PALAEONTOLOGICAL IMPACT ASSESSMENT: DESKTOP STUDY

Proposed photovoltaic power station adjacent to Greefspan Substation near Douglas, Northern Cape Province

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1. SUMMARY

The proposed 5 MW photovoltaic power plant on the Farm Kwartelspan 25 near Douglas, Northern Cape Province involves the construction of a 25 ha photovoltaic array close to the existing Greefspan Substation. The development footprint is underlain by thin aeolian sands of the Quaternary Gordonia Formation (Kalahari Group) and calcretes. These are in turn underlain at depth by Permocarboniferous age rocks of the Karoo Supergroup – *viz*. the glacially-related Mbizane Formation (Dwyka Group) and possibly also the postglacial Prince Albert Formation (lower Ecca Group). This last rock unit is exceptionally fossil-rich in the Douglas region. However, the palaeontological sensitivity of the near-surface sediments at Greefspan is low, the development footprint is small, and extensive bedrock excavations that might intersect Karoo bedrocks are not envisaged. Therefore further palaeontological mitigation of this project is not considered necessary. Should substantial fossil remains be exposed during construction, however, these should be safeguarded – if possible *in situ* – and SAHRA should be notified by the responsible ECO as soon as possible so that appropriate palaeontological mitigation (fossil sampling and relevant data collection) can be undertaken.

2. INTRODUCTION & BRIEF

Alt-e Technologies in partnership with AMDA energía are proposing to construct six new 5 MW photovoltaic power stations alongside existing Eskom substations in the Northern Cape. According to the BID document prepared by Van Zyl Environmental Consultants cc the footprint of the PV power station will be *c*. 25 ha, and at least two alternative sites will be considered for each substation. Associated infrastructure includes an access road in certain cases, fencing, guardrooms, toilet, shower, washbasin, security systems, lights on poles, lightning conductor poles, a hanger to store spare parts and a workshop. Around the premises a furrow will be constructed to prevent vehicles from entering the site at any other place than the main entrance.

The Greefspan PV power station is to be located south of the Orange River on the farm Kwartelspan 25. The site lies on the north side of the R357 from Prieska to Douglas, some 60 km southwest of Douglas (Fig. 1). The proposed construction site overlies potentially fossiliferous sands and bedrock of the Late Caenozoic Kalahari Group and the Palaeozoic Dwyka Group. A desktop palaeontological impact assessment for the project is therefore necessary in accordance with the requirements of the National Heritage Resources Act, 1999. This study has accordingly been commissioned by Ms I.B. Van Zyl of Van Zyl Environmental Consultants cc, Upington.

2.1. National Heritage Monuments Act

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.

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 scoping study 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, most effectively, during the construction phase while fresh, potentially 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.

