PALAEONTOLOGICAL SPECIALIST STUDY: PRELIMINARY DESKTOP SCREENING ASSESSMENT

Proposed Mainstream solar park near Douglas, Northern Cape Province

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SUMMARY

The company Mainstream Renewable Power Ltd is proposing to construct a photovoltaic solar park of 50 MW capacity on the western bank of the Orange River about 10 km southwest of Douglas, Northern Cape Province. The study area for the solar park near is underlain by (1) small areas of ancient Precambrian volcanic rocks (Allanridge Formation) that are unfossiliferous; (2) a small area of Permocarboniferous sediments of the Karoo Supergroup that are likely to be largely or entirely glacially-related deposits of the Dwyka Group (Mbizane Formation) of low to moderate palaeontological sensitivity. However, they may well also include marine beds of the lowermost Ecca Group (Prince Albert Formation) that are sometimes richly fossiliferous in the Douglas area (marine shells, fish, wood *etc*); (3) alluvial gravels associated with the Orange River system that are of Late Caenozoic to Recent age and may locally be highly fossiliferous (*e.g.* bones and teeth of extinct mammals); and (4) a large area Late Caenozic superficial sediments (wind-blown sands, calcretes, surface gravels *etc*) that are generally of low palaeontological sensitivity.

The overall impact significance of the proposed development is likely to be LOW because most of the study area is mantled by superficial sediments of low palaeontological sensitivity. Furthermore, extensive, deep excavations are unlikely to be involved in this sort of solar park project. In terms of fossil heritage the proposed development does not present any fatal flaws. While areas of *potentially* high palaeontological sensitivity can be mapped, it is not possible at this stage to identify no-go areas or buffer zones on the basis of the geological maps available since these do not clearly differentiate all the palaeontologically critical rock units near Douglas.

Since the proposed solar park may well have an impact on local fossil heritage, a permit application supported by a specialist palaeontological heritage study is required by SAHRA before development may proceed. Provided that the development footprint lies outside the outcrop area of the Prince Albert Formation (if actually present) and the various bodies of alluvial gravels, the significance of the proposed development in fossil heritage terms is low and a reasoned application to SAHRA for exemption from further specialist studies or permit applications is warranted.

If the development footprint overlaps the outcrop areas of the potentially fossil-rich alluvial gravels and / or the Karoo Supergroup, a pre-construction field assessment of these areas is needed to determine their actual palaeontological sensitivity (which may well prove to be low). The resulting report, to be submitted to SAHRA, should make specific recommendations for any no-go areas, buffer zones or specialist palaeontological mitigation required during the pre-construction or construction phases. The palaeontologist concerned with field assessment and mitigation work will need a valid fossil collection permit from SAHRA.

1. INTRODUCTION

The company Mainstream Renewable Power Ltd, Ireland, is proposing to construct a photovoltaic solar park of 50 MW capacity on the western bank of the Orange River about 10 km southwest of Douglas, Northern Cape Province (Fig. 1).

A detailed technical description for this project has not yet been developed. In brief, the development will entail the following major components of relevance to the present impact study:

1. Photovoltaic power plant:
   - Solar field of PV panel arrays (each 15m x 4m) supported on concrete or screw pile foundations and covering an area of approximately 300 ha;
   - Building infrastructure: administration buildings, possible warehouse, security facilities.

2. Associated infrastructure:
   - Buried or pole-mounted cables;
   - Transformers plus probable central sub-station adjacent to existing power line;
   - Access road and internal site road network (*c*. 10 m wide) with drainage trenches;
   - Fencing;
   - Permanent solar resource measuring station;
   - Lay-down area (temporary or permanent).

The Mainstream solar park near Douglas is to be located on 300 ha of land on Farm 5, Portion 1, Roode Kop and will be connected to the Ovaal Pumps substation. The proposed development area overlies unfossiliferous Precambrian rocks, potentially fossiliferous bedrock of Palaeozoic age (Karoo Supergroup) as well as a variety of Late Caenozoic superficial sediments, some of which may contain fossil remains.

The extent of the proposed development (over 5000 m^2) falls within the requirements for a Heritage Impact Assessment (HIA) as required by Section 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999). 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

Minimum standards for the palaeontological component of heritage impact assessment reports are currently being developed by SAHRA. The latest version of the SAHRA guidelines is dated May 2007.

The present desktop report forms part of a preliminary screening study of the proposed solar park and power line connection to the grid that is being carried out by the CSIR to identify any major environmental risks or threats to heritage resources and to propose appropriate mitigation.

2. APPROACH & METHODOLOGY

2.1. Details of specialist

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, Free State and Mpumalanga 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 APHAP (Association of Professional Heritage Assessment Practitioners – Western Cape).

2.2. General approach used for palaeontological impact desktop studies

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 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 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. Most detrimental impacts on palaeontological heritage occur during the construction phase when fossils may be disturbed, destroyed or permanently sealed-in during excavations and subsequent construction activity. Where specialist palaeontological mitigation is recommended, this may take place before construction starts or during the construction phase while fresh, portentially fossiliferous bedrock is still exposed for study. Mitigation usually involves the judicious sampling, collection and recording of fossils as well as of relevant contextual data concerning the surrounding sedimentary matrix. It should be emphasised that, *provided* appropriate mitigation is carried out, many developments involving bedrock excavation actually have a *positive* impact on our understanding of local palaeontological heritage. Constructive collaboration between palaeontologists and developers should therefore be the expected norm.

2.3. Terms of reference

The scope of work for the present palaeontological heritage screening assessment, as defined by the CSIR, is briefly as follows:

- Production of a basic series of maps illustrating identified heritage features and identified sensitive areas. The mapping indicating the potential risks linked to the proposed activities shall represent a zoning of the area on a low-medium-high sensitivity rating, with indication of any identified „no-go" areas or recommended buffer zones, for the proposed activities where the panels should not be located.

- Description of the site in terms of heritage features supported by expert scientific advice, a brief discussion focused on sensitivity rating for each locality with indication of any identified „no-go" areas for the proposed activities where the panels should not be located.

- Reference to any relevant information on potential issues related to future planning and any potential fatal flaws due to the proposed project and proposed facilities.

- Recommendations of practical measures which can be incorporated into the planning of the project that will result either in the avoidance of potentially significant negative environmental impacts or their mitigation to the extent that residual effects fall within acceptable limits; and enhancement of positive aspects of the project shall be indicated; as well as an estimation of the carrying capacity of the site for solar energy development in terms of environmental / social criteria within the specialists expertise.

- Brief recommendation of possible baseline studies to address specific environmental and social issues that may require a greater level of understanding before proceeding to an EIA.

2.4. Information sources

The information used in this fossil heritage screening study was based on the following:

1. A short project outline provided by CSIR Consulting and Analytical Services, Stellenbosch;

2. A review of the relevant scientific literature, including published geological maps and accompanying sheet explanations as well as recent palaeontological impact studies in the same region (notably Almond 2010a, 2010b, 2010c, 2010d);

3. The author"s previous field experience with the formations concerned and their palaeontological heritage (*e.g.* Almond 2010b);

2.5. 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 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 present case two specific factors constrain the reliability of the assessment of fossil heritage within the development area:

- The lack of a published sheet explanation for the relevant 1: 250 000 geological map (sheet 2922 Prieska);

- The uncertainty concerning the presence or absence within the study area of the rock units of high palaeontological sensitivity - notably the Prince Albert Formation and older alluvial gravels associated with the Orange River drainage system. These rock units are not clearly defined on the 1: 250 000 scale geological map available.

