediments (quartzites, hornfels) adjacent to dolerite intrusions may be well-preserved, but are very difficult to prepare out from the matrix and therefore usually of limited scientific value.

A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Kitching (1977), Keyser and Smith (1979) and Rubidge (1995). The first two articles do not specify an assemblage zone for the study area near De Aar.). As mentioned earlier (Section 3.2) the sediments here are assigned to the *Pristerognathus* Assemblage Zone according to the most recent fossil biozonation map of the Beaufort Group published by Van der Walt *et al*. (2010). The paucity of fossil data for the Lower Beaufort succession in the Colesberg sheet explanation (Le Roux 1993) also suggests that this region is palaeontologically under-explored; any new fossil finds here are consequently of palaeontological significance. This is emphasized by the absence of fossil records from the De Aar area in the recent maps of Karoo vertebrate fossil sites produced by Nicolas (2007).

Fossils of the *Pristerognathus* Assemblage Zone characterize the arenaceous Poortjie Member as well as the uppermost beds of the underlying Abrahamskraal Formation in the western Main Karoo Basin as well as the laterally equivalent beds spanning the Koonap / Middleton Formation boundary in the eastern Karoo (Smith & Keyser 1995). This important terrestrial biota is dominated by various therapsids ("mammal-like reptiles") such as the moderate-sized therocephalian carnivore *Pristerognathus* as well as several gorgonopsian predators / scavengers and herbivorous dicynodonts (Fig. 27). The commonest genus by far is the small burrowing dicynodont *Diictodon* (Keyser and Smith 1977-78, Smith & Keyser 1995b, MacRae 1999, Cole *et al*., 2004, Rubidge 2005, Almond 2010, Nicolas 2007, Nicolas & Rubidge 2010). There are also large, rhino-sized herbivorous pareiasaur reptiles (*Bradysaurus* spp.), crocodile-like temnospondyl amphibians (*Rhinesuchus*), palaeoniscoid fish, vascular plant fossils of the *Glossopteris* Flora (fossil wood, leaves *etc*) and various trace fossils, including invertebrate and therapsid burrows as well as tetrapod trackways. The comparatively low number of specimens and major taxa represented in fossil collections from this biozone has been highlighted by Nicolas (2007). The fossil biota of the *Pristerognathus* AZ is of special interest because it possibly represents an impoverished post-extinction recovery fauna following a late Mid Permian extinction event that preceded the well-known end-Guadalupian biotic crisis (*cf* Benton 2003, Retallack *et al.,* 2006, Lucas 2009).

Most fossils in the *Pristerognathus* Assemblage Zone are found in the softer-weathering mudrock facies (floodplain sediments) that are usually only exposed on steeper hill slopes and in stream gullies. Fossils here are often associated with pedogenic limestone nodules or calcretes (Smith 1993, Smith & Keyser 1995). The mudrocks lie between the more resistant-weathering channel sandstones, which in the Poortjie Member display a distinctive "golden yellow" tint. Fossil skeletal remains also occur in the lenticular channel sandstones, especially in intraformational lag conglomerates towards the base, but are usually very fragmentary and water-worn ("rolled bone").

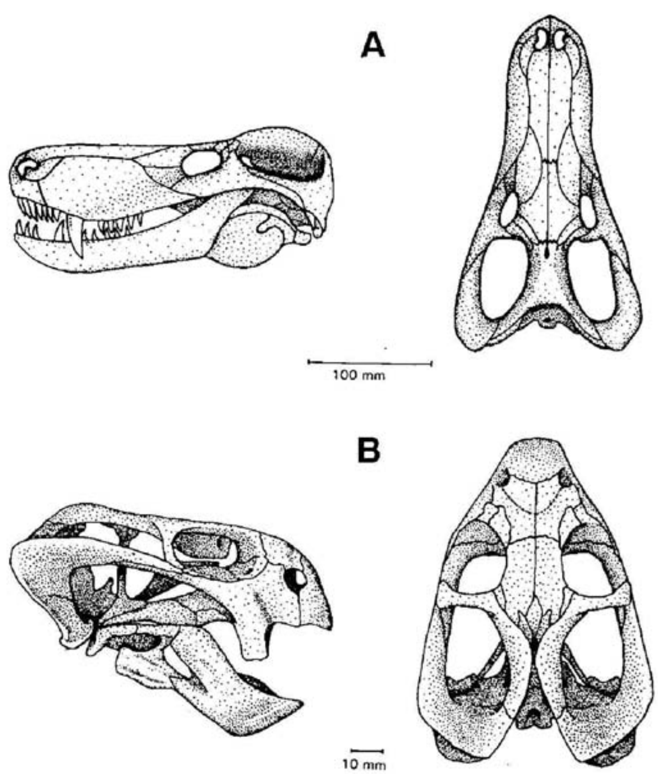

Fig. 27. Skulls of typical therapsids from the *Pristerognathus* Assemblage Zone: A. the dog-sized carnivorous therocephalian *Pristerognathus* and B. the small herbivorous dicynodont *Diictodon* (From Smith & Keyser 1995).