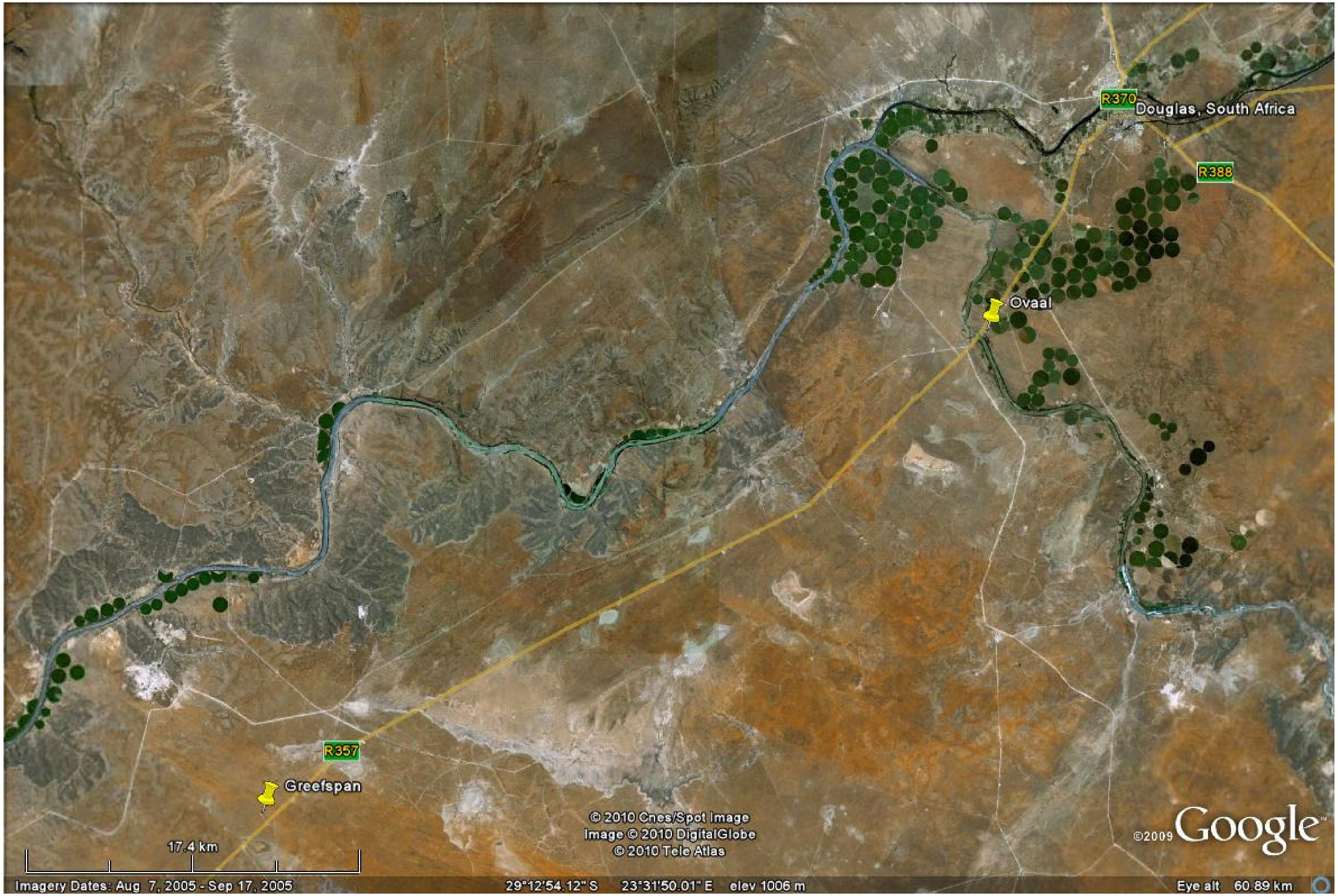

Fig. 1. ***Google Earth*®** **satellite image showing the location (bottom left) of the proposed photovoltaic power station at Greefspan, south of the Orange River and *c.* 60 km southwest of Douglas, Northern Cape Province (Image provided by Van Zyl Environmental Consultants cc).**

3. GEOLOGICAL BACKGROUND

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 critical details of the local stratigraphy relevant to the present impact study remain ambiguous. However, several of the rock units 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).

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

The site of the proposed Greefspan photovoltaic power station is underlain near-surface by unconsolidated aeolian (*i.e.* wind-blown) sands of the Quaternary **Gordonia Formation** (**Kalahari Group**) (**Qs** in Fig. 2) whose thickness in the study region is uncertain (See discussion below). In the study region 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 1.8 Ma 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 30 m 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 calcretised "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 "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).