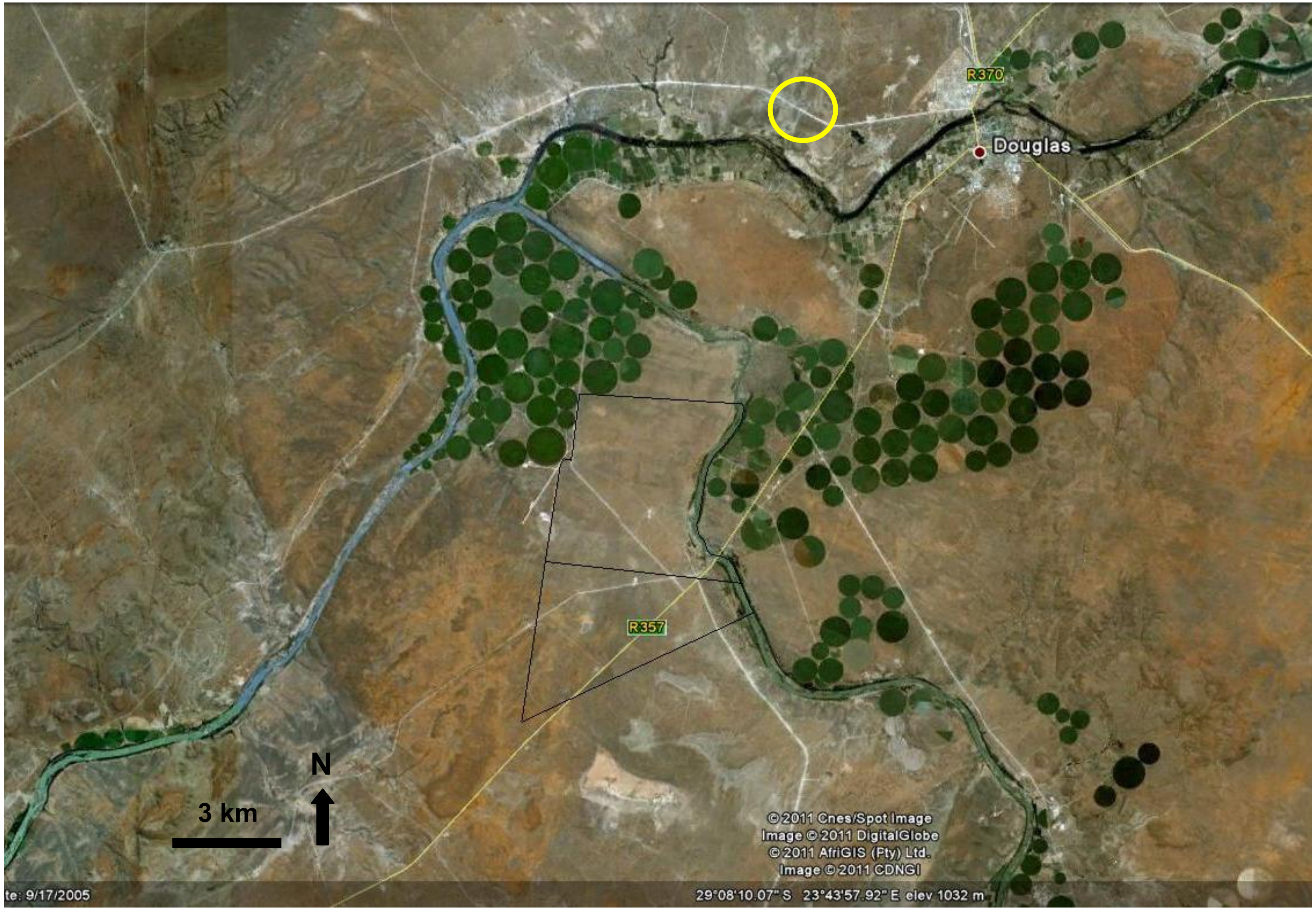

Fig. 1. ***Google Earth*® satellite image showing the location (black polygons) of the proposed Mainstream photovoltaic solar park on the western bank of the Orange River about 10 km southwest of Douglas, Northern Cape Province. The Stratotype C section of the Mbizane Formation (Dwyka Group) north of the Vaal River is indicated by the yellow circle.**

3. DESCRIPTION OF THE STUDY AREA

3.1. Location and brief description of study area

As shown in the satellite image in Figure 1 the study area for the proposed Mainstream PV solar park (Farm 5, Portion 1, Roode Kop) is located in fairly flat-lying, semi-arid terrain at *c*. 1000 m amsl on the west bank of the Orange River some 10 km southwest of Douglas in the Northern Cape Province. The confluence of the Vaal and Orange Rivers lies about 10 km to the northwest. The area is traversed by the R357 Douglas to Prieska road. Most of the study area is mantled in geologically recent (Late Tertiary / Quaternary) superficial deposits with small areas of bedrock exposure mapped only along the southwestern and southeastern margins. Windblown sands mantle much of the northern portion, with WNW-ESE trending dune ridges visible on satellite images, and there is a small pan (Googatjiespan) in the southern portion.

3.2. Geology of the study area

The geology of the study area around Douglas is shown on the 1: 250 000 geology map 2922 Prieska (Council for Geoscience, Pretoria; Fig. 2 herein). The explanation for the Prieska geological map has not yet been published and therefore some details of the local stratigraphy relevant to the present impact study remain ambiguous. However, several of the rock units mapped here are treated in some detail in the explanations for the Britstown sheet to the south (Prinsloo, 1989) and the Koffiefontein sheet to the east (Zawada,1992). A number of previous palaeontological impact studies dealing with these rock units in the Douglas area have been carried out by Almond (2010a, 2010b, 2010c, 2010d). In particular, the study by Almond (2010b) involved field examinations of Early Precambrian, Palaeozoic and Late Caenozoic rocks that are directly relevant to the present Mainstream solar park project.

According to the 1: 250 000 geology map (Fig. 2) the study area of the proposed Mainstream PV solar park is largely mantled in superficial sediments of Late Caenozoic age. These include **Late Tertiary to Quaternary calcretes** (**T-Qc**; *i.e.* carbonate-cemented surface deposits) towards the south, unconsolidated **aeolian (*i.e.* wind-blown) sands** (**Qs**) of the **Kalahari Group** (**Gordonia Formation**) in the north, a small outlier of **ancient alluvial gravels** (double “flying bird” symbol) in the west-central area, as well as **younger alluvial sediments** (single “flying bird” symbol) along the banks of the Orange River. Narrow stringers and sheets of geologically recent alluvial or down-wasted gravels and finer sediments (*e.g.* sheet wash) can be expected at surface in many areas. Fine-grained sediments (*e.g.* silts, fine sands, clays) as well as possible evaporites (salt deposits) and calcretes are generally associated with pans, such as those mapped in the southern part of the study area (Partridge & Scott 2000, Partridge *et al.* 2006).

Small exposures of the Permocarboniferous **Dwyka Group** (**C-Pd, Karoo Supergroup**) are mapped along the western banks of the Orange River in the south-eastern corner of the study area as well as just to the north of the area. It is likely that these Palaeozoic sediments also underlie a substantial portion of the entire study area beneath the superficial sediment cover. As discussed below, the Dwyka Group in the Douglas area is, at least locally, overlain by highly fossiliferous mudrocks of the **Prince Albert Formation** (**Ecca Group**), but unfortunately this rock unit is *not* mapped separately in Fig. 2 (probably for reasons of scale). The geology and palaeontology of these Karoo Supergroup units are reviewed in Sections 3.2.2, 3.2.2, 4 and the Appendix to this report.

The Late Caenozoic and Karoo Supergroup sediments in the Douglas area unconformably overlie much older (> 2.65 Ga = billion years) Precambrian basement rocks, *viz*:

- Late Archaean volcanic rocks – predominantly dark green lavas with overlying volcaniclastic sediments - of the **Allanridge Formation** (**Ra**) within the **Ventersdorp Supergroup** which is dated at approximately 2.7 Ga (Van der Westhuizen *et al.* 2006). Small inliers of these igneous rocks are mapped on the western margins of Farm 5.

- Late Archean sediments of the **Vryburg Formation** (**Vv**) situated stratigraphically between the Venterdorp Subgroup and the base of the Ghaap Group. This fluvial to marginal marine succession is predominantly siliciclastic (quartzites, shales, conglomerates) but may contain minor stromatolitic carbonates. Associated lavas have been dated to 2.6 Ga (Eriksson *et al*., 2006). A small exposure of these ancient basement rocks is mapped on the north banks of the Orange River just to the north of the study area.

Since these Early Precambrian rocks are either unfossiliferous (Allanridge Formation) or unproven within the study area itself (Vryburg Formation) they will not be considered further here. Furthermore, recent field examination of Vryburg Formation streambed exposures (largely quartzitic sandstones or wackes) on the north bank of the Vaal River some 6km west of Douglas did not reveal any carbonate horizons or fossil heritage (Almond 2010b), which is not surprising given their considerable age.

3.2.1. Superficial deposits: Kalahari Group sands, calcretes, alluvial gravels

Unconsolidated aeolian (*i.e.* wind-blown) sands of the Quaternary **Gordonia Formation** (**Kalahari Group**) (**Qs** in Fig. 2) blanket large areas of the landscape in the Douglas area. To the southwest of town these sands form a series of bands stretching WNW-ESE from the Orange River. The geology of the Late Cretaceous to Recent Kalahari Group is reviewed by Thomas (1981), Dingle *et al.* (1983), Thomas & Shaw 1991, Haddon (2000) and Partridge *et al.* (2006). The Gordonia dune sands are considered to range in age from the Late Pliocene / Early Pleistocene to Recent, dated in part from enclosed Middle to Later Stone Age stone tools (Dingle *et al*., 1983, p. 291). Note that the recent extension of the Pliocene - Pleistocene boundary from 1.8Ma back to 2.588 Ma would place the Gordonia Formation almost entirely within the Pleistocene Epoch.

A number of older Kalahari formations underlie the young wind-blown surface sands in the main Kalahari depository to the north of the study area (Fig. 3). However, at the latitude of Douglas (*c*. 29° S) Gordonia Formation sands less than 30m thick are likely to be the main or perhaps only Kalahari sediments present (*cf* isopach map of the Kalahari Group, fig. 6 *in* Partridge *et al*., 2006). These unconsolidated sands might be locally underlain by thin surface gravels equivalent to the **Obobogorop Formation**, formed from down-wasted (residual) or water-transported clasts weathered out of the Dwyka tillites, as well as by pebbly calcretes of Plio-Pleistocene age or younger. Indeed, the extensive **calcretes** (**T-Qc**) overlying the Karoo Supergroup and older basement rocks in the Douglas area, forming a broad band either side of the Orange River, may be, at least in part, stratigraphically equivalent to the **Mokalanen Formation** of the Kalahari Group (Fig. 3). According to Zawada (1992) calcretes are especially well developed overlying the Ecca Group outcrop in the Koffiefontein sheet area to the east of Douglas. The commonest type in this region are the so-called Second Intermediate Calcretes that contain Middle Stone Age tools dated between *c*. 300 000 and 50 000 years, indicating a Pleistocene age (Note that Partridge *et al*., 2006, suggest an older, Late Pliocene, age for the Mokalanen Formation proper). Older calcretes are associated with calcified alluvial gravels (see below), and younger ones form hard pans adjacent to extant pans (Potgieter 1974). The thickness of these surface calcretes is not specified, but is unlikely to exceed a few meters in most areas.

Relict patches of elevated Late Tertiary to Quaternary **alluvial gravels** ("High Level Gravels") are mapped along both the Vaal and Orange Rivers in the Windsorton – Kimberley – Douglas - Prieska area, where they have been associated with diamond mining (De Wit *et al*., 2000, their table 4.1 and fig. 4.1; DA in Fig. 2). In the Windsorton area to the northeast of Douglas heavily calcretized "Older Gravels" have been grouped into the **Windsorton Formation** and are suspected to be Miocene-Pliocene in age (Partridge & Brink 1967, De Wit *et a*l., 2000, Partridge *et al.* 2006). The isolated patch of older alluvial gravels on Marktsdrift 3, close to the Vaal – Orange River confluence (Fig. 2) may belong to this stratigraphic unit. Coarse, heavily-calcretised, polymict gravels of alluvial to colluvial origin found in the Douglas area have been briefly described and illustrated by Almond (2010b).