Apart from vague trace fossils (horizontal burrows) observed on weathered upper surfaces of sandstones, no fossils were observed in the Beaufort Group bedrocks in the study area. Sparse skulls and postcranial remains of small-bodied therapsids (probably *Diictodon* and a slightly larger form) have recently been collected from Poortjie Member sediments in the escarpment area to the east of De Aar (Almond, unpublished obs., 2012).

4.3. 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" (*ie*. recrystallised, impregnated with secondary minerals). Embedded fossil material of phosphatic composition, such as bones and teeth, is frequently altered by baking – bones may become blackened, for example - and can be very difficult to extract from the hard matrix by mechanical preparation (Smith & Keyser 1995). Thermal metamorphism by dolerite intrusions therefore tends to reduce the palaeontological heritage potential of Beaufort Group sediments. In some cases (*e.g.* fossil moulds of mesosaurid reptiles and palaeoniscoid fish) baking may enhance the quality of preservation of Ecca fossils while other fossil groups (*e.g*. carbonaceous remains of plants, organic-walled palynomorphs) are more likely to be compromised.

4.4. Quaternary to Recent superficial deposits

The central Karoo drift deposits have been comparatively neglected in palaeontological terms. However, they may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals as well as remains of reptiles like tortoises. Good examples are the Pleistocene mammal faunas at Florisbad, Cornelia and Erfkroon in the Free State and elsewhere (Wells & Cooke 1942, Cooke 1974, Skead 1980, Klein 1984, Brink, J.S. 1987, Bousman *et al.* 1988, Bender & Brink 1992, Brink *et al*. 1995, MacRae 1999, Meadows & Watkeys 1999, Churchill *et al*. 2000 Partridge & Scott 2000). Other late Caenozoic fossil biotas from these superficial deposits include non-marine molluscs (bivalves, gastropods), ostrich egg shells, 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 5cm across as well as hollow subhorizontal root moulds and / or invertebrate burrows are exposed below the calcrete hardpan in a quarry near the N10, close to the southern boundary of the PV3 study area (Figs. 28 & 29). Identifiable embedded stone artefacts (useful for dating purposes) were not seen within coarse gravel layers, although good examples (MSA flaked hornfels) have been observed elsewhere in the De Aar region (Almond, recent field obs., 2012). As already mentioned in Section 4,1, reworked clasts of resistant-weathering, cherty fossil wood is locally common both in subsurface gravels as well as sheetwash gravels at the soil surface (Figs. 23, 26).

Fig. 28. Irregular, subvertical calcretised rhizoliths (plant root casts) in calcrete hardpan exposed in quarry near N10, PV3 study area (Q4 in Fig 4) (Hammer = 30 cm).

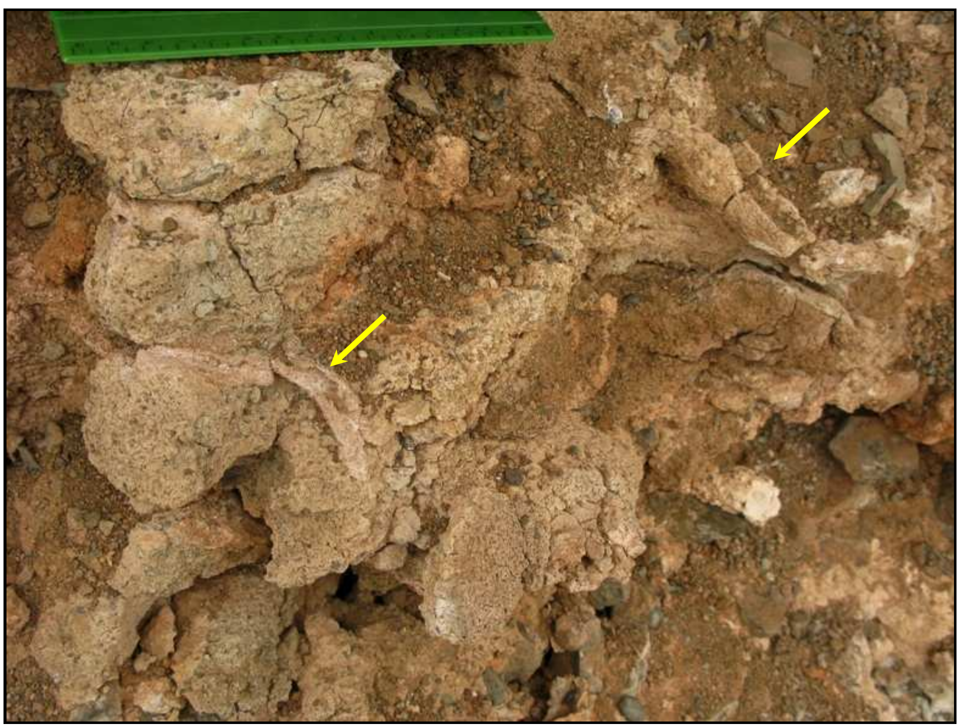

Fig. 29. Hollow calcrete root mould or invertebrate burrows (arrowed) within calcrete hardpan exposed in quarry near N10, PV3 study area (Q4 in Fig. 4) (Scale in cm).

5. ASSESSMENT OF SIGNIFICANCE OF PALAEONTOLOGICAL HERITAGE IMPACTS

The three proposed PV solar energy facilities near De Aar are located in an area that is underlain by potentially fossiliferous sedimentary rocks of Palaeozoic and younger, probably Quaternary age (Sections 3 & 4). The construction phase of these alternative energy developments will entail numerous, but mostly shallow, excavations into the superficial sediment cover and in some areas into the underlying bedrock as well. These include, for example, excavations for the solar panel foundations, underground cables, new electricity transmission lines, as well as new gravel access roads and any control / administrative buildings. In addition, substantial areas of bedrock will be sealed-in or sterilized by infrastructure such as solar panel arrays and new gravel roads. All these developments may adversely affect fossil heritage within the development footprint by destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good.

The significance of expected impacts on palaeontological heritage resources within each of the three De Aar PV facility study areas are assessed separately for the construction phase in Tables 2A, 2B and 2C below, according to the scheme specified by Aurecon. 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;
- substantial differences in impacts between the preferred and the alternative sites for each solar facility are not anticipated, so these assessments apply equally to both options for each solar facility;
- impacts from the construction of associated new road infrastructure and transmission lines is treated as part of the overall impact of each PV development, and have not been considered separately.

Table 2A: Evaluation of impacts of proposed De Aar PV2 solar energy facility on fossil heritage resources (Applies equally to preferred and alternative layout)

CRITERIA	CATEGORY	COMMENTS
Extent	Site specific	Limited to development footprint
Magnitude	Low	Highly significant fossil material (*e.g.* vertebrate remains) is sparsely distributed and occurs widely outside study area
Duration	Long term	Permanent
Significance	Low	Monitoring or mitigation measures therefore not proposed for this project
Probability	Definite	Commoner bedrock fossils (*e.g.* trace fossils, petrified wood) are probably ubiquitous in the broader study region
Confidence	Sure	Limited by low levels of bedrock exposure within study areas (This is partially compensated by study of better exposures elsewhere)
Reversibility	Irreversible	Loss of fossil heritage is generally permanent

Table 2B: Evaluation of impacts of proposed De Aar PV3 solar energy facility on fossil heritage resources (Applies equally to preferred and alternative layout)

CRITERIA	CATEGORY	COMMENTS
Extent	Site specific	Limited to development footprint
Magnitude	Low	Highly significant fossil material (*e.g.* vertebrate remains) is sparsely distributed and occurs widely outside study area
Duration	Long term	Permanent
Significance	Low	Monitoring or mitigation measures therefore not proposed for this project
Probability	Definite	Commoner bedrock fossils (*e.g.* trace fossils, petrified wood) are probably ubiquitous in the broader study region
Confidence	Sure	Limited by low levels of bedrock exposure within study areas (This is partially compensated by study of better exposures elsewhere)
Reversibility	Irreversible	Loss of fossil heritage is generally permanent

Table 2C: Evaluation of impacts of proposed De Aar PV4 solar energy facility on fossil heritage resources (Applies equally to preferred and alternative layout)

CRITERIA	CATEGORY	COMMENTS
Extent	Site specific	Limited to development footprint
Magnitude	Low	Highly significant fossil material (*e.g.* vertebrate remains) is sparsely distributed and occurs widely outside study area
Duration	Long term	Permanent
Significance	Low	Monitoring or mitigation measures therefore not proposed for this project
Probability	Definite	Commoner bedrock fossils (*e.g.* trace fossils, petrified wood) are probably ubiquitous in the broader study region
Confidence	Sure	Limited by low levels of bedrock exposure within study areas (This is partially compensated by study of better exposures elsewhere)
Reversibility	Irreversible	Loss of fossil heritage is generally permanent

6. CONCLUSIONS & RECOMMENDATIONS

The fossil record and inferred palaeontological sensitivity of fossil heritage within each of the main rock units represented in the three PV study areas near De Aar is summarized in Table 3 below (See also Almond & Pether 2008). The Ecca and Beaufort Group sediments here generally have a moderate to high palaeontological sensitivity.

The potentially fossiliferous sediments of the Karoo Supergroup (Ecca and Beaufort Groups) that underlie the three study areas (Farms De Aar 180 / Badenhorst Dam, Annex Du Plessis Dam, Paarde Valley 145) are almost entirely mantled in a thick layer of superficial deposits of probable Pleistocene to Recent age. They include various soils, gravels and – at least in some areas - a very well-developed calcrete hardpan. The upper Ecca Group bedrocks in the De Aar area contain locally abundant fossil wood (of palaeontological interest for dating and palaeoenvironmental studies) as well as low diversity trace fossil assemblages typical of the Waterford Formation, rather than the Tierberg Formation as mapped.

No fossils were observed within the Lower Beaufort Group rocks where exposed in various small quarries in the southern portion of the PV3 study area. However, various trace fossils, silicified woods and rare vertebrate remains (therapsids) of the Middle Permian *Pristerognathus* Assemblage Zone have recently been recorded from these successions in the De Aar area. Jurassic dolerite sill and dyke rocks here are entirely unfossiliferous (igneous intrusions), as are rare kimberlite pipes of Cretaceous age.

The diverse superficial deposits in the study region are of low palaeontological sensitivity as a whole. Calcretized rhizoliths (root casts) and possible invertebrate burrows of probable Quaternary age were observed during field studies (PV3 study area). Good examples of silicified fossil wood were recorded from gravels overlying Ecca bedrock as well as reworked into surface gravels in the PV4 study area. Fossil wood material probably occurs widely in similar settings within all three study areas, albeit usually buried beneath superficial deposits.

Fossils exposed at the surface or underground may be damaged, disturbed or sealed-in during the construction phase of the three proposed solar energy facilities near De Aar. However these developments are all inferred to be of LOW significance in terms of palaeontological heritage resource conservation because:

- The potentially fossiliferous Karoo Supergroup rocks within the development footprints (solar panel arrays, transmission lines, roads and other infrastructure) are generally buried beneath a mantle of fossil-poor superficial sediments (soils, gravels, calcretes);

- The Karoo Supergroup rocks are often extensively disrupted by near-surface secondary calcrete formation. Baking by dolerite intrusion has often further compromised their original fossil heritage;

- The solar energy facilities each have a small footprint while extensive, deep bedrock excavations are not envisaged for this sort of alternative energy development.

The two alternative layouts for each of the three proposed PV solar energy facility near De Aar are of equal, low impact significance in fossil heritage terms. The construction of new access roads and transmission lines in this region are likewise considered to be of low significance as far as fossil heritage is concerned.

Given the low overall palaeontological sensitivity of the region around De Aar, and the widespread occurrence elsewhere in the Great Karoo of the fossils so far recorded there, the successive or concurrent development of all three PV sites near De Aar that have been proposed by Mulilo Renewable Energy (Pty) Ltd does not pose a significant cumulative impact on local fossil heritage.

In view of the overall low significance of the proposed development on palaeontological heritage resources, it is concluded that no further palaeontological heritage studies or specialist mitigation are required for these three PV projects, pending the exposure of any substantial fossil remains (*e.g.* vertebrate bones and teeth, large blocks of petrified wood) during the construction phase. The ECO responsible for these developments should be alerted to the possibility of fossil remains being found on the surface or exposed by fresh excavations during construction. Should substantial fossil remains be discovered during construction, these should be safeguarded (preferably *in situ*) and the ECO should alert SAHRA so that appropriate mitigation (*e.g.* recording, sampling or collection) can be taken by a professional palaeontologist.

The specialist involved would require a collection permit from SAHRA. Fossil material must be curated in an approved repository (*e.g.* museum or university collection) and all fieldwork and reports should meet the minimum standards for palaeontological impact studies developed by SAHRA.

These recommendations should be incorporated into the EMP for the three PV developments.

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Table 3: Palaeontological record and sensitivity of rocks units represented in the broader De Aar study region

TABLE 1: FOSSIL HERITAGE IN THE DE AAR AREA				
GEOLOGICAL UNIT	**ROCK TYPES & AGE**	**FOSSIL HERITAGE**	**PALAEONT-OLOGICAL SENSITIVITY**	**RECOMMENDED MITIGATION**
Superficial deposits ("drift")	**Alluvium, colluvium (scree), pan sediments, 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**

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9. QUALIFICATIONS & EXPERIENCE OF THE AUTHOR

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

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

Declaration of Independence

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

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