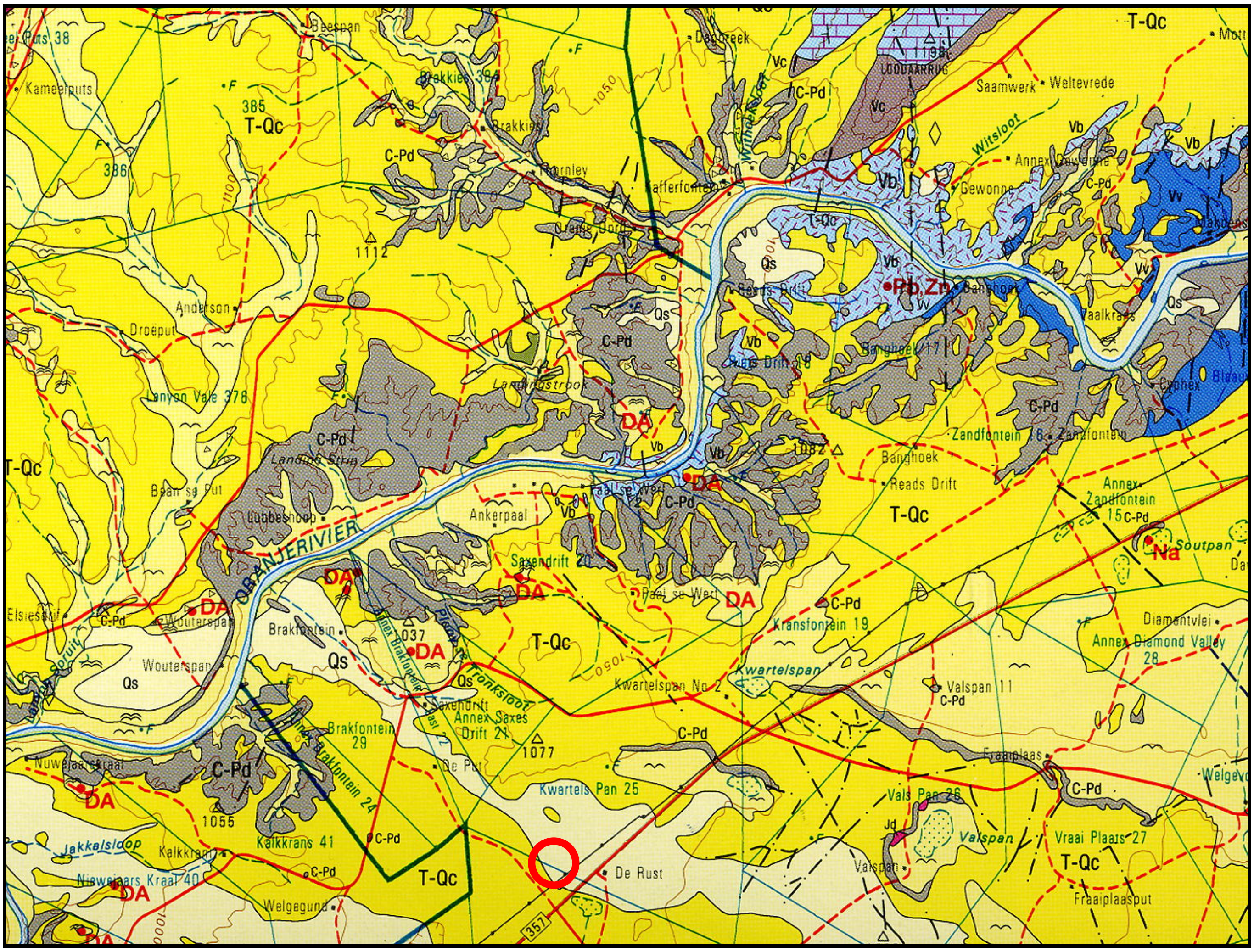

Fig. 2. Extract from 1:250 000 geological map 2922 Prieska (Council for Geoscience, Pretoria) showing location of proposed Greefspan photovoltaic power station (red circle). Grey (C-Pd) = Dwyka Group Yellow (T-Qc) = Neogene calcrete Pale yellow (Qs) = Quaternary to Recent sands and sandy soil of the Gordonia Formation (Kalahari Group). Note mudrocks of the Prince Albert Formation (Pp) are *not* mapped separately in this area but might be locally present above the Dwyka Group. DA marks ancient High Level Gravels associated with alluvial diamond occurrences close to the Orange River.

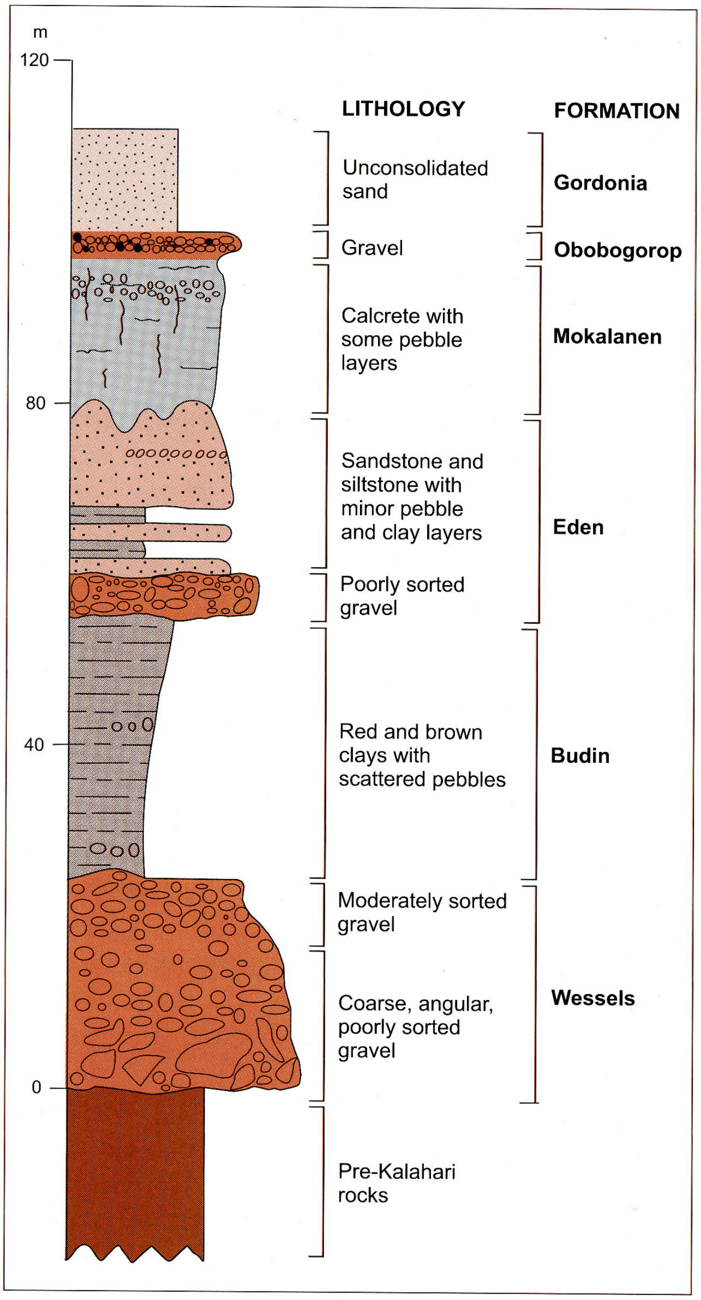

Fig. 3. Stratigraphy of the Kalahari Group (From Partridge *et al.,* 2006). Aeolian sands of the Gordonia Formation as well as calcretes possibly equivalent to the Mokalanen Formation are represented in the study area.

3.2. Dwyka Group

Permocarboniferous glacial sediments of the **Dwyka Group** (**C-Pd** in Fig. 2) underlie the thin, superficial cover of Gordonia sands and calcrete south of the Orange River. Dwyka rocks might therefore be intersected by deeper excavations during development. 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 northwestern 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 gravelly 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 190 m 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). The composite section, which overlies glacially-striated Precambrian bedrock, is some 25-30 m 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.

3.3. 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. 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) that the Dwyka Group is at least locally overlain here 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 and Fig. 4 herein). Some of these carbonate concretions are richly fossiliferous (See Section 4.3 below). Much of the Ecca shale outcrop has been modified by surface calcretisation (Zawada 1992). Exposures in incised river banks near Douglas are described by McLachlan and Anderson (1973; Figs. 5-6 herein). The Ecca beds here are mantled with a thin veneer (*c*. 3 m) 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 6 m-thick zone of fossiliferous calcareous concretions that lies 9 m above the base of the formation.

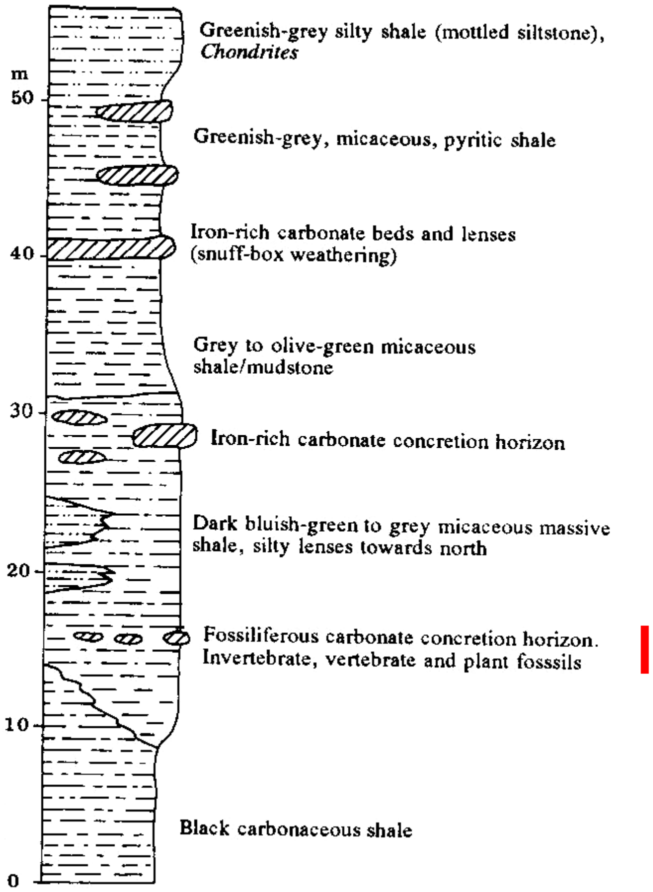

Fig. 4. Schematic section through the Prince Albert Formation in the Kimberley-Britstown area (From Visser et al., 1977-78). Note horizon of fossiliferous concretions towards the base of the succession (red line).

Due to inadequate detail on the available geological maps, it is unclear whether or not potentially fossiliferous Prince Albert Formation is present beneath the surface deposits in the Greefspan study area. If present, they are quite likely to be extensively disrupted by near-surface calcrete development (Zawada 1992).

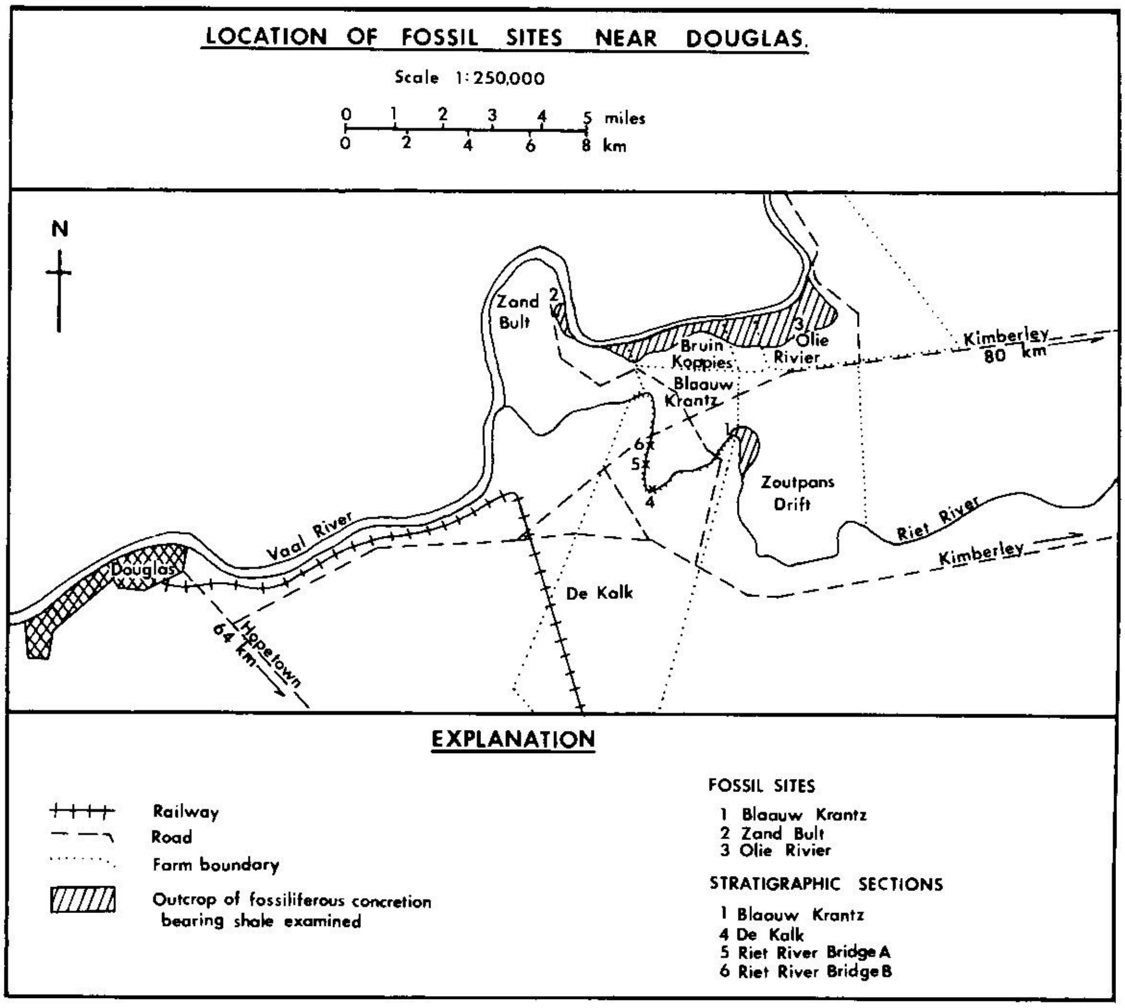

Figure 5. Sketch map of the area immediately east of Douglas showing location of fossiliferous outcrops within the "Upper Dwyka Shales" (*i.e.* Prince Albert Formation) along the banks of the Vaal River (From McLachlan & Anderson 1973). The best-known localities here are Zand Bult and Blaaw Krantz. See also stratigraphic log in Fig. 6 below.

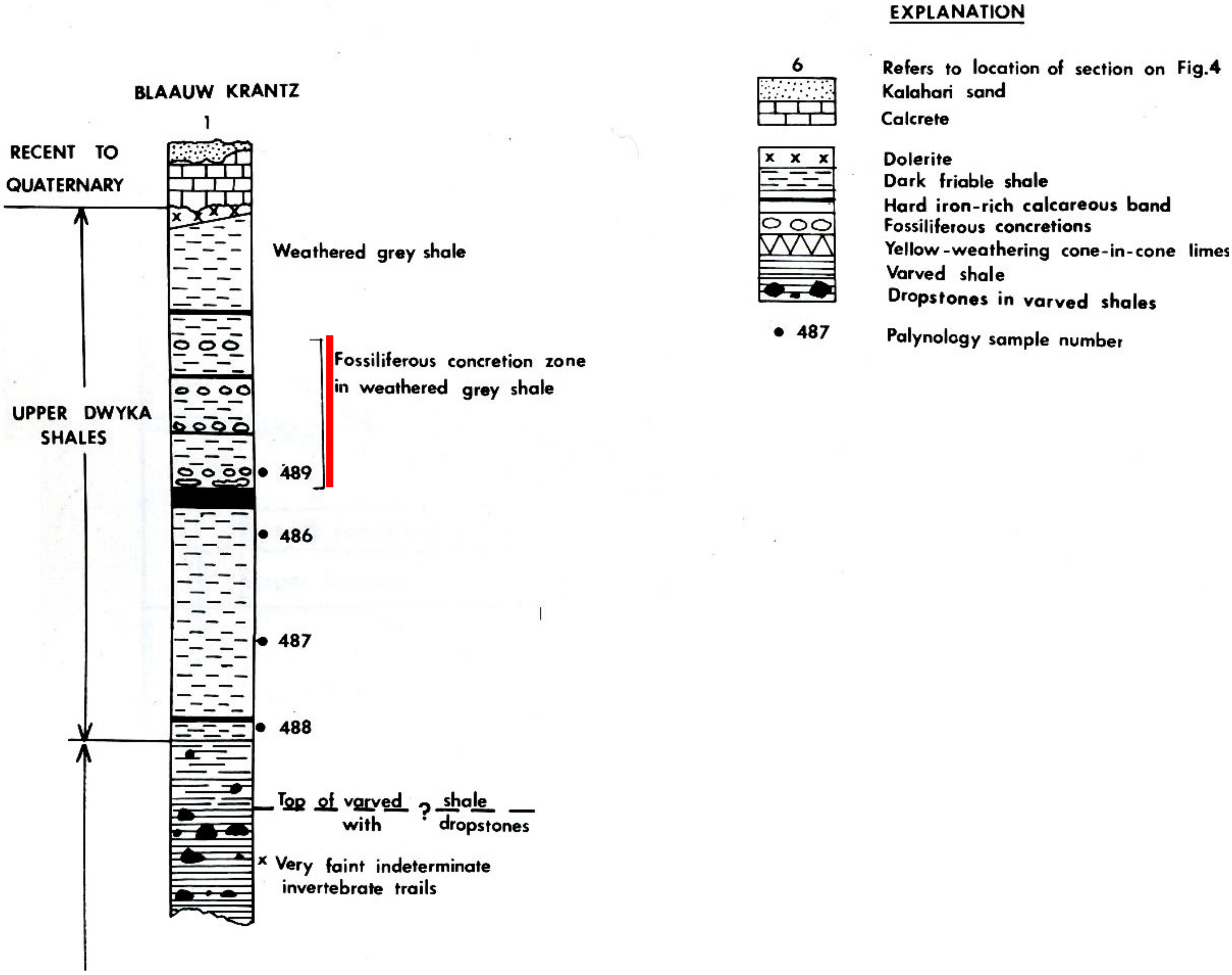

Fig. 6. Vertical section through the Dwyka/Ecca contact beds east of Douglas (See Fig. 5 above for locality area). The vertical scale is approx. 1 cm = 3 m. A 6 m-thick zone rich in fossiliferous concretions within the Prince Albert Formation ("Upper Dwyka Shales") is emphasized by the red line. Note the Ecca beds are mantled here with a thin veneer (*c.* 3 m) of dolerite, calcrete and Kalahari sands (= Gordonia Formation) (From McLachlan & Anderson 1973).

4. PALAEONTOLOGICAL HERITAGE

The fossil heritage recorded within each of the main sedimentary rock successions occurring within the study region near Douglas is outlined here (See also summary in Table 1 below).

4.1. Fossils within the 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 calcretised rhizoliths (root casts) and termitaria (*e.g. Hodotermes*, the harvester termite), ostrich egg shells (*Struthio*) and shells of land snails (*e.g. Trigonephrus*) (Almond 2008, 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. Underlying **calcretes** might 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, amphibians or even crocodiles in wetter depositional settings) may be expected to occur occasionally within Kalahari Group sediments and calcretes, notably those associated with ancient alluvial gravels .

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).

4.2. 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, Visser 2003, Almond & Pether 2008) is hardly surprising given the glacial climates that prevailed during much of the Late Carboniferous to 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 the 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 4.3 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 postglacial 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 postglacial 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; Fig. 7 herein). 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 mudrocks) are worth investigating for fossils, however.

Fig. 7. Large horizontally-directed U-burrows of the ichnogenus *Rhizocorallium* in ripple-marked sandstones of the upper Dwyka Group, Britstown sheet area (From Prinsloo, 1989).

4.3. 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 4.2) 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 are those 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 (McLachlan and Anderson 1973, Table 3; see map and section in Figs. 5-6 herein, also Visser *et al.,* 1977-78). 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 (Fig. 8). 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.

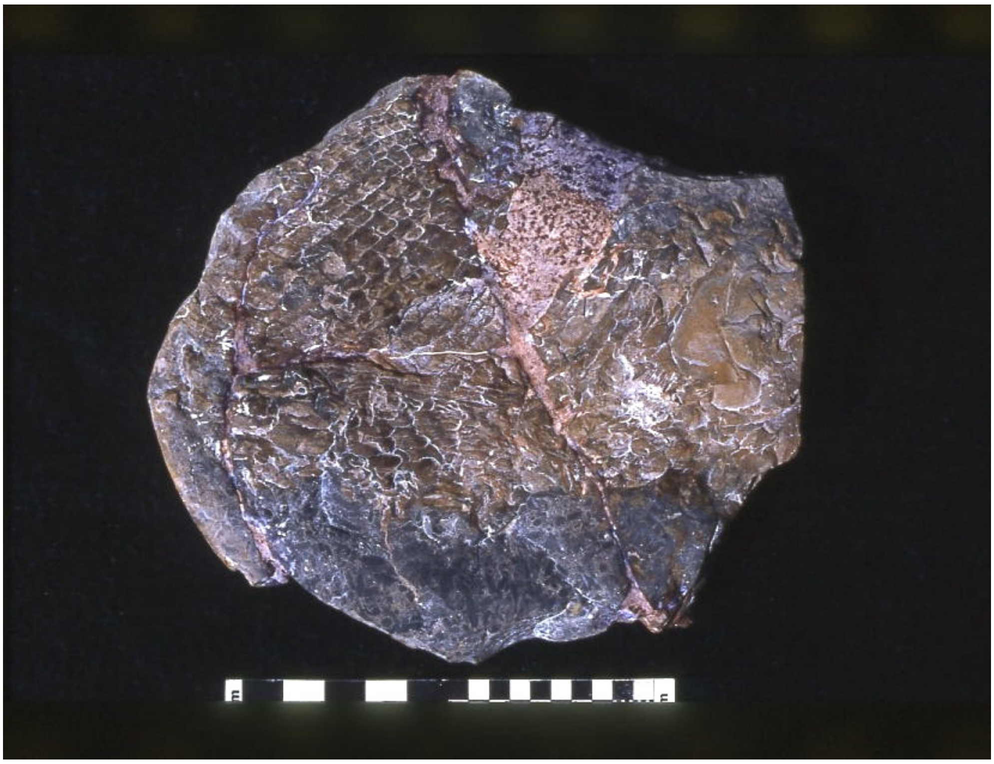

Fig. 8. Articulated palaeoniscoid fish remains preserved within a calcareous concretion from the Prince Albert Formation at Zand Bult near Douglas. Scale in cm and half cm. (McGregor Museum, Kimberley).

5. CONCLUSIONS & RECOMMENDATIONS

The inferred palaeontological sensitivity of each of the main fossil-bearing rock units represented within, or close to, the study area near Douglas is summarized in Table 1 below (See also Almond & Pether 2008).

The proposed Greefspan PV power station site is directly underlain by geologically young aeolian sediments of the Gordonia Formation as well as calcretes, both of which are of low palaeontological sensitivity. Late Tertiary to Pleistocene High Level Gravels are not mapped in the development area which lies more than 10 km from the Orange River. Foundations for the structures that will house the photovoltaic panels will not be more than a meter or so deep. The same applies to associated infrastructure such as fencing, trenches for cabling and lightning conductors. It is therefore unlikely that the underlying Karoo Supergroup bedrock will be intersected, whether or not this comprises Dwyka or Prince Albert sediments. The thinner-bedded Prince Albert Formation rocks are often extensively disrupted by calcrete formation in this region, lowering their palaeontological heritage value in many areas.

Given the generally low palaeontological sensitivity of sedimentary rocks in the study area, the small footprint of the development and the shallow excavations envisaged, no further palaeontological mitigation is recommended for this development. Should substantial fossil remains be exposed during construction, however, the ECO should safeguard these, preferably *in situ*, and alert SAHRA as soon as possible so that appropriate action (*e.g.* recording, sampling or collection) can be taken by a professional palaeontologist.

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TABLE 1: FOSSIL HERITAGE IN THE DOUGLAS AREA				
GEOLOGICAL UNIT	**ROCK TYPES & AGE**	**FOSSIL HERITAGE**	**PALAEONT-OLOGICAL SENSITIVITY**	**RECOMMENDED MITIGