Palaeontological specialist assessment: desktop study

PROPOSED RENOSTERBERG SOLAR PV AND WIND ENERGY FACILITIES NEAR DE AAR, NORTHERN CAPE PROVINCE

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EXECUTIVE SUMMARY

The Renosterberg Wind Energy Company (Pty) Ltd (RWEC) in partnership with the Industrial Development Corporation of South Africa (IDC) is proposing to develop a 250 MW wind energy facility as well as a 150 MW concentrated photovoltaic solar facility in the vicinity of the Renosterberg, approximately 25 km north of De Aar, Northern Cape.

The lower-lying portions of the study area are underlain by offshore basinal to nearshore sediments of the Early to Middle Permian Ecca Group (Karoo Supergroup). These subaqueous deposits are variously assigned to the Tierberg Formation or Waterford Formation and are of moderate palaeontological sensitivity, containing locally abundant petrified woods, trace fossil assemblages (including possible large amphibian impressions) and microvertebrate remains (*e.g.* disarticulated teeth, scales of fish). The overlying Middle Permian fluvial sediments of the Lower Beaufort Group (Adelaide Subgroup, Karoo Supergroup) crop out along the slopes of the Renosterberg *koppies*, but are largely mantled by colluvial deposits here (notably dolerite scree). These rocks have recently yielded rare but palaeontologically significant fossil remains of small therapsids ("mammal-like reptiles") and turtle-like parareptiles, *plus* occasional fossil plants and silicified woods, in the escarpment zone east of De Aar. The Renosterberg *koppies* are capped by substantial sills of unfossiliferous dolerite of the Early Jurassic Karoo Dolerite Suite. Much of the subdued Ecca Group outcrop area is covered by a thin to thick (few dm to several meters) succession of Late Caenozoic (Neogene to Recent) superficial deposits such as alluvium, surface gravels, soils and calcrete hardpans. These younger rocks contain sparse, low diversity fossil assemblages such as rhizoliths (calcified plant root casts) and invertebrate burrows, but locally important vertebrate material (*e.g.* mammalian or reptilian bones and teeth) or even human remains may be expected here.

The same limited spectrum of rock units is represented within the broader "all-inclusive" study region encompassing all the infrastructural components of the proposed alternative energy facilities (including transmission lines, substations *etc*) and extending from the Renosterberg area itself southwards to De Aar and beyond. A sizeable area of potentially fossiliferous Adelaide Subgroup rocks cropping out near the Eskom Hydra substation to the southeast of De Aar is of particular note.

The construction phase of the proposed Renosterberg wind and solar energy developments will entail substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock. These notably include excavations for the wind turbine and solar panel foundations, buried cables, transmission line pylons as well as new gravel access roads, substations and administration buildings. In addition, large areas of bedrock will be sealed-in or sterilized by infrastructure such as standing areas for each wind turbine, lay-down areas as well as the new gravel road system. All these developments may adversely affect potential fossil heritage within the study area by destroying, disturbing or permanently sealing-in fossils at or beneath the surface of the ground that are then no longer available for scientific research or other public good. Once constructed, the operational and decommissioning phases of the wind and solar energy facilities will not involve further adverse impacts on palaeontological heritage, however.

In view of the potential for significant impacts on fossil heritage within the Karoo Supergroup sediments (Ecca and Beaufort Groups), a pre-construction field assessment of all the land parcels involved in the proposed Renosterberg wind and solar energy developments is necessary as part of the EIA process. This field study should record significant fossil occurrences and horizons within the broader development footprint, including transmission line corridors, and make recommendations for any further specialist palaeontological studies or mitigation that should take place before or during the construction phase. These recommendations should also be incorporated into the Environmental Management Plan for the proposed alternative energy developments.

1. INTRODUCTION AND BRIEF

The Renosterberg Wind Energy Company (Pty) Ltd (RWEC) in partnership with the Industrial Development Corporation of South Africa (IDC) is proposing to develop a wind energy facility (WEF) as well as a concentrated photovoltaic solar facility on the summit and in the vicinity of the Renosterberg in the Northern Cape. The study area is situated to the west of the De Aar to Kimberley tar road (R338) and railway line approximately 45km west of Philipstown and 25 km north of De Aar (Fig. 1). The wind energy facility will have a total generation capacity of about 250 MW. The solar PV power plant will occupy an area of *c*. 250 hectares and have a total generation capacity of up to 150 MW.

The main components of the **wind energy facility** of relevance to the present palaeontological heritage assessment include:

- Approximately 83 to 138 wind turbines, each of 1.8 to 3 MW generation capacity. Foundations for the turbines will be about 18 m x 18 m and up to 4 m deep.
- A hard standing area for each turbine (1250 m^2 to 3750 m^2 in area).
- Buried 33 kV voltage cables connecting the wind turbines with each other and to a substation (with overhead lines where appropriate over rivers and gullies).
- A transmission line connection to the Eskom grid, linking either with existing lines (with a switchyard) or a completely new line linking with an existing Eskom substation.
- A new on-site transformer substation.
- Gravel access roads (5-8 m wide) from the site to a public road as well as internal road network to the turbines and other infrastructure. Where required existing roads will be upgraded.
- An on-site administration building (*c*. 150 to 350 m^2 footprint).
- A general construction lay-down area of 80 hectares or less.

The main components of the **solar PV energy facility** of relevance to the present palaeontological heritage assessment include:

- A solar field containing arrays of PV panels in metal frames (5-10m above ground level) and mounted on concrete or screw pile foundations.
- A single-storey on-site administration building (*c*. 150 to 350 m^2 footprint).
- Buried or pole-mounted 33 kV cables between the PV arrays and the transformer substation.
- A central transformer substation (likely option) and a transmission substation located close to existing power lines.
- A transmission line connection to the Eskom grid, linking either with existing lines (with a switchyard) or a completely new line linking with an existing Eskom substation.
- A general construction lay-down area of approximately 80 hectares or less.

At this stage, pending the outcome of the EIA and design processes, the final layout of the WEF and solar energy facility infrastructure has not been decided. Options include alternative locations for the on-site substations, lay-down areas and administration buildings as well as several options for the power line connection with an existing transmission line or a nearby Eskom substation (*e.g.* Behrshoek 132 kV Distribution Substation, Hydra 765 kV Distribution Substation, Britsville 132 kV Distribution Substation, De Aar 132 kV Distribution Substation. The location of these substations is shown in Fig. 1). All major infrastructural components should lie within the broader, “all inclusive scoping area” that is indicated by the larger polygon in satellite image Fig. 1. In the case of the WEF and solar energy facility the “no go option” of not constructing the proposed alternative energy facilities will also be assessed during the EIA phase.

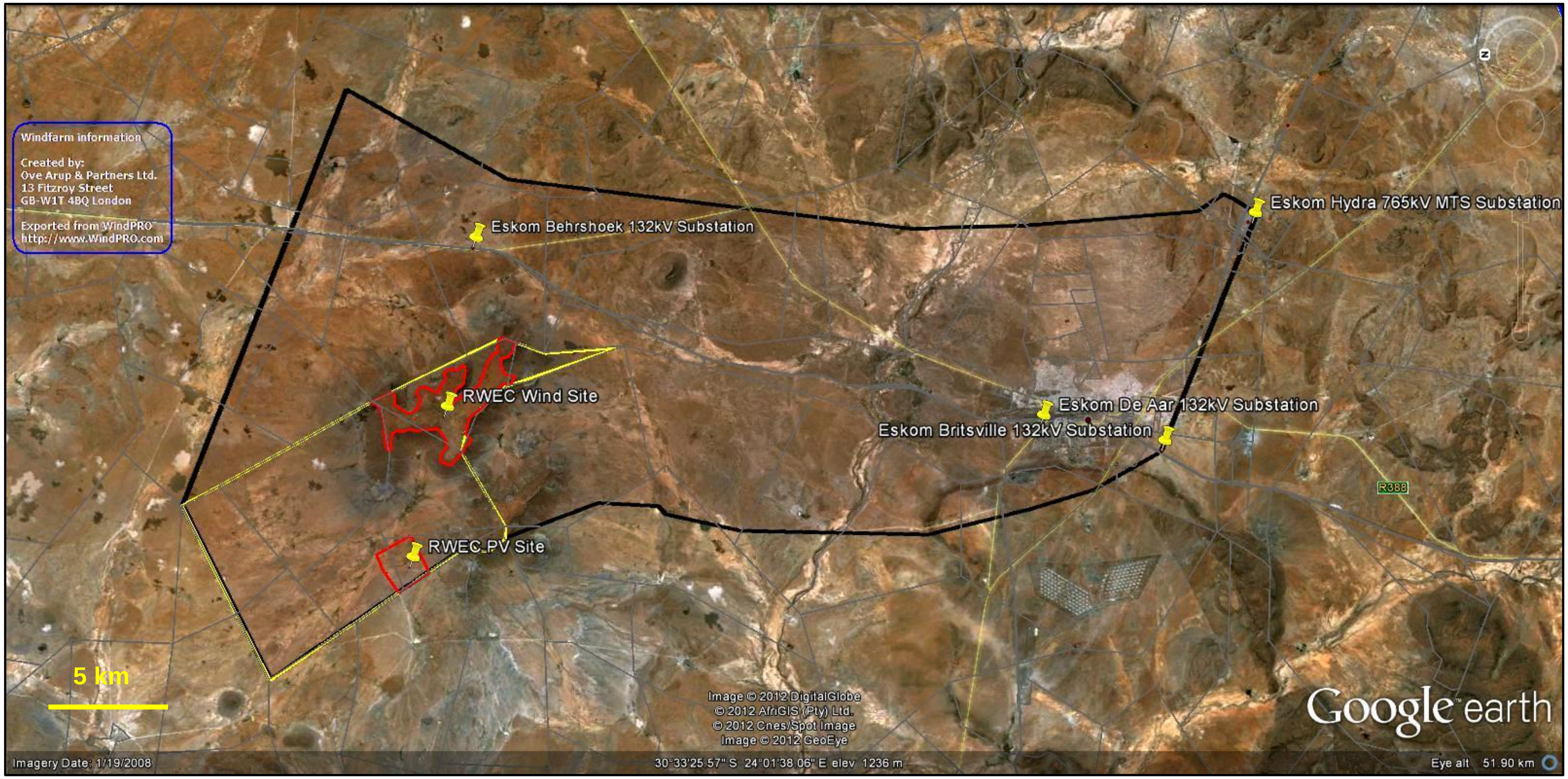

Fig. 1. Google earth© satellite image of the region north of De Aar, Northern Cape (Note N is to the *left*). The yellow polygon indicates land parcels containing the proposed Renosterberg wind energy and solar energy developments. Provisional locations for these developments on the main plateau of the Renosterberg, *c*. 25 km north of De Aar, as well as in the *vlaktes* to the west are indicated in red, but these sites may well change during the EIA process. The large black polygon indicates the broader "all inclusive" study area that should contain all ancillary infrastructural components of the Renosterberg projects, notably transmission line connections to one or more of the Eskom substations indicated here (yellow symbols).

1.1. Legislative context for palaeontological assessment studies

An Environmental Impact Assessment is being undertaken by SiVEST Environmental Division, Rivonia (Contact details: 51 Wessel Road, PO Box 2921, Rivonia 2128; Phone + 27 11 798 0600; Fax + 27 11 803 7272; Email info@sivest.co.za), for the proposed Renosterberg wind and solar energy facilities near De Aar in accordance with the National Environmental Management Act 1998 (Act 107 of 1998).

The present report forms part of the EIA for the proposed alternative energy developments, also falling under Section 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999), and it will also inform the Environmental Management Plan for this project.

The proposed Renosterberg developments are located in an area that is underlain by potentially fossil-rich sedimentary rocks of Palaeozoic and younger, Tertiary or Quaternary age (Sections 2 and 3). The construction phase of the developments will entail substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock. These notably include excavations for the wind turbine and solar panel foundations, buried cables, transmission line pylons as well as new gravel access roads, substations and administration buildings. In addition, large areas of bedrock will be sealed-in or sterilized by infrastructure such as standing areas for each wind turbine, lay-down areas as well as the new gravel road system. All these developments may adversely affect potential fossil heritage at or beneath the surface of the ground within the study area by destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good. Once constructed, the operational and decommissioning phases of the wind and solar energy facilities will not involve further adverse impacts on palaeontological heritage, however.

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

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

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

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

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

(3) Any person who discovers archaeological or palaeontological objects or material or a meteorite in the course of development or agricultural activity must immediately report the find to the responsible heritage resources authority, or to the nearest local authority offices or museum, which must immediately notify such heritage resources authority.

(4) No person may, without a permit issued by the responsible heritage resources authority—

(a) destroy, damage, excavate, alter, deface or otherwise disturb any archaeological or palaeontological site or any meteorite;

(b) destroy, damage, excavate, remove from its original position, collect or own any archaeological or palaeontological material or object or any meteorite;

(c) trade in, sell for private gain, export or attempt to export from the Republic any category of archaeological or palaeontological material or object, or any meteorite; or

(d) bring onto or use at an archaeological or palaeontological site any excavation equipment or any equipment which assist in the detection or recovery of metals or archaeological and palaeontological material or objects, or use such equipment for the recovery of meteorites.

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

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

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

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

(d) recover the costs of such investigation from the owner or occupier of the land on which it is believed an archaeological or palaeontological site is located or from the person proposing to undertake the development if no application for a permit is received within two weeks of the order being served.

Minimum standards for the palaeontological component of heritage impact assessment reports (PIAs) are currently being developed by SAHRA. The latest version of the SAHRA draft guidelines was circulated for comment in November 2011.

1.1. Scope and brief for the desktop study

This desktop palaeontological specialist report provides an assessment of the observed or inferred palaeontological heritage within the broader Renosterberg study area, with recommendations for further specialist palaeontological studies and / or mitigation where this is considered necessary.

The report has been commissioned by SiVEST Environmental Division (Contact details: 51 Wessel Road, PO Box 2921, Rivonia 2128; Phone + 27 11 798 0600; Fax + 27 11 803 7272; Email info@sivest.co.za). It contributes to the comprehensive EIA for the proposed Renosterberg wind and solar energy facilities and it will also inform the Environmental Management Plan for the project. The scope of work for this desktop study, as defined by SiVEST, is as follows:

To compile a scoping level palaeontology specialist report including (but not limited to) the following aspects:

- Introduction;
- Legislative Background as applicable to the Proposed Activity;
- High level Environmental Baseline in terms of the Specialist Area;
- Methodology;
- High level identification and mapping of palaeontology sensitive areas identified within the project area;

- Scope and elaborate on potential anticipated impacts related to palaeontology and the proposed development;
- Provide recommendations for further assessment; and
- Conclusion.

Given that the precise layout of the various infrastructural components of the Renosterberg wind and solar energy facilities have not yet been decided, an "all-inclusive study area" (as shown in Fig. 1) has been delineated so as to incorporate potential areas for the grid connections to the solar PV and Wind Farm. All the currently proposed transmission line routes are included, as well as the provisional substation sites. This broader "all-inclusive study area" is briefly covered in the present desktop assessment.

1.3. Approach to the desktop study

The approach to this desktop study is briefly as follows. Fossil bearing rock units occurring within the broader study area are determined from geological maps and satellite images (Fig. 2). Known fossil heritage in each rock unit is inventoried from scientific literature, previous assessments of the broader study region, and the author's field experience and palaeontological database (Table 1). Based on this data as well as field examination of representative exposures of all major sedimentary rock units present, the impact significance of the proposed development is assessed with recommendations for any further studies or mitigation

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 field assessment during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development (Provisional tabulations of palaeontological sensitivity of all formations in 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 significantly the extent of fresh bedrock excavation envisaged. When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a Phase 1 field assessment study by a professional palaeontologist is usually warranted to identify any palaeontological hotspots and make specific recommendations for any mitigation required before or during the construction phase of the development.

On the basis of the desktop and Phase 1 field assessment studies, the likely impact of the proposed development on local fossil heritage and any need for specialist mitigation are then determined. Adverse palaeontological impacts normally occur during the construction rather than the operational or decommissioning phase. Phase 2 mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) may be required (a) in the pre-construction phase where important fossils are already exposed at or near the land surface and / or (b) during the construction phase when fresh fossiliferous bedrock has been exposed by excavations. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority (*e.g.* SAHRA for the Northern Cape). 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.

1.4. Assumptions & limitations

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

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

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

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

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

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

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

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

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

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

In the case of the Renosterberg WEF and solar PV study areas a major limitation for fossil heritage studies is the low level of exposure of potentially fossiliferous bedrocks of the Karoo Supergroup. This is in part compensated by palaeontological field data obtained from better exposed sites within the De Aar region (*e.g.* Almond 2010a, 2010b, 2011, 2012a, 2012b, 2012c).

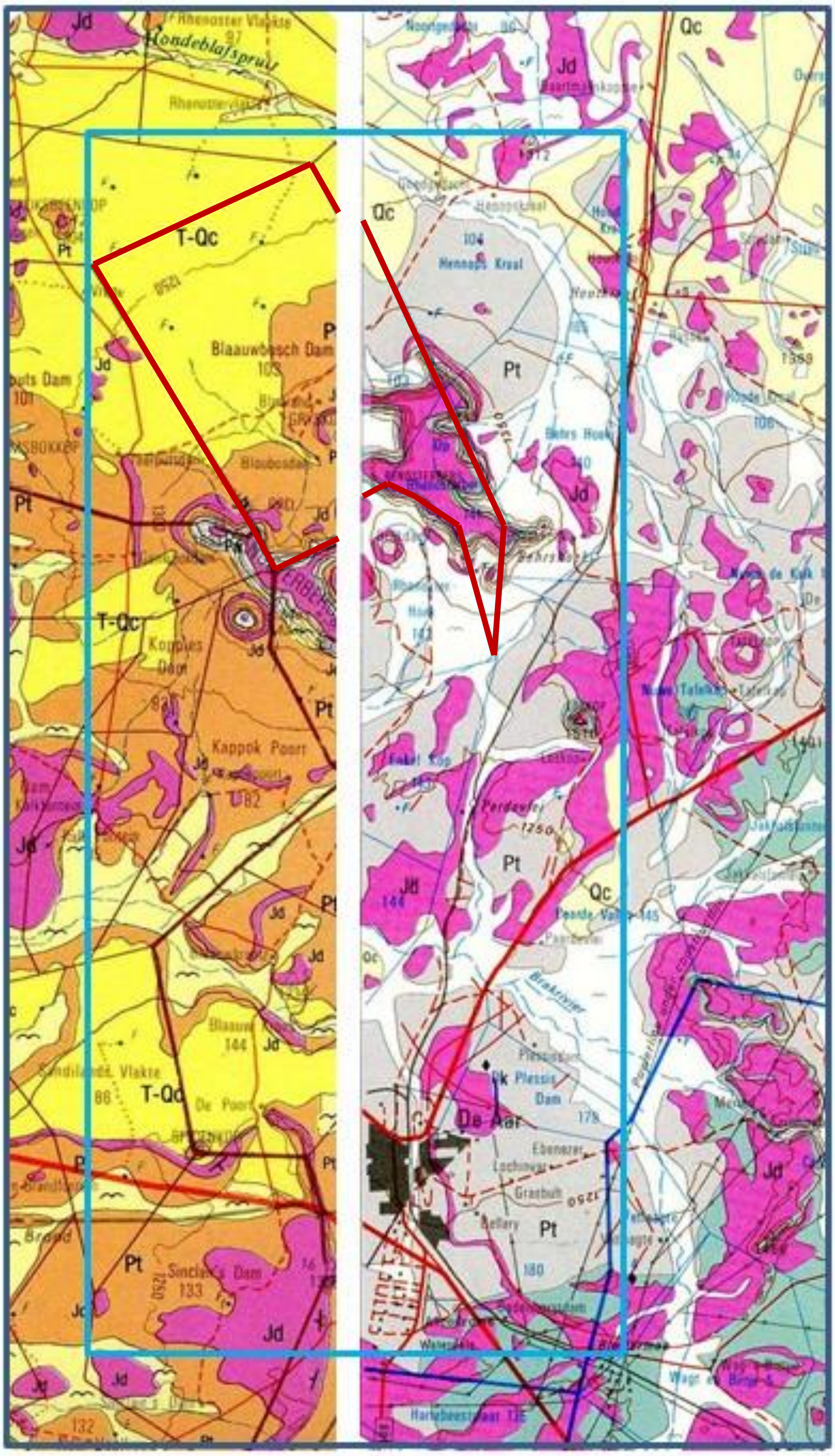

Fig. 2. Geology of the broader Renosterberg – De Aar study region (blue rectangle) abstracted from 1: 250 000 geological maps 3022 Britstown (left) and 3024 Colesberg (right) (Council for Geoscience, Pretoria). The dark red polygon outlines the land parcels around the Renosterberg within which the core wind and solar facilities will be constructed. The major rock units represented in this and the broader study area include: Pt (orange / grey) = Tierberg Formation (ECCA GROUP); Pa (blue-green) = Adelaide Subgroup (BEAUFORT GROUP); Jd (pink) = Karoo Dolerite Suite; T-Qc / Qc (yellow) = Late Caenozoic calcretes; Pale yellow / white = Quaternary alluvium. Of these rock units, only the Ecca and Beaufort Group rocks are of moderate to high palaeontological sensitivity.

1.5. Information sources

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

1. A short project outline provided by SiVEST Environmental Division;

2. A review of the relevant scientific literature, including published geological maps and accompanying sheet explanations as well as several field-based palaeontological assessment studies in the broader De Aar region by the author (*e.g.* Almond 2010a, 2010b, 2011, 2012a, 2012b, 2012c);

3. The author's previous field experience with the formations concerned and their palaeontological heritage.

2. GEOLOGICAL OUTLINE OF THE STUDY AREA

The core Renosterberg project study area north of De Aar (dark red polygon in Fig. 1) is situated in the semi-arid Great Karoo region that is drained by several intermittent, NW-flowing rivers including the Brakrivier to the south and the Hondeblafspruit to the north. The southern portion of the study area is dominated by a group of flat-topped hills or koppies that are collectively known as the Renosterberg. The larger, more eastern hill, on which it is proposed to construct the wind energy facility, rises to *c*. 1650m amsl. The central and northern portion of the area comprises gently NW-sloping terrain at c. 1350-240m amsl that is traversed by several small intermittent-flowing streams. The fairly flat-lying proposed solar PV site along the western edge of the study area lies at 1300 to 1330m amsl and some 1.5 km west of the Blaauwbosch Dam farmstead. Note the precise location of these sites within the core study area has yet to be decided.

The geology of the Renosterberg alternative energy project area near De Aar is outlined on the adjacent 1: 250 000 geology sheets 3024 Colesberg (Le Roux 1993) and 3022 Britstown (Prinsloo 1989) (Fig. 2). The study area is entirely underlain at depth by sedimentary rocks of the Karoo Supergroup (Fig. 3). These comprise Early to Middle Permian basinal and nearshore mudrocks and sandstones assigned to the **Tierberg Formation** (**Ecca Group**) (**Pt**) that lie at or close to the surface in the lower-lying parts of the area. However, over much of this region the Ecca mudrocks are mantled by much younger (Late Tertiary to Recent) superficial deposits including pedogenic **calcrete hardpans** (**T-Qc**), especially in the north, as well as **alluvial deposits**, **sheet wash sediments**, **surface gravels** generated by downwasting, and **soils**. Overlying the subaqueously - deposited Ecca Group mudrocks are terrestrial fluvial sediments of the **Beaufort Group** that in this area are assigned to the Middle Permian **Adelaide Subgroup** (**Pa**). These younger Permian sedimentary rocks build the steep slopes of the two main Renosterberg koppies but their exposure here is limited by the extensive cover by **colluvial (slope) deposits**, mainly composed of dolerite and sandstone scree, as well as by vegetation and soil. The plateaux capping the Renosterberg *koppies* are built of resistant-weathering igneous intrusions of the **Karoo Dolerite Suite** (**Jd**). Comparable gently-dipping sills intrude the older Tierberg rocks around the base of the koppies. In the low-relief region between the Renosterberg and De Aar the readily-weathered Tierberg sediments are also intruded by Karoo dolerite sills and dykes and extensively mantled by alluvial and other superficial deposits. Within the broad "all-inclusive study area" shown in Fig.1 Beaufort Group rocks (here also intruded by dolerites) are represented in the south-eastern corner in the vicinity of the Hydra Substation.

As far as the Karoo Supergroup is concerned the De Aar - Philipstown study region is of special geological and palaeontological interest in that the stratigraphic boundary between the Ecca Group, largely composed of marine (actually freshwater inland sea) rocks, and the overlying continental sediments of the Beaufort Group runs along the base of the major escarpment to the east of town as well as around the slopes of isolated Karoo *koppies* to the north such as the Renosterberg and

Tierberg ranges. This marine-to-land transition across the ancient Ecca Sea shoreline has been much discussed in the geological literature, but many details remain to be resolved (*e.g.* Visser & Loock 1974, Visser *et al.* 1978, Smith & Zawada 1988, 1989, Rust *et al.* 1991, Zawada 1992, Rubidge *et al.* 2000, Viljoen 2005). As discussed below, the precise stratigraphic position and classification of the Ecca and Beaufort Group rocks in the De Aar – Philipstown region remain ambiguous, and the identification and distribution of the various formations as shown on geological maps (Fig. 2) does not accord with palaeoenvironmental data shown by the rocks on the ground. The stratigraphic subdivision of the uppermost Ecca Group and lowermost Beaufort Group succession in the Main Karoo Basin is given in Fig. 3, which also shows the fossil assemblage zones recognised in these rocks – mainly based on vertebrate fossils (See Section 3).

The geology of the main rock units represented within the Renosterberg study area (including the broader "all-inclusive" area) is briefly outlined in the following section, based largely of previous field and desktop assessments in the region by the author (See reference list, especially Almond 2012a).

2.1. 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 (Visser *et al.* 1978, Prinsloo 1989, Le Roux 1993, Viljoen 2005, Johnson *et al*., 2006). The Tierberg shales are Early 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 and Colesberg geology sheet explanation by Prinsloo (1989) and Le Roux (1993) respectively. 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 (Le Roux 1993, p. 4, following Nel 1977). The marine or 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. In contrast to the *Mermia* Ichnofacies traces of the basinal Tierberg mudrocks sensu stricto, the Carnarvon facies trace fossil assemblages have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Siebrits 1987, Smith & Zawada 1988, 1989, 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. 2) and the key SACS publication by Viljoen (2005). It is important to note that the key holostratotype (Stratotype A) section through the Tierberg Formation identified by Viljoen (2005) is located just to the north of Tierberg, some 18 km northeast of the Renosterberg study area (Fig. 4). On the basis of both sedimentary facies and fossil assemblages, the rocks here closely resemble the tempestite-dominated nearshore "Carnarvon-type" facies of the Waterford Formation.