The "Younger Gravels" (**Rietputs Formation**) of the Vaal River system, at lower elevations, are associated with Acheulian stone tools and are therefore considered to be Early to Middle

Pleistocene (Cornelian) in age (Klein 1984, Table 2, Butzer *et al*., 1973, Partridge *et al*., 2006). Recent cosmogenic nuclide dating of coarse gravels and sands in the Rietputs Formation gave an age of *c*. 1.57 Ma (Gibbon *et al.,* 2009). The younger alluvial gravels mapped along the western banks of the Orange River in the Mainstream solar park study area are likely to be of similar age. Thick silty alluvium containing fossiliferous conglomeratic lenses was observed along the Vaal River at Blaauwboschdrift to the north of the study area by Almond (2010b).

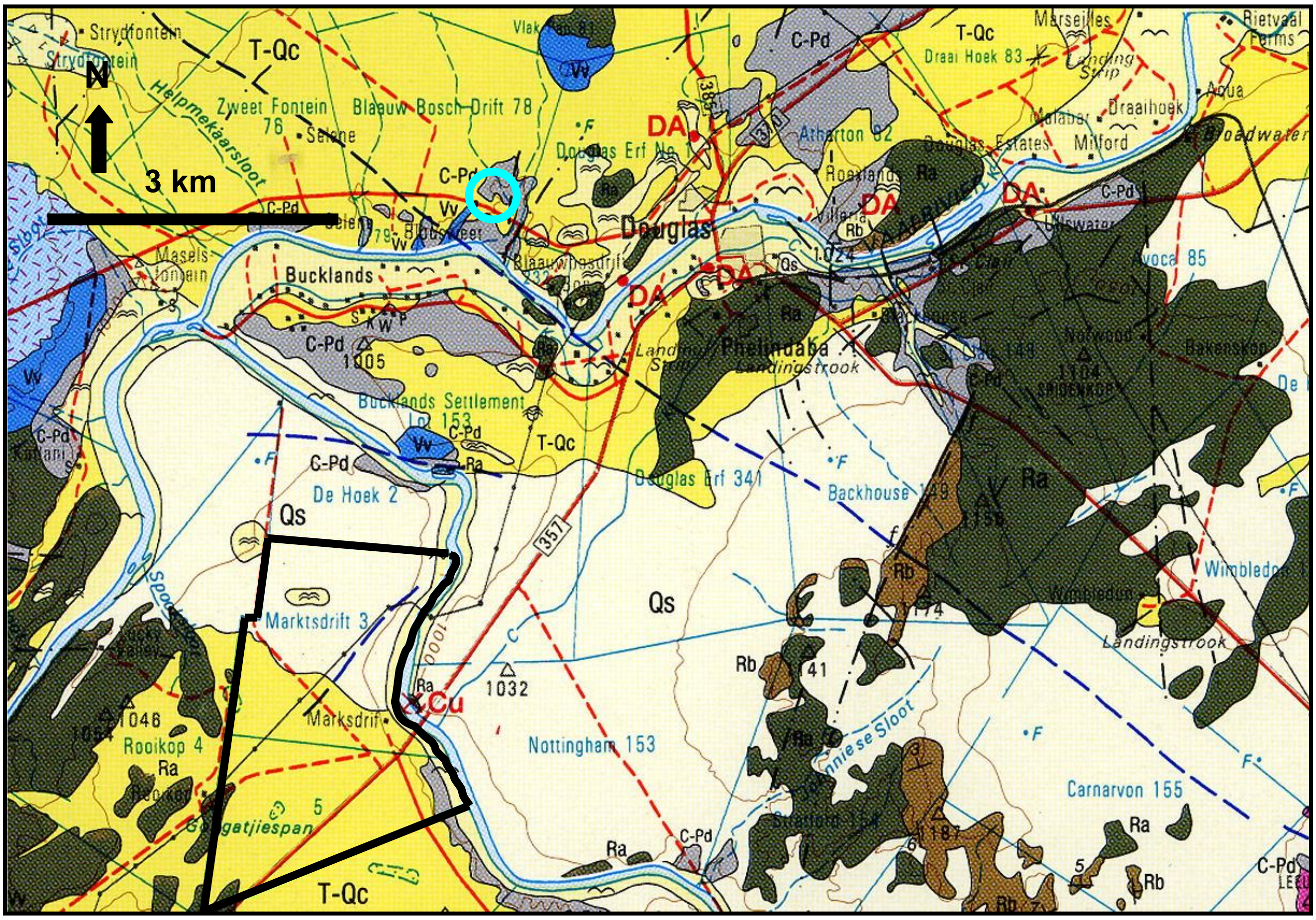

Fig. 2. Extract from 1: 250 000 geological map 2922 Prieska (Council for Geoscience, Pretoria) showing location of proposed Mainstream PV solar park study area *c*. 10 km southwest of Douglas (black polygon). The pale blue circle to the north indicates the Stratotype C section of the Mbizane Formation (Dwyka Group) designated by Von Brunn & Visser (1999). This section is capped by mudrocks of Prince Albert Formation (Ecca Group) which are *not* separately indicated on the map.

Dark Blue (Vv) = Vryburg Formation (Ghaap Group); Dark Grey (Ra) = Allanridge Formation (Ventersdorp Supergroup); Grey (C-Pd) = Dwyka Group *plus* Prince Albert Formation of Ecca Group; Yellow (T-Qc) = Neogene (Late Tertiary) calcrete; Very pale yellow (Qs) = Quaternary to Recent sands and sandy soil of the Gordonia Formation (Kalahari Group); Pale Yellow (with double "flying bird" symbol) = Neogene (Late Tertiary) to Pleistocene alluvial gravels; Pale Yellow (with single "flying bird" symbol) = Pleistocene to Recent alluvium. DA marks ancient High Level Gravels associated with alluvial diamond occurrences close to the Orange and Vaal Rivers.

Refer to Table 1 for an assessment of the palaeontological sensitivity of the various rock units represented within the study area.

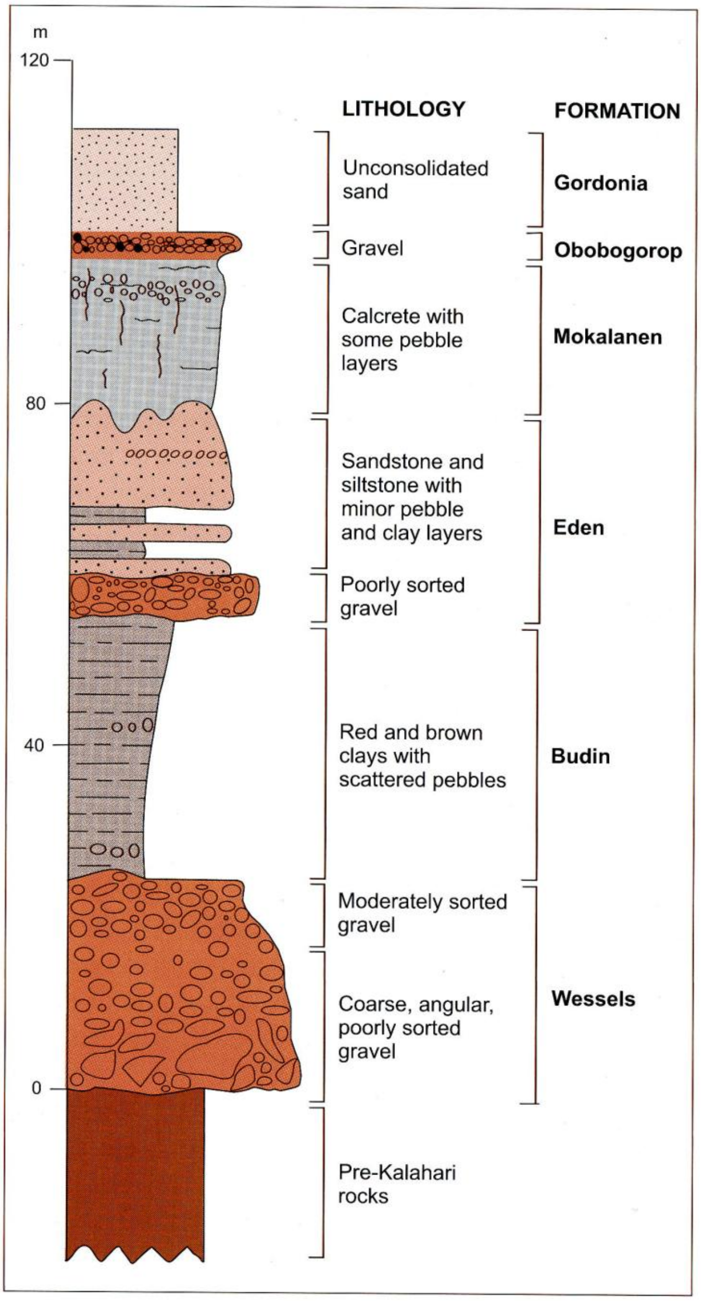

Fig. 3. Stratigraphy of the Kalahari Group (From Partridge *et al.,* 2006). Aeolian sands of the Gordonia Formation as well as calcretes possibly equivalent to the Mokalanen Formation are represented in the Douglas study area.

3.2.2. Dwyka Group

Permocarboniferous glacial sediments of the **Dwyka Group** (**C-Pd** in Fig. 2) underlie the thin, superficial cover of Gordonia sands and calcrete close to the confluence of the Orange and Vaal Rivers near Douglas. The geology of the Dwyka Group has been summarized by Visser (1989), Visser *et al.* (1990) and Johnson *et al.* (2006), among others.

The geology of the Dwyka Group along the north-western margin of the Main Karoo Basin in particular has been reviewed by Visser (1985), but this study only extends as far east as Prieska. Other studies on the Dwyka in or near the Prieska Basin include those by Visser *et al.* (1977-78; summarized by Zawada 1992) and Visser (1982). Fairly detailed observations by Prinsloo (1989) on the Dwyka beds on the northern edge of the Britstown 1: 250 000 geology sheet are in part relevant to the more proximal (near-source) outcrops at Douglas. Massive tillites at the base of the

Dwyka succession (Elandsvlei Formation) were deposited by dry-based ice sheets in deeper basement valleys. Later climatic amelioration led to melting, marine transgression and the retreat of the icesheets onto the continental highlands in the north. The valleys were then occupied by marine inlets within which drifting glaciers deposited dropstones onto the muddy sea bed ("boulder shales"). The upper Dwyka beds are typically heterolithic, with shales, siltstones and fine-grained sandstones of deltaic and / or turbiditic origin. These upper successions are typically upwards-coarsening and show extensive soft-sediment deformation (loading and slumping). Varved (rhythmically laminated) mudrocks with gritty to fine gravely dropstones indicate the onset of highly seasonal climates, with warmer intervals leading occasionally even to limestone precipitation.

According to maps in Visser *et al.* (1990) and Von Brunn and Visser (1999) the Dwyka rocks in the Douglas - Prieska area close to the northern edge of the Main Karoo Basin belong to the **Mbizane Formation**. This is equivalent to the Northern (valley and inlet) Facies of Visser *et al*. (1990). The Mbizane Formation, up to 190m thick, is recognized across the entire northern margin of the Main Karoo Basin where it may variously form the whole or only the *upper* part of the Dwyka succession. It is characterized by its extremely heterolithic nature, with marked vertical and horizontal facies variation (Von Brunn & Visser 1999). The proportion of diamictite and mudrock is often low, the former often confined to basement depressions. Orange-tinted sandstones (often structureless or displaying extensive soft-sediment deformation, amalgamation and mass flow processes) may dominate the succession. The Mbizane-type heterolithic successions characterize the thicker Dwyka of the ancient palaeovalleys cutting back into the northern basement rocks. The key Reference Stratotype C section for the valley fill facies of the Mbizane Formation is in fact located a few kilometres west of Douglas on the northern side of the Vaal River (Von Brunn & Visser 1999 map fig. 9 and section fig. 10; see Figs 1, 2 herein). The composite section, which overlies glacially-striated Precambrian bedrock (Vryburg Formation), is some 25-30m thick. The lower part of the section consists of massive diamictites with subordinate conglomerates and siltstones. The upper half is dominated by laminated mudrocks with thin diamictites, lonestones (dropstones) and calcareous concretions. The section is conformably overlain by mudrocks of the Prince Albert Formation (lowermost Ecca Group). A brief, illustrated description of these glacially-related sediments is given by Almond (2010b).

3.2.3. Lower Ecca Group

Basinal sediments of the Lower Ecca Group are *not* separately mapped in the Douglas area on the 1:250 000 geology sheet 2922 Prieska, probably for reasons of scale. However, it is clear from detailed studies of the upper Dwyka succession near Douglas by McLachlan and Anderson (1973) as well as Von Brunn and Visser (1999) *plus* the more regional account of the Lower Karoo succession in the Kimberley – Britstown area by Visser *et al.* (1977-78) and fieldwork by Almond (2010b) that the Dwyka Group here is at least locally overlain by laminated mudrocks of the **Prince Albert Formation** of the Ecca Group. This unit of Early Permian (Asselian / Artinskian) age was previously known as "Upper Dwyka Shales". Key geological accounts of this formation are given by Visser (1992) and Cole (2005).

The Prince Albert Formation in the Kimberley - Britstown area consists predominantly of well-laminated basinal mudrocks (shales, siltstones) that are sometimes carbonaceous or pyritic and typically contain a variety of diagenetic concretions enriched in iron and carbonate minerals (Zawada 1992). Some of these carbonate concretions are richly fossilferous (See Section 4 and Appendix). Much of the Ecca shale outcrop has been modified by surface calcretization (Zawada 1992). Exposures in incised river banks near Douglas are described by McLachlan and Anderson (1973; Fig. 4). The Ecca beds here are mantled with a thin veneer (*c*. 3m) of intrusive dolerite, Quaternary calcrete and reddish Kalahari sands (= Gordonia Formation). They mainly comprise shales with a band of ferruginous carbonate as well as a 6m-thick zone of fossiliferous calcareous concretions that lies 9m above the base of the formation.

Due to insufficient detail on the available 1: 250 000 scale geological maps, it is unclear whether or not potentially fossiliferous Prince Albert Formation is present at surface or perhaps beneath younger surface deposits in the Mainstream solar park study area near Douglas. However, its presence here is possible since the Prince Albert formation is definitely found above the Stratotype C section of the Mbizane Formation, Dwyka Group (Von Brunn & Visser 1999) come 10 km to the north of the study area as well as in the key Vaal River sections of "Upper Dwyka Shales" described by McLachlan and Anderson (1973), located about 35 km northeast of Douglas (See also Almond 2010b).

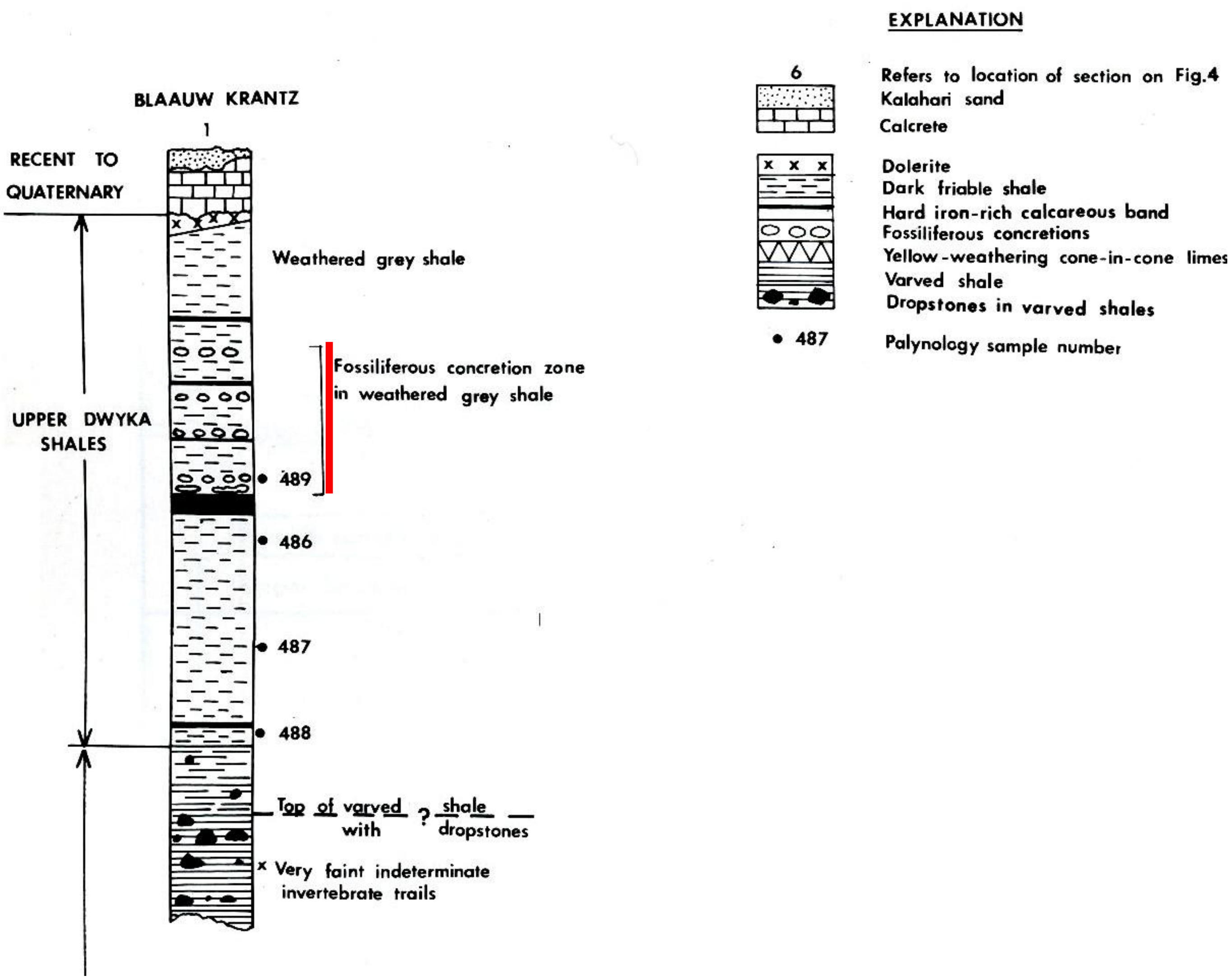

Fig. 4. Vertical section through the Dwyka / Ecca contact beds east of Douglas. The vertical scale is approx. 1cm = 3m. A 6m-thick zone rich in fossiliferous concretions within the Prince Albert Formation ("Upper Dwyka Shales") is emphasized by the red line. Note the Ecca beds are mantled here with a thin veneer (*c*. 3m) of dolerite, calcrete and Kalahari sands (= Gordonia Formation) (From McLachlan & Anderson 1973).

4. PALAEONTOLOGICAL HERITAGE

The fossil assemblages recorded within each of the main rock units that are mapped within the study region near Douglas are briefly outlined here in tabular form (Table 1), together with an indication of their inferred palaeontological sensitivity (*cf* review of Northern Cape Fossil Heritage by Almond & Pether 2008). Following geological convention, the rock units are listed in stratigraphic order with the oldest units at the bottom of the table and the youngest at the top.

Supplementary information supporting this palaeontological review is given in Appendix 1 and full references are given in Section 8 below.

TABLE 1: FOSSIL HERITAGE IN THE DOUGLAS AREA				
GEOLOGICAL UNIT	**ROCK TYPES & AGE**	**FOSSIL HERITAGE**	**PALAEONT-OLOGICAL SENSITIVITY**	**RECOMMENDED MITIGATION**
Gordonia Formation (Qs) **KALAHARI GROUP** ***plus*** **SURFACE CALCRETE (T-Qc)**	**mainly aeolian sands *plus* minor fluvial gravels, freshwater pan deposits, calcretes** **PLEISTOCENE to RECENT**	**calcretised rhizoliths & termitaria, ostrich egg shells, land snail shells, rare mammalian and reptile (*e.g.* tortoise) bones, teeth** **freshwater units associated with diatoms, molluscs, stromatolites *etc***	**LOW**	**none recommended** **any substantial fossil finds to be reported by ECO to SAHRA**
YOUNGER ALLUVIAL DEPOSITS	**mainly unconsolidated gravels and finer-grained alluvium (*e.g.* silts)** **POSSIBLY MID-PLEISTOCENE to RECENT**	**diverse mammalian fossils (bones, teeth, horncores), Acheulian or younger stone artefacts**	**LOCALLY HIGH**	**pre-construction field assessment by professional palaeontologist**
OLDER "HIGH LEVEL" ALLUVIAL GRAVELS	**alluvial gravels (often heavily calcretised)** **POSSIBLY MIOCENE to MID PLEISTOCENE**	**sparse vertebrate remains (poorly recorded)**	**LOCALLY HIGH**	**pre-construction field assessment by professional palaeontologist**

Table 1 is continued below.

TABLE 1 *continued* : FOSSIL HERITAGE IN THE DOUGLAS AREA				
GEOLOGICAL UNIT	**ROCK TYPES & AGE**	**FOSSIL HERITAGE**	**PALAEONT-OLOGICAL SENSITIVITY**	**RECOMMENDED MITIGATION**
Prince Albert Formation (within C-Pd) **ECCA GROUP**	**basinal mudrocks with calcareous concretions** **EARLY PERMIAN**	**marine invertebrates (esp. molluscs, brachiopods), coprolites, palaeoniscoid fish & sharks, trace fossils, various microfossils, petrified wood**	**HIGH IN DOUGLAS REGION**	**pre-construction field assessment by professional palaeontologist**
Mbizane Formation (C-Pd) **DWYKA GROUP**	**tillites, interglacial mudrocks, deltaic & turbiditic sandstones, minor thin limestones** **LATE CARBONIFER-OUS – EARLY PERMIAN**	**sparse petrified wood & other plant remains, palynomorphs, trace fossils (*e.g.* arthropod trackways, fish trails, U-burrows) possible stromatolites in limestones**	**LOW TO MODERATE** **(*N.B.* stratotype section in the Douglas area)**	**pre-construction field assessment by professional palaeontologist**
Allanridge Formation (Ra) **VENTERSDORP SUPERGROUP**	**lavas and volcaniclastic sediments** **LATE ARCHAEAN**	**no fossils recorded**	**LOW**	**none recommended** **any substantial fossil finds to be reported by ECO to SAHRA**

N.B. Please note that the presence of fossiliferous exposures of the Prince Albert Formation (Ecca Group) and Miocene / Pleistocene alluvial deposits within the study area cannot be determined from the available 1: 250 000 scale geological maps or satellite images, nor are these units invariably fossil-rich. For example, the thin-bedded Prince Albert Formation rocks are often extensively disrupted by calcrete formation in this region, lowering their palaeontological heritage value in many areas. The precautionary principle has been applied here in ranking the palaeontological sensitivity of the alluvial gravels and Karoo Supergroup outcrop area as high. It is quite possible that (a) the Karoo sediments here belong entirely to the glacially-influenced Mbizane Formation and contain few or no fossils; (b) the alluvial gravels present are only sparsely fossiliferous. A site visit would be required to more accurately assess the actual palaeontological sensitivity of these rock units.

A preliminary palaeontological sensitivity map of the Mainstream solar park study area near Douglas is given in Fig. 5 below, largely based on the 1: 250 000 Prieska geology map and Table 1 above.

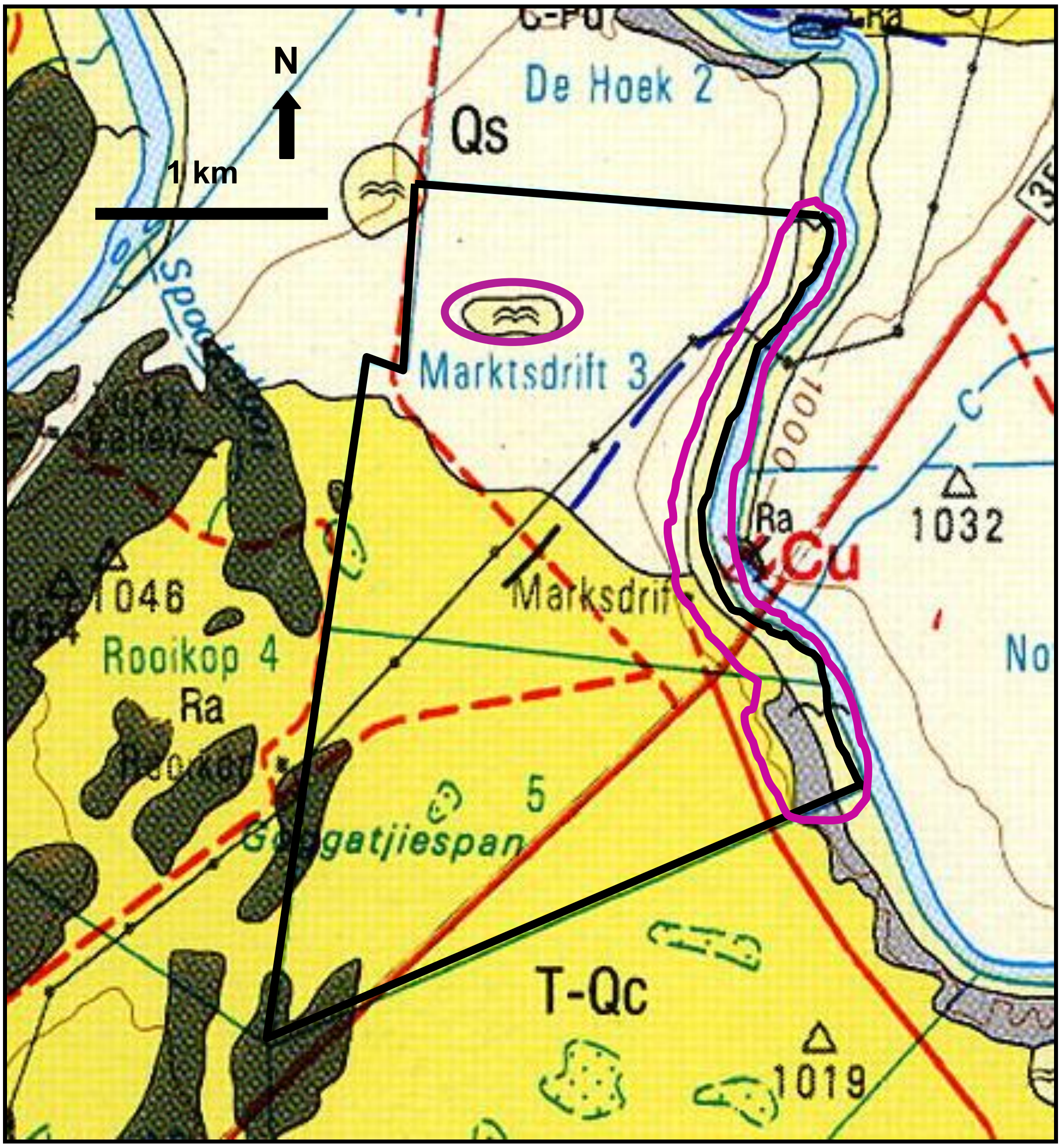

Fig. 5. Enlarged extract from 1: 250 000 geological map 2922 Prieska (Council for Geoscience, Pretoria) showing the outline of the proposed Mainstream PV solar park study area *c*. 10 km southwest of Douglas (black polygon). See Figure 2 above for broader geological context and list of rock units represented.

Sectors of potentially HIGH palaeontological sensitivity within the study area are outlined in LILAC. These include (a) alluvial gravels of various ages along the Orange River and to the west (pale yellow with single or double "flying bird" symbols) and (b) Karoo Supergroup sediments in the south-eastern corner of the study area (Dwyka and / or Ecca Groups) (grey).

The remainder of the study area is assessed to be of LOW palaeontological sensitivity.

5. INDENTIFICATION OF POTENTIAL IMPACTS *plus* RECOMMENDED MITIGATION

The proposed Mainstream solar park near Douglas is located in an area that is in part underlain by potentially fossil-rich sedimentary rocks of (a) the Karoo Supergroup that are of Permocarboniferous age as well as (b) Late Caenozoic alluvial gravels (Table 1 and Figure 5).

The construction phase of the development will entail fresh excavations into the superficial sediment cover (soils, alluvium *etc*) and perhaps also into the underlying bedrock. These notably include excavations for the solar panel foundations, buried cables (probably around 1m deep), new gravel roads with drainage trenches, and associated building infrastructure. In addition, sizeable areas of bedrock may be sealed-in or sterilized by infrastructure such as a lay down area (this may well be temporary, however), ancillary buildings (*e.g.* administration building, warehouse) as well as the new gravel road system.

All these developments may adversely affect fossil heritage at or near the surface 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 energy facility will not involve further adverse impacts on palaeontological heritage, however.

The overall impact significance of the proposed development is likely to be LOW because:

- Most of the study area is mantled by superficial sediments of low palaeontological sensitivity;
- Extensive, deep excavations are unlikely to be involved in this sort of solar park project.

However, significant negative impacts on local fossil heritage *may* occur if excavations are carried out within those sectors identified as of potentially high palaeontological sensitivity in map Fig. 5.

If the development footprint lies within these identified areas, the potential negative impacts of the proposed development can be substantially reduced by *pre-construction* field assessment by a professional palaeontologist of study area sectors identified as of potentially high sensitivity. The purposes of the field assessment study would be (a) to identify the rock units actually present, especially given the ambiguities regarding the available geological maps, (b) to carry out judicious sampling of any fossil heritage currently exposed, together with pertinent geological and palaeontological data, (c) to determine the likely impact of the proposed development on local fossil heritage based on the new field-based information, and finally (d) to make recommendations for any no-go areas, buffer zones or further palaeontological mitigation deemed necessary for this project (*e.g.* comprehensive pre-construction sampling of near-surface surface fossil material, palaeontological monitoring of excavations). Note that further mitigation may be most useful during the construction phase of the development while fresh, potentially fossiliferous bedrock is still exposed.

As previously noted, *provided* appropriate mitigation is carried out, many developments involving fresh excavation of fossiliferous sedimentary rocks actually have a *positive* impact on our understanding of local palaeontological heritage.

If the development footprint is confined to areas designated as of low palaeontological sensitivity (Fig. 5) then a reasoned recommendation to the responsible heritage authority (SAHRA) by a professional palaeontologist for exemption from further specialist palaeontological studies or permit requirements is necessary.

In all cases, whether or not a professional palaeontologist is involved in mitigation:

- The ECO responsible for the development should be aware of the possibility of important fossils being present or unearthed on site and should monitor all substantial excavations into fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;

- In the case of any significant fossil finds (*e.g.* vertebrate teeth, bones, burrows, petrified wood) during construction, these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to the relevant heritage management authority (SAHRA) so that any appropriate mitigation by a palaeontological specialist can be considered and implemented, at the developer"s expense;

- These recommendations should be incorporated into the EMP for the solar park development.

5. RELEVANT LEGISLATIVE AND PERMIT REQUIREMENTS

According to the National Heritage Resources Act (Act 25 of 1999, Sections 3 and 35) all geological sites of scientific or cultural importance, palaeontological sites, palaeontological objects and material, meteorites and rare geological specimens are regarded as part of the National Estate and are protected by law.

According to Section 35 of the Act, no person may, without a permit issued by the responsible heritage resources authority:

- destroy, damage, excavate, alter, deface or otherwise disturb any palaeontological site;
- destroy, damage, excavate, remove from its original position, collect or own any palaeontological material or object;
- trade in, sell for private gain, export or attempt to export from the Republic any category of palaeontological material or object; or
- bring onto or use at a palaeontological site any excavation equipment or any equipment which assist in the detection or recovery of palaeontological material or objects.

The extent of the proposed solar park development (over 5000 m^2) falls within the requirements for a Heritage Impact Assessment (HIA) as required by Section 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999). A specialist palaeontological study would form an essential part of such a HIA and its conclusions and recommendations would need to be combined with those of other heritage specialists as an integrated heritage study.

As already noted in Section 4, if the development footprint is confined to areas designated as of low palaeontological sensitivity then a formal recommendation to the responsible heritage authority (SAHRA) by a professional palaeontologist for exemption from further specialist palaeontological studies or permit requirements is necessary.

The palaeontologist concerned with any necessary field assessment and mitigation work will need a valid fossil collection permit from SAHRA.

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

6. DISCUSSION & CONCLUSIONS

The study area for the proposed Mainstream solar park near Douglas is underlain by (1) small areas of ancient Precambrian volcanic rocks (Allanridge Formation) that are unfossiliferous; (2) a small area of Permocarboniferous sediments of the Karoo Supergroup that are likely to be largely or entirely glacially-related deposits of the Dwyka Group (Mbizane Formation) of low to moderate palaeontological sensitivity, but may well include marine beds of the lowermost Ecca Group (Prince Albert Formation) that are sometimes richly fossiliferous in the Douglas area (marine shells, fish, wood *etc*); (3) alluvial gravels associated with the Orange River system that are of Late Caenozoic to Recent age and may locally be highly fossiliferous (*e.g.* bones and teeth of extinct mammals); and (4) a large area Late Caenozic superficial sediments (wind-blown sands, calcretes, surface gravels *etc*) that are generally of low palaeontological sensitivity.

The overall impact significance of the proposed development is likely to be LOW because most of the study area is mantled by superficial sediments of low palaeontological sensitivity. Furthermore, extensive, deep excavations are unlikely to be involved in this sort of solar park project.

Since the proposed solar park may well have an impact on local fossil heritage, however, a permit application supported by a specialist palaeontological heritage study is required by SAHRA before development may proceed. Provided that the development footprint lies outside the outcrop area of the Prince Albert Formation (if actually present) and the various bodies of alluvial gravels, the significance of the proposed development in fossil heritage terms is low and a reasoned application to SAHRA for exemption from further specialist studies or permit applications is warranted.

If the development footprint overlaps the outcrop areas of the potentially fossil-rich sedimentary units mentioned earlier (*i.e.* alluvial gravels, Karoo Supergroup), a pre-construction field assessment of these areas is needed to determine their actual palaeontological sensitivity (which may well prove to be low). The resulting report, to be submitted to SAHRA, should make specific recommendations for any no-go areas, buffer zones or specialist mitigation required during the pre-construction or construction phases. The palaeontologist concerned with field assessment and mitigation work will need a valid fossil collection permit from SAHRA.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

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

ALMOND, J.E. 2008b. Palaeozoic fossil record of the Clanwilliam sheet area (1: 250 000 geological sheet 3218). Unpublished report for the Council for Geoscience, Pretoria, 49 pp. (To be published by the Council in 2009).

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

ALMOND, J.E. 2010a. Proposed photovoltaic power station adjacent to Herbert Substation near Douglas, Northern Cape Province: desktop study, 23 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2010b. Proposed photovoltaic power station adjacent to Herbert Substation near Douglas, Northern Cape Province: field scoping study, 23 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2010c. Proposed photovoltaic power station adjacent to Greefspan Substation near Douglas, Northern Cape Province: desktop study, 22 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. 2010d. Proposed photovoltaic power station adjacent to Ovaal Substation near Douglas, Northern Cape Province: recommended exemption from further palaeontological studies, 22 pp. Natura Viva cc, Cape Town.

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

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

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

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

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

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

ANDERSON, J.M. 1977. The biostratigraphy of the Permian and the Triassic. Part 3: A review of Gondwana Permian palynology with particular reference to the northern Karoo Basin, South Africa. Memoirs of the Botanical Survey of South Africa 45, 14-36.

ANDERSON, J.M. & ANDERSON, H.M. 1985. Palaeoflora of southern Africa. Prodromus of South African megafloras, Devonian to Lower Cretaceous, 423 pp, 226 pls. Botanical Research Institute, Pretoria & Balkema, Rotterdam.

BAMFORD, M.K. 2000. Fossil woods of Karoo age deposits in South Africa and Namibia as an aid to biostratigraphical correlation. Journal of African Earth Sciences 31, 119-132.

BAMFORD, M.K. 2004. Diversity of woody vegetation of Gondwanan South Africa. Gondwana Research 7, 153-164.

BANGERT, B., STOLLHOFEN, H., LORENTZ, V. & ARMSTRONG, R. 1999. The geochronology and significance of ash-fall tuffs in the glacigenic Carboniferous – Permian Dwyka Group of Namibia and South Africa. Journal of African Earth Sciences 29: 33-49.

BANGERT, B., STOLHOFEN, H., GEIGER, M. & LORENZ, V. 2000. Fossil record and high resolution tephrostratigraphy of Carboniferous glaciomarine mudstones, Dwyka Group, southern Namibia. Communications of the Geological Survey of Namibia 12, 235-245.

BANGERT, B. & BAMFORD, M. 2001. Carboniferous pycnoxylic woods from the Dwyka Group of southern Namibia. Palaeontologia africana 37, 13-23.

BUATOIS, L. & MANGANO, M.G. 1995. The paleoenvironmental and paleoecological significance of the lacustrine *Mermia* ichnofacies: an archetypal subaqueous nonmarine trace fossil assemblage. Ichnos 4: 151-161.

BUATOIS, L. & MANGANO, M.G. 2004. Animal-substrate interactions in freshwater environments: applications of ichnology in facies and sequence stratigraphic analysis of fluvio-lacustrine successions. In: McIlroy, D. (Ed.) The application of ichnology to palaeoenvironmental and stratigraphic analysis. Geological Society, London, Special Publications 228, pp 311-333.

BUTZER, K.W., HELGREN, D.M., FOCK, G. & STUCKENRATH, R. 1973. Alluvial terraces of the Lower Vaal River, South Africa: a re-appraisal and re-investigation. Journal of geololgy 81, 341-362.

COLE, D.I. 2005. Prince Albert Formation. SA Committee for Stratigraphy, Catalogue of South African Lithostratigraphic Units 8: 33-36.

COOKE, H.B.S. 1949. Fossil mammals of the Vaal River deposits. Memoirs of the geological Survey of South Africa 35, 1-117.

COOPER, M.R. & OOSTHUIZEN, R. 1974. Archaeocyathid-bearing erratics from Dwyka Subgroup (Permo-Carboniferous) of South Africa, and their importance to continental drift. Nature 247, 396-398.

DE WIT, M.C.J. 2008. Canteen Koppie at Barkly West: South Africa"s first diamond mine. South African Journal of Geology 111, 53-66.

DE WIT, M.C.J., MARSHALL, T.R. & PARTRIDGE, T.C. 2000. Fluvial deposits and drainage evolution. In: Partridge, T.C. & Maud, R.R. (Eds.) The Cenozoic of southern Africa, pp.55-72. Oxford University Press, Oxford.

DICKENS, J.M. 1961. *Eurydesma* and *Peruvispira* from the Dwyka Beds of South Africa. Palaeontology 4: 138-148, pl. 18.

DICKENS, J.M. 1984. Late Palaeozoic glaciation. BMR Journal of Australian Geology and Geophysics 9: 163-169.

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

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

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

EVANS, F.J.E. 2005. Taxonomy, palaeoecology and palaeobiogeography of some Palaeozoic fish of southern Gondwana. Unpublished PhD thesis, University of Stellenbosch, 628 pp.

GRILL, H. 1997. The Permo-Carboniferous glacial to marine Karoo record in southern Namibia: sedimentary facies and sequence stratigraphy. Beringeria 19: 3-98, 1 pl.

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

HELGREN, D.M. 1977. Geological context of the Vaal River faunas. South African Journal of Science 73, 303-307.

HERBERT, C.T. & COMPTON, J.S. 2007. Depositional environments of the lower Permian Dwyka diamictite and Prince Albert shale inferred from the geochemistry of early diagenetic concretions, southwest Karoo Basin, South Africa. Sedimentary Geology 194: 263-277.

JOHNSON, M.R., VAN VUUREN, C.J., VISSER, J.N.J., COLE, D.I., De V. WICKENS, H., CHRISTIE, A.D.M., ROBERTS, D.L. & BRANDL, G. 2006. Sedimentary rocks of the Karoo Supergroup. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 461-499. Geological Society of South Africa, Marshalltown.

KLEIN, R.G. 1984. The large mammals of southern Africa: Late Pliocene to Recent. In: Klein, R.G. (Ed.) Southern African prehistory and paleoenvironments, pp 107-146. Balkema, Rotterdam.

MACRAE , C. 1999. Life etched in stone. Fossils of South Africa. 305 pp. The Geological Society of South Africa, Johannesburg.

MCLACHLAN, I.R. & ANDERSON, A. 1973. A review of the evidence for marine conditions in southern Africa during Dwyka times. Palaeontologia africana 15: 37-64.

MILLER, R.M. 2008. Karoo Supergroup, pp. 16-1 to 16-115 *in* Miller, R.G. The geology of Namibia. Volume 3. Upper Palaeozoic to Cenozoic. Geological Survey, Namibia.

OELOFSEN, B.W. 1986. A fossil shark neurocranium from the Permo-Carboniferous (lowermost Ecca Formation) of South Africa. In: Uyeno, T, Arai, R., Taniuchi, T & Matsuura, K. (Eds.) Indo-Pacific fish biology. Proceedings of the Second International Conference on Indo-Pacific Fishes. Ichthyological Society of Japan, Tokyo, pp 107-124.

PARTRIDGE, T.C. & BRINK, A.B.A. 1967. Gravels and terraces of the lower Vaal River basin. South African Geographical Journal 49, 21-38.

PARTRIDGE, T.C. & SCOTT, L. 2000. Lakes and pans. . In: Partridge, T.C. & Maud, R.R. (Eds.) The Cenozoic of southern Africa, pp.145 - 161. Oxford University Press, Oxford.

PARTRIDGE, T.C., BOTHA, G.A. & HADDON, I.G. 2006. Cenozoic deposits of the interior. In: Johnson, M.R., Anhaeusser, C.R. & Thomas, R.J. (Eds.) The geology of South Africa, pp. 585-604. Geological Society of South Africa, Marshalltown.

PICKFORD, M. & SENUT, B. 2002. The fossil record of Namibia. 39 pp. The Geological Survey of Namibia.

PLUMSTEAD, E.P. 1969. Three thousand million years of plant life in Africa. Alex Du Toit Memorial Lectures No. 11. Transactions of the Geological Society of South Africa, Annexure to Volume 72, 72pp. 25 pls.

POTGIETER, G.J.A. 1974. The geology of an area south of Kimberley, 91 pp. Unpublished MSc Thesis, University of the Orange Free State.

PRINSLOO, M.C. 1989. Die geologie van die gebied Britstown. Explanation to 1: 250000 geology Sheet 3022 Britstown, 40 pp. Council for Geoscience, Pretoria.

SAVAGE, N.M. 1970. A preliminary note on arthropod trace fossils from the Dwyka Series in Natal. IUGS Second Gondwana Symposium, South Africa, 1970, Proceedings and Papers, pp 627-635, pls. 1-5.

SAVAGE, N.M. 1971. A varvite ichnocoenosis from the Dwyka Series of Natal. Lethaia 4: 217-233.

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

SLABBERT, M.J., MOEN, H.F.G. & BOELEMA, R. 1999. Die geologie van die gebied Kenhardt. Explanation to 1: 250 000 geology Sheet 2920 Kenhardt, 123 pp. Council for Geoscience, Pretoria.

STAPLETON, R.P. Carboniferous unconformity in southern Africa. Nature 268, 222-223.

STEPHENSON, M.H. 2008. A review of the palynostratigraphy of Gondwanan Late Carboniferous to Early Permian glacigene successions. In: Fielding, C.R., Frank, T.D. & Isbell, J.L. (eds). Resolving the Late Paleozoic Ice Age in time and space. Geological Society of America Special Paper 441, 317-330.

STOLLHOFEN, H., STANISTREET, I.G., BANGERT, B. & GRILL, H. 2000. Tuffs, tectonism and glacially-related sea-level changes, Carboniferous-Permian, southern Namibia. Palaeogeography, Palaeoclimatology, Palaeoecology 161: 127-150.

STONE, P. & THOMSON, M.R.A. 2005. Archaeocyathan limestone blocks of likely Antarctic origin in Gondwanan tillite from the Falkland Islands. Geological Society, London, Special Publications 246, 347-357.

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

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

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

VEEVERS, J.J., COLE, D.I. & COWAN, E.J. 1994. Southern Africa: Karoo Basin and Cape Fold Belt. Geological Society of America, Memoir 184: 223-279.

VISSER, J.N.J. 1982. Upper Carboniferous glacial sedimentation in the Karoo Basin near Prieska, South Africa. Palaeogeography, Palaeoclimatology, Palaeoecology 38, 63-92.

VISSER, J.N.J. 1985. The Dwyka Formation along the north-western margin of the Karoo Basin in the Cape Province, South Africa. Transactions of the Geological Society of South Africa 88, 37-48.

VISSER, J.N.J. 1989. The Permo-Carboniferous Dwyka Formation of southern Africa: deposition by a predominantly subpolar marine ice sheet. Palaeogeography, Palaeoclimatology, Palaeoecology 70, 377-391.

VISSER, J.N.J. 1992. Deposition of the Early to Late Permian Whitehill Formation during a sea-level highstand in a juvenile foreland basin. South African Journal of Geology 95: 181-193.

VISSER, J.N.J. 1997. Deglaciation sequences in the Permo-Carboniferous Karoo and Kalahari Basins of southern Africa: a tool in the analysis of cyclic glaciomarine basin fills. Sedimentology 44: 507-521.

VISSER, J.N.J. 2003. Lithostratigraphy of the Elandsvlei Formation (Dwyka Group). South African Committee for Stratigraphy, Lithostratigraphic Series No. 39, 11 pp. Council for Geoscience, Pretoria.

VISSER, J.N.J., LOOCK, J.C., VAN DER MERWE, J., JOUBERT, C.W., POTGIETER, C.D., MCLAREN, C.H., POTGIETER, G.J.A., VAN DER WESTHUIZEN, W.A., NEL, L. & LEMER, W.M. 1977-78. The Dwyka Formation and Ecca Group, Karoo Sequence, in the northern Karoo Basin, Kimberley-Britstown area. Annals of the Geological Survey of South Africa 12, 143-176.

VISSER, J.N.J., VAN NIEKERK, B.N. & VAN DER MERWE, S.W. 1997. Sediment transport of the Late Palaeozoic glacial Dwyka Group in the southwestern Karoo Basin. South African Journal of Geology 100: 223-236.

VISSER, J.N.J., VON BRUNN, V. & JOHNSON, M.R. 1990. Dwyka Group. Catalogue of South African Lithostratigraphic Units 2, 15-17. Council for Geoscience, Pretoria.

VON BRUNN, V. & VISSER, J.N.J. 1999. Lithostratigraphy of the Mbizane Formation (Dwyka group). South African Committee for Stratigraphy, Lithostratigraphic Series No. 32, 10 pp. Council for Geoscience, Pretoria.

WELLS, L.H. 1964. The Vaal River „Younger Gravels" faunal assemblage: a revised list. South African Journal of Science 60, 92-94.

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

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 Mainstream solar park development 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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APPENDIX 1: FOSSIL HERITAGE WITHIN THE MAINSTREAM SOLAR PARK STUDY AREA NEAR DOUGLAS, NORTHERN CAPE

A summary of the fossil heritage recorded within each of the sedimentary units represented within the Mainstream solar park study area near Douglas is given here, together with references to relevant scientific literature (Based on previous fossil heritage studies byAlmond 2008a, 2008b, 2010a to 2010d). Note that the Early Precambrian basement rocks found here (Allanridge Formation) are volcanic in origin and do not contain fossils.

1. Fossils within the Late Caenozoic superficial deposits

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

Late Caenozoic calcretes may also contain trace fossils such as rhizoliths, termite and other insect burrows, or even mammalian trackways. Mammalian bones, teeth and horn cores (also tortoise remains, and fish, amphibian or even crocodiles in wetter depositional settings) may be expected occasionally expected within Kalahari Group sediments and calcretes, notably those associated with ancient alluvial gravels and pans (*cf* Almond 2008a).

The “Older” Vaal River Gravels (**Windsorton Formation**) of possible Miocene-Pliocene age have not yet yielded well-dated fossil biotas (Partridge *et al.,* 2006). A “sparse, poorly provenanced vertebrate fauna from diamond diggings” is noted herein by De Wit *et al.* (2000) who favour a Pliocene age (4.5-3.5 Ma). In contrast, a wide range of Pleistocene mammal remains (bones, teeth) as well as Acheulian stone tools are recorded from the “Younger” Vaal River Gravels or **Rietputs Formation** (Cooke 1949, Wells 1964, Partridge & Brink 1967, Helgren 1977, Klein 1984). These are assigned to the Mid Pleistocene Cornelian Mammal Age and include various equids and artiodactyls as well as African elephant and hippopotamus (See MacRae 1990, De Wit 2008 for brief reviews, and Gibbon *et al.* 2009 for recent dating of the matrix). Still younger silty alluvium along the Vaal River north of the study area (Blaauwboschdrift) contain diverse fossil to subfossil remains including calcretized rhizoliths (root casts), mammalian teeth, water-worn bones as well as horn cores (Almond 2010b). They are associated with MSA and LSA stone artefacts, stone-lined hearths, ostrich egg shells and chunks of crude pottery and therefore of Pleistocene to Recent age.

2. Fossils in the Dwyka Group

The generally poor fossil record of the Dwyka Group (McLachlan & Anderson 1973, Anderson & McLachlan 1976, Visser 1989, Visser *et al*., 1990, Von Brunn & Visser 1999, Visser 2003, Almond & Pether 2008) is hardly surprising given the glacial climates that prevailed during much of the Late Carboniferous to Early Permian Periods in southern Africa. However, most Dwyka sediments were deposited during periods of glacial retreat associated with climatic amelioration. Sparse, low diversity fossil biotas from the **Mbizane Formation** in particular mainly consist of arthropod trackways associated with dropstone laminites and sporadic vascular plant remains (drifted wood and leaves of the *Glossopteris* Flora), while palynomorphs (organic-walled microfossils) are also likely to be present within finer-grained mudrock facies. Glacial diamictites (tillites or "boulder mudstones") are normally unfossiliferous but do occasionally contain fragmentary transported plant material as well as palynomorphs in the fine-grained matrix. There are interesting records of limestone glacial erratics from tillites along the southern margins of the Great Karoo (Elandsvlei Formation) that contain Cambrian eodiscid trilobites as well as archaeocyathid sponges. Such derived fossils provide important data for reconstructing the movement of Gondwana ice sheets (Cooper & Oosthuizen 1974, Stone & Thompson 2005).

A limited range of marine fossils are associated with the later phases of several of the four main Dwyka deglaciation cycles (DSI to DSIV). These are especially well known in the Kalahari Basin of southern Namibia but also occur sporadically within the Main Karoo Basin in South Africa (Oelofsen 1986, Visser 1989, 1997, Visser *et al*. 1997, Bangert *et al*. 1999, Stollhofen *et al*. 2000, Almond 2008). These deglaciation sequences are estimated to have lasted five to seven million years on average (Bangert *et al*. 1999). A range of stenohaline (*i.e.* exclusively salt water) invertebrate fossils indicates that fully marine salinities prevailed at the end of each sequence, at least in the western outcrop area (Namibia, Northern Cape). These invertebrates include echinoderms (starfish, crinoids, echinoids), cephalopods (nautiloids, goniatites), articulate brachiopods, bryozoans, foraminiferans, and conulariids, among others. Primitive bony fish (palaeoniscoids), spiral "coprolites" attributable to sharks or eurypterids, as well as wood and trace fossils are also recorded from mudrock facies at the tops of DSII (Ganikobis Shale Member), DS III (Hardap Member) and DSIV (Nossob Shale Member), as well as base of the Prince Albert Formation (Ecca Group) in southern Namibia and, in the last case at least, in the Northern Cape near Douglas, as discussed further in Section 3 below (McLachlan and Anderson 1973, Veevers *et al*. 1994, Grill 1997, Bangert *et al*. 1999, Pickford & Senut 2002, Evans 2005). The Ganikobis (DSII) fauna has been radiometrically dated to *c*. 300 Ma, or end-Carboniferous (Gzhelian), while the Hardap fauna (DSIII) is correlated with the *Eurydesma* transgression of earliest Permian age (Asselian) that can be widely picked up across Gondwana (Dickens 1961, 1984, Bangert *et al*. 1999, Stollhofen *et al*. 2000). The distinctive thick-shelled bivalve *Eurydesma*, well known from the Dwyka of southern Namibia, has not yet been recorded from the main Karoo Basin, however (McLachlan and Anderson 1973). The upper part of DSIV, just above the Dwyka / Ecca boundary in the western Karoo Basin (*i.e.* situated within the basal Prince Albert Formation), has been radiometrically dated to 290-288 Ma (Stollhofen *et al*. 2000).

Low diversity ichnoassemblages dominated by non-marine arthropod trackways are widely associated with cold water periglacial mudrocks, including dropstone laminites, within the Mbizane Formation in the Main Karoo Basin (Von Brunn & Visser, 1999, Savage 1970, 1971, Anderson 1974, 1975, 1976, 1981, Almond 2008, 2009). They are assigned to the non-marine / lacustrine *Mermia* ichnofacies that has been extensively recorded from post-glacial epicontinental seas and large lakes of Permian age across southern Gondwana (Buatois & Mangano 1995, 2004). These Dwyka ichnoassemblages include the arthropod trackways *Maculichna*, *Umfolozia* and *Isopodichnus*, the possible crustacean resting trace *Gluckstadtella*, sinuous fish-fin traces (*Undichna*) as well as various unnamed horizontal burrows. The association of these interglacial or post-glacial ichnoassemblages with rhythmites (interpreted as varvites generated by seasonal ice melt), the absence of stenohaline marine invertebrate remains, and their low diversity suggest a restricted, fresh- or brackish water environment. Herbert and Compton (2007) also inferred a freshwater depositional environment for the Dwyka / Ecca contact beds in the SW Cape based on geochemical analyses of calcareous and phosphatic diagenetic nodules within the upper Elandsvlei and Prince Albert Formations respectively. Well-developed U-shaped burrows of the ichnogenus *Rhizocorallium* are recorded from sandstones interbedded with varved mudrocks within the upper Dwyka Group (Mbizane facies) on the Britstown sheet (Prinsloo 1989). Similar *Rhizocorallium* traces also described from the Dwyka Group of Namibia (*e.g.* the Hardap Shale Member, Miller 2008). References to occurrences of the complex helical spreiten burrow *Zoophycos* in the Dwyka of the Britstown sheet and elsewhere (*e.g.* Prinsloo 1989) are probably in error, since in Palaeozoic times this was predominantly a shallow marine to estuarine ichnogenus (Seilacher 2007).

Scattered records of fossil vascular plants within the Dwyka Group of the Main Karoo Basin record the early phase of the colonisation of SW Gondwana by members of the *Glossopteris* Flora in the Late Carboniferous (Plumstead 1969, Anderson & McLachlan 1976, Anderson & Anderson 1985 and earlier refs. therein). These records include fragmentary carbonized stems and leaves of the seed ferns *Glossopteris* / *Gamgamopteris* and several gymnospermous genera (*e.g. Noeggerathiopsis, Ginkgophyllum*) that are even found within glacial tillites. More "primitive" plant taxa include lycopods (club mosses) and true mosses such as *Dwykea*. It should be noted that the depositional setting (*e.g.* fluvial *versus* glacial) and stratigraphic position of some of these records are contested (cf Anderson & McLachlan 1976). Petrified woods with well-developed seasonal growth rings are recorded from the upper Dwyka Group (Mbizane Formation) of the northern Karoo Basin (*e.g.* Prinsloo 1989) as well as from the latest Carboniferous of southern Namibia. The more abundant Namibian material (*e.g. Megaporoxylon*) has recently received systematic attention (Bangert & Bamford 2001, Bamford 2000, 2004) and is clearly gymnospermous (pycnoxylic, *i.e.* dense woods with narrow rays) but most woods cannot be assigned to any particular gymnosperm order.

Borehole cores through Dwyka mudrocks have yielded moderately diverse palynomorph assemblages (organic-walled spores, acanthomorph acritarchs) as well as plant cuticles. These mudrocks are interbedded with diamictites in the southern Karoo as well as within Dwyka valley infills along the northern margin of the Main Karoo Basin (McLachlan & Anderson 1973, Anderson 1977, Stapleton 1977, Visser 1989, Anderson & Anderson 1985). Thirty one Dwyka palynomorph species are mentioned by the last authors, for example. Anderson"s (1977) Late Carboniferous to Early Permian Biozone 1 based on Dwyka palynomorph assemblages is characterized by abundant *Microbaculispora*, monosaccate pollens (*e.g. Vestigisporites*) and nontaeniate bisaccate pollens (*e.g. Pityosporites*) (Stephenson 2008). Prinsloo (1989) mentions stromatolitic limestone lenses within the uppermost Dwyka Group in the Britstown sheet area. These may be comparable to interglacial microbial mats and mounds described from the Ganikobis Shale Member (DSII) of southern Namibia by Grill (1997) and Bangert *et al.* (2000).

Although a wide range of fossils are now known from the Dwyka Group, most sediments assigned to this succession are unfossiliferous (with the possible exception of microfossils). The overall palaeontological sensitivity of the Dwyka Group is therefore rated as low (Almond & Pether 2008). Any interglacial mudrocks and heterolithic successions (*i.e.* interbedded sandstones and may in general be considered to be of moderate palaeontological sensitivity. Recent field examination of well-exposed Mbizane Formation beds at the Stratotype C section west of Douglas failed to reveal any fossils (Almond 2010b), so their sensitivity in this region may be generally low.

3. Fossils in the Lower Ecca Group

The fossil biota of the post-Dwyka mudrocks of the **Prince Albert Formation** has already been outlined above (Section 2) under Deglaciation Cycle 4 (DSIV) and is usefully summarized by Cole (2005). The typical *Umfolozia / Undichna* – dominated trace fossil assemblages of the non-marine *Mermia* Ichnofacies commonly found in basinal mudrock facies of the Prince Albert Formation throughout the Ecca Basin have been briefly reviewed by Almond (2008a, b). Diagenetic nodules containing the remains of palaeoniscoids (primitive bony fish), sharks, spiral bromalites (coprolites *etc*) and wood have been found in the Ceres Karoo and rare shark remains (*Dwykaselachus*) near Prince Albert on the southern margin of the Great Karoo (Oelofsen 1986). Microfossil remains in this formation include sponge spicules, foraminiferal and radiolarian protozoans, acritarchs and miospores.

The most diverse as well as biostratigraphically, palaeobiogeographically and palaeoecologically interesting fossil biota from the Prince Albert Formation is that described from calcareous concretions exposed along the Vaal River in the Douglas area of the Northern Cape. The most famous localities are known as Zand Bult and Blaauw Kranz, situated *c*. 35 km northeast of the study area (McLachlan and Anderson 1973, Table 3; see maps and section in Fig. 4 herein, and also Visser *et al.,* 1977-78, Almond 2010b). The important Douglas biota contains petrified wood (including large tree trunks), palynomorphs (miospores), orthocone nautiloids, nuculid bivalves, articulate brachiopods, spiral and other "coprolites" (probably of fish, possibly including sharks) and fairly abundant, well-articulated remains of palaeoniscoid fish. Most of the fish have been assigned to the palaeoniscoid genus *Namaichthys* but additional taxa, including a possible acrolepid, may also be present here (Evans 2005, referring to specimen figured by MacRae 1999, p134). The invertebrates are mainly preserved as moulds.