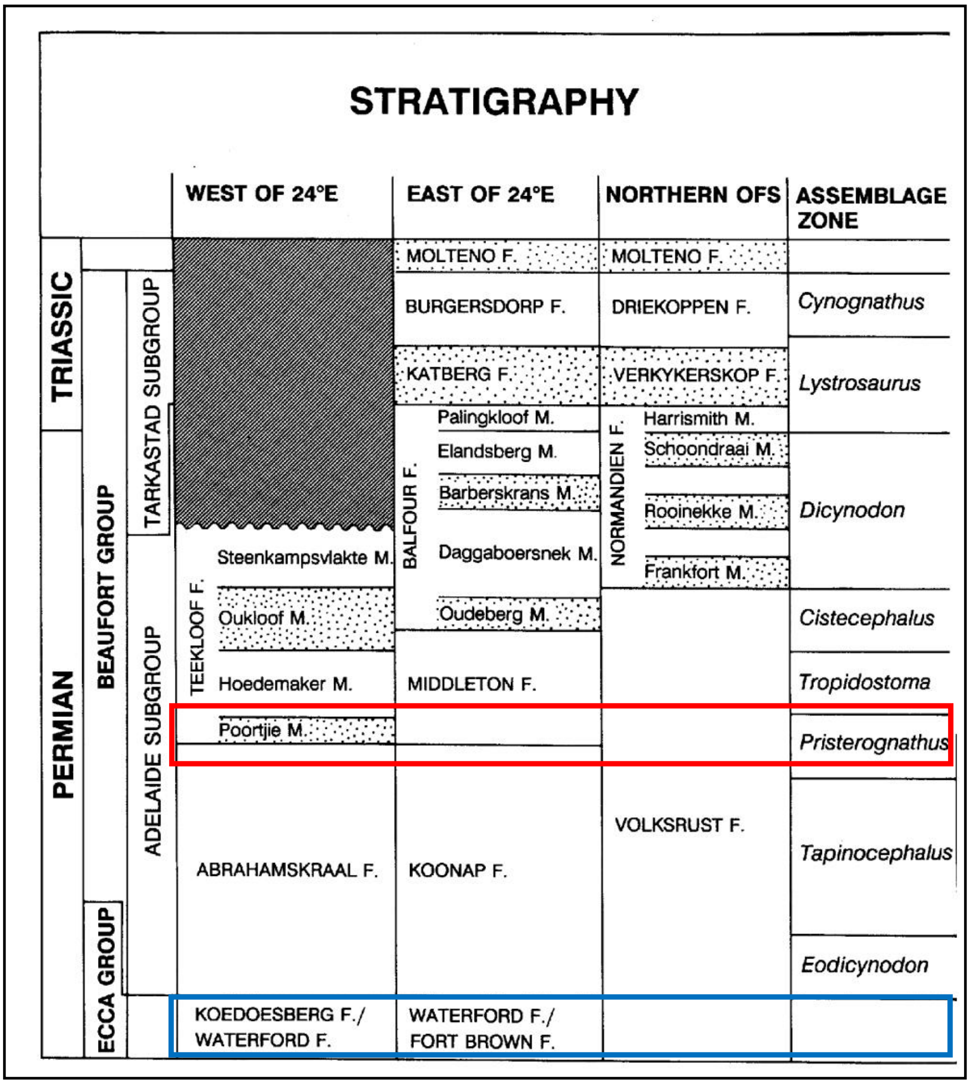

Fig. 3. Stratigraphic subdivision of the Beaufort Group in the Main Karoo Basin of South Africa (From Rubidge 1995). Although mapped as Tierberg Formation, the uppermost Ecca Group sediments in the De Aar study area are assigned here to the Waterford Formation (blue rectangle), and in particular to the storm-influenced Carnarvon-type facies of this unit. In this area these marine shelf to foreshore sediments are overlain by a sandstone-rich fluvial succession that is probably equivalent to the Poortjie Member (Teekloof Formation) of the Lower Beaufort Group / Adelaide Subgroup, characterized by fossils of the *Pristerognathus* Assemblage Zone. There is therefore little or no representation of the Abrahamskraal Formation and its associated *Tapinocephalus* Assemblage Zone fossils here.

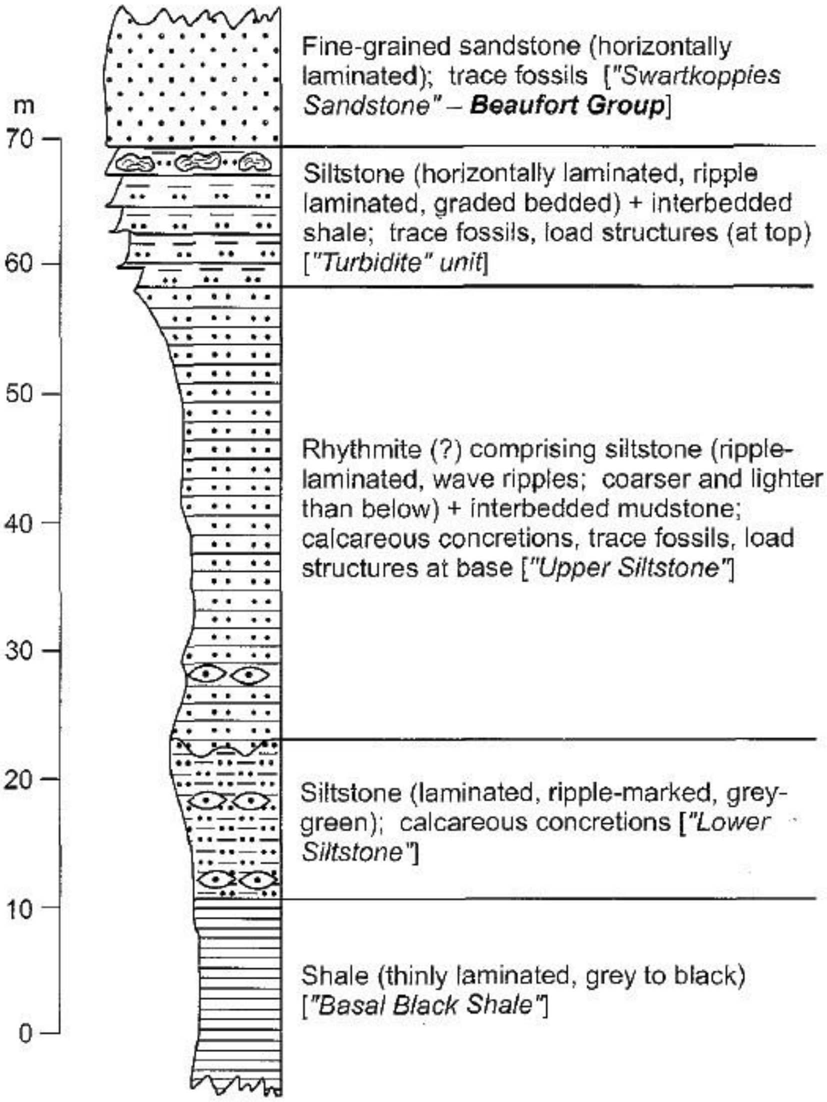

Fig. 4. Upper part of the fossiliferous Holostratotype section through the Tierberg Formation exposed just north of Tierberg, some 18 km NE of the Renosterberg study area (From Viljoen 2005). However, the sediments and fossil assemblages here resemble the storm-dominated Carnarvon-type facies of the Waterford Formation (See text for discussion).

2.2. 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) (Fig. 3). De Aar is situated on the (arbitrary) cut-off line between these two stratigraphic schemes. The lowermost Beaufort Group rocks in the escarpment 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 (the parareptile *Eunotosaurus plus* the dicynodonts *Pristerodon* and *Diictodon*), recorded during the recent palaeontological field assessment by Almond (2012a). According to Smith and Keyser (1995) the Poortjie Member is some 120m thick at Victoria West and thins to the north. There remains a possibility that the Adelaide Subgroup succession in the Eastern Escarpment area to the east of De Aar, which is well over 100m thick, includes Teekloof Formation successions above the Poortjie Member proper, *i.e*. equivalents of the mudrock-dominated Hoedmaker Member, and therefore perhaps also fossil assemblages of the Late Permian *Tropidostoma* Assemblage Zone. However, the thin Adelaide Subgroup successions overlying the Ecca Group rocks in the Renosterberg area are likely to equate with the Poortjie Member alone.

Compared with the older Abrahamskraal Formation rocks of the Adelaide Subgroup, 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 in the western part of the Main Karoo Basin, 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).

2.3. 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. 2), extensive dolerite intrusion of both the upper Ecca Group as well as the Lower Beaufort Group rocks is observed in the De Aar region. A major dolerite sill caps the Eastern Escarpment and underlies most of the provisional Renosterberg WEF development footprint. 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.

2.5. Superficial deposits

Quaternary (and possibly even Late Tertiary / Neogene) to Recent superficial deposits cover all but the steepest slopes of the isolated Karoo koppies and escarpment of the Eastern Plateau as well as most of the plains at their feet, including dry river courses such as the Brakrivier and Hondeblafrivier in the broader De Aar study region. Various types of superficial deposits of geologically young, Late Caenozoic age (Miocene / Pliocene to Recent, *i.e.* < 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, surface gravels of various origins, 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.

3. PALAEONTOLOGICAL HERITAGE WITHIN THE STUDY AREA

Fossil biotas recorded from each of the main stratigraphic units mapped in the study area are briefly reviewed in this section (Based largely on Almond 2012a and references therein) and summarized in Table 1 below, where an indication of the palaeontological sensitivity of each rock unit is also given. 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 portions of the Karoo Supergroup sediments due to resulting thermal metamorphism. In addition, pervasive calcretisation and chemical weathering 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" (possibly temnospondyl amphibians) within fine-grained sandstones in the Britstown sheet area. Dark carbonaceous Ecca mudrocks are likely to contain palynomorphs (*e.g.* pollens, spores, acritarchs).

The commonest fossils by far in the Tierberg Formation are sparse to locally concentrated assemblages of trace fossils that are often found in association with thin event beds (*e.g.* distal turbidites, prodeltaic sandstones) within more heterolithic successions. A modest range of ten or so different ichnogenera have been recorded from the Tierberg Formation (*e.g.* Abel 1935, Anderson 1974, 1976, Wickens 1980, 1984, 1994, 1996, Prinsloo 1989, De Beer *et al*., 2002, Viljoen 2005, Almond 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 2) it is considered likely that the uppermost Ecca Group rocks in the De Aar study region 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). Fragments of silicified gymnospermous woods, some showing the original xylem tissue preserved in fine detail (*e.g.* clear seasonal growth rings), are among the commonest fossil remains from the Ecca Group outcrop area near De Aar reported in the various recent field studies by Almond (2012a, 2012b, 2012c) (Fig. 6). Sheetwash and other near-surface gravels overlying the Ecca Group outcrop area consistently contain small cherty fragments of silicified woods reworked from the underlying bedrocks. Larger petrified wood samples also occur within subsurface gravels overlying Ecca bedrocks where these are exposed at surface near De Aar.

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) (Fig. 5). 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*. Non-marine arthropod feeding and resting scratch burrows of the ichnogenera *Cruziana* and *Rusophycus* are also reported here; they may have been generated by crustaceans. Possibly limb and belly impressions of large tempnospondyl amphibians were recorded from a wave-rippled surface northeast of De Aar (Almond 2012a). The Holostratotype section through the Tierberg Formation designated by Viljoen (2005) features a variety of trace fossil occurrences as well as occasional fossil wood material (Fig. 4).

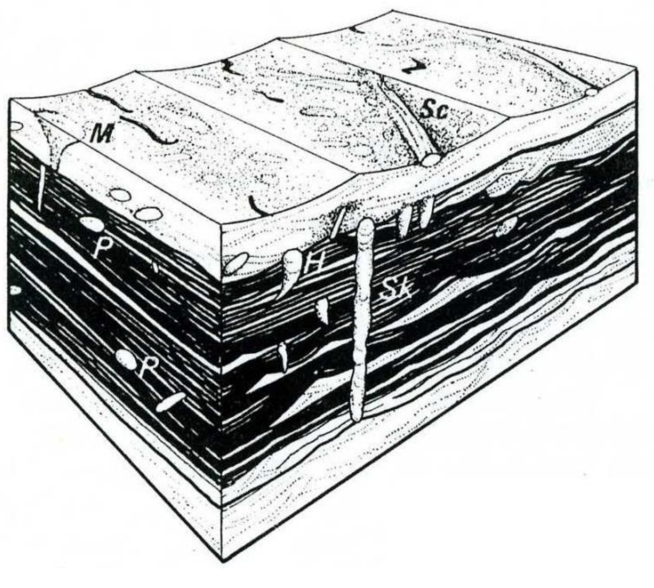

Fig. 5. Schematic figure showing typical trace fossil assemblages within the storm-influenced, wave ripple laminated Carnarvon facies of the Waterford Formation (From Rust *et al.* 1991). Ichnogenera shown here include vertical burrows *Monocraterion* (M), *Skolithos* (Sk) and *Rosselia* or *Histioderma* (H) as well as horizontal burrows *Planolites* (P) and *Palaeophycus* (Sc).

Fig. 6. Locally abundant fragments of silicified fossil wood from the Ecca Group (probably Waterford Formation) in the De Aar region (From Almond 2012b) (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) (Fig. 3). 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 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) (Fig. 7). 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) (Fig. 8).

Fossils of the *Pristerognathus* Assemblage Zone characterize the arenaceous Poortjie Member of the Teekloof Formation 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) (Fig.3). 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. 9). 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.), small tortoise-like parareptiles like *Eunotosaurus*, crocodile-like temnospondyl amphibians (*Rhinesuchus*), palaeoniscoid bony 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").

During recent palaeontological field assessments in the De Aar region a small number of fossil vertebrate specimens have been recorded that are of value for the biostratigraphic zonation of the Adelaide Subgroup rocks here (Almond 2012a). Provisional identifications of the material indicate the presence of the small dicynodonts *Pristerodon* and *Diictodon* as well as the distinctive turtle-like parareptile *Eunotosaurus* (Mike Day & Bruce Rubidge, pers. comm., 2012). These rare finds support as assignation of the lowermost Beaufort Group beds near De Aar to the *Pristerognathus* Assemblage Zone, as discussed above. Other fossils reported from these rocks include vertebrate and arthropod scratch burrows (*Cruziana* and *Scoyenia* respectively), and plant remains such as sphenophyte (horsetail fern) stems and silicified wood showing well-developed seasonal growth rings.

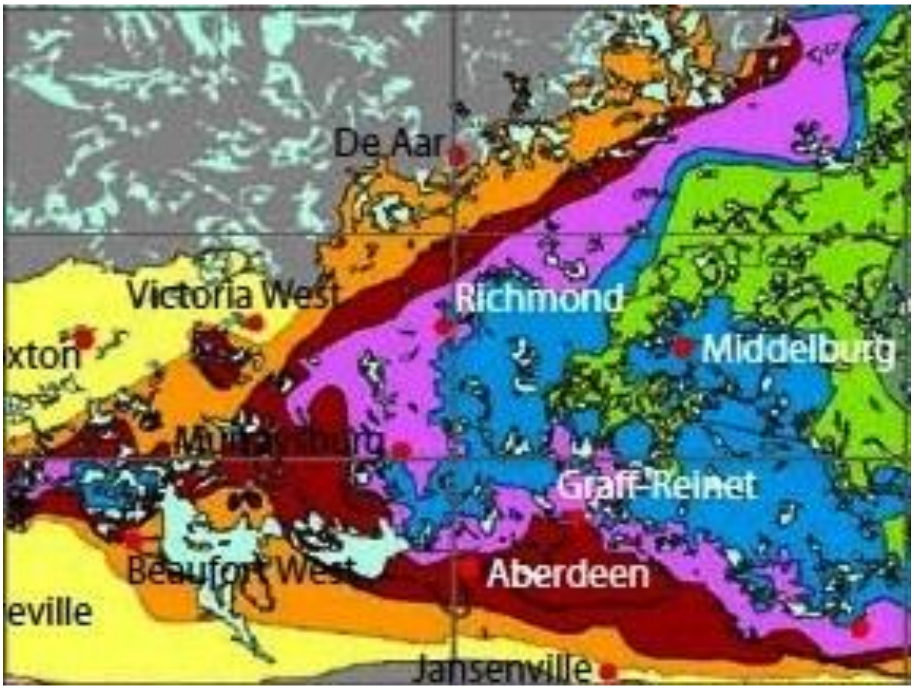

Fig. 7. Abstract from recent fossil assemblage zone map for the Main Karoo Basin published by Van der Walt *et al.* (2010). The study region to the north and east of De Aar is assigned here to the *Pristerognathus* Assemblage Zone (orange), with the overlying *Tropidostoma* Assemblage Zone (red) only appearing well to the southeast. It is likely that the map will be refined in future in the light of new vertebrate fossil discoveries.

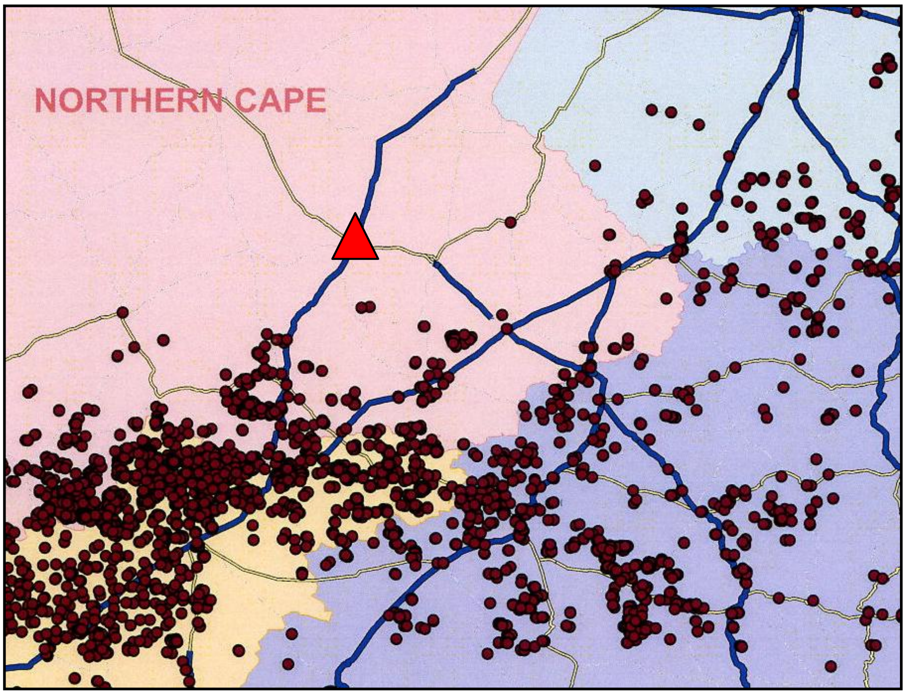

Fig. 8. Distribution map of recorded vertebrate fossil sites within the Beaufort Group of the Great Karoo around the junction of the Western, Northern and Eastern Cape and the Free State (From Nicolas 2007). Note absence of documented fossil sites from the De Aar area (red triangle). This is in large part probably due to the low levels of bedrock exposure, as well as general lower abundance of fossils in the *Pristerognathus* Assemblage Zone. Rare vertebrate fossils have been recorded here recently during field studies by Almond (2012a).

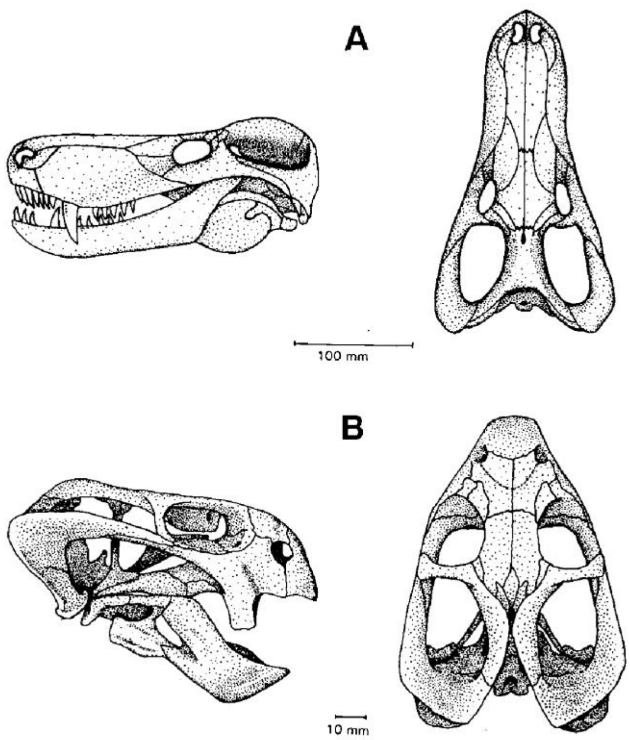

Fig. 9. Skulls of typical therapsids from the *Pristerognathus* Assemblage Zone: A. the dog-sized carnivorous therocephalian *Pristerognathus* and B. the small herbivorous dicynodont *Diictodon* (From Smith & Keyser 1995).

Fig. 10. Skull of a small dicynodont (probably *Pristerodon*), seen in dorsal view, from the Adelaide Subgroup to the east of De Aar (From Almond 2012a) (Scale in cm and mm).

4.3. Karoo Dolerite Suite

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

4.4. 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, invertebrate burrows), 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 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.

Only sparse fossil to subfossil remains have been reported from Late Caenozoic superficial deposits in the De Aar region. They include three to four centimetre wide vertical spreiten burrows attributed to an unknown invertebrate were recorded from thick bedded alluvium. A systematic search of gravels within these beds might eventually yield Pleistocene vertebrate bones and teeth. Numerous Middle Stone Age artefacts embedded within these gravels point towards a long Pleistocene human occupation of the region, so fossil human remains are also a possibility, albeit a remote one (*cf* Late Pleistocene skull of *Homo sapiens* from alluvial deposits in the Eastern Cape Karoo near Hofmeyr, Grine *et al.* 2007). Well-developed calcrete hardpans southeast of De Aar display large calcretized plant root casts or rhizoliths (Almond 2012b) (Fig. 11).

Fig. 11. Irregular calcretised root casts or rhizoliths within well-developed surface calcretes to the southeast of De Aar (From Almond 2012b) (Hammer = 29 cm).

5. SCOPING LEVEL IMPACTS ASSOCIATED WITH THE DEVELOPMENT

During the construction phase excavations for the wind turbine and solar panel foundations, buried cables, transmission line pylons as well as new gravel access roads, substations and administration buildings may irreversibly disturb, damage or destroy fossil remains already exposed at the ground surface or embedded within sedimentary rocks underground. Mechanical clearance or levelling of substantial areas of ground may likewise have a significant negative impact on surface fossils. Infrastructure such as standing areas for wind turbines, lay down areas, building foundations and solar arrays may seal-in buried fossils over extensive tracts of land, although these impacts may not be permanent or irreversible. The operational and decommissioning phases of the wind and solar energy facilities will generally not involve further adverse impacts on palaeontological heritage, however.

A summary of the potential negative impacts is provided in Table 2 below.

Table 2. Summary of destruction, damage or disturbance of fossil remains potential impacts.

ISSUE	**Impact: destruction, damage or disturbance of fossil remains preserved at or beneath the ground surface**
DISCUSSION	Negative impacts confined to the construction phase and largely restricted to the development footprint, notably where extensive bedrock excavations occur (*e.g.* wind turbine foundations).
EXISTING IMPACT	Negligible, although fossils at or near the ground surface are constantly being destroyed by weathering and erosion.
PREDICTED IMPACT	Moderate to low, depending on siting of development footprint within the study area, local concentration of fossil heritage, and thickness of relatively unfossiliferous superficial deposits overlying fossil-bearing bedrocks within development footprint.
EIA INVESTIGATION REQUIRED	Yes. Specialist palaeontological field-based assessment of study area is necessary to assess palaeontological sensitivity of rock units represented here, distribution of fossils, and necessity for any further specialist studies and / or mitigation measures.
CUMULATIVE EFFECT	Predicted to be low as given that the majority of the site will potentially be retained once the infrastructure is in place.

6. CONCLUSIONS AND RECOMMENDATIONS

The lower-lying portions of the study area for the proposed wind energy and solar PV facilities at or near Renosterberg, to the north of De Aar, Northern Cape, are underlain at depth by offshore basinal to nearshore sediments of the Early to Middle Permian Ecca Group (Karoo Supergroup). These subaqueous deposits are variously assigned to the Tierberg Formation or Waterford Formation and are of moderate palaeontological sensitivity, containing locally abundant petrified woods, trace fossil assemblages (including possible large amphibian impressions) and microvertebrate remains (*e.g.* disarticulated teeth, scales of fish). Middle Permian fluvial sediments of the Lower Beaufort Group (Adelaide Subgroup, Karoo Supergroup) crop out along the slopes of the Renosterberg *koppies*, but are largely mantled by colluvial (slope) deposits here. These rocks have recently yielded rare but palaeontologically significant fossil remains of small therapsids ("mammal-like reptiles") and turtle-like parareptiles, *plus* occasional fossil plants and silicified woods, in the escarpment zone east of De Aar. The Ecca – Beaufort transition between subaqueous (Ecca Sea) and terrestrial depositional environments in the De Aar – Philipstown region is of geological interest and is recorded in the slopes of the escarpment zone east of De Aar as well as on isolated koppies such as Renosterberg and Tierberg to the north of De Aar. These *koppies* are capped by substantial sills of unfossiliferous dolerite of the Early Jurassic Karoo Dolerite Suite. Much of the subdued Ecca Group outcrop area is covered by a thin to thick (few dm to several meters) succession of Late Caenozoic (Neogene to Recent) superficial deposits such as alluvium, surface gravels, soils and calcrete hardpans. These younger rocks contain sparse, low diversity fossil assemblages such as rhizoliths (calcified plant root casts) and invertebrate burrows, but locally important vertebrate material (*e.g.* mammalian or reptilian bones and teeth) or even human remains may be expected here.

The same limited spectrum of rock units is represented within the broader "all-inclusive" study region encompassing all the infrastructural components of the proposed alternative energy facilities (including transmission lines, substations *etc*) and extending from the Renosterberg area itself southwards to De Aar and beyond. A sizeable area of Adelaide Subgroup rocks cropping out near the Eskom Hydra substation to the southeast of De Aar is of particular note.

The construction phase of the proposed Renosterberg wind and solar energy developments will entail substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock. These activities could potentially result in destruction, damage or disturbance of fossil remains preserved at or beneath the ground surfaceOnce constructed, the operational and decommissioning phases of the wind and solar energy facilities will not involve further adverse impacts on palaeontological heritage.

In view of the potential for significant impacts on fossil heritage within the Karoo Supergroup sediments (Ecca and Beaufort Groups), a pre-construction field assessment of all the land parcels involved in the proposed Renosterberg wind and solar energy developments is necessary as part of the EIA process. This field study should record significant fossil occurrences and horizons within the broader development footprint and make recommendations for any further specialist palaeontological studies or mitigation that should take place before or during the construction phase. These recommendations should also be incorporated into the Environmental Management Plan for the proposed alternative energy developments.

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Table 1: Palaeontological record and sensitivity of the major rocks units represented in the broader De Aar study region. Units highlighted in blue and (especially) red are known to contain significant fossil heritage.

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, invertebrate burrows), 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
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, reptiles) 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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8. QUALIFICATIONS & EXPERIENCE OF THE AUTHOR

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

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

Declaration of Independence

I, John E. Almond, declare that I am an independent consultant and have no business, financial, personal or other interest in the proposed alternative 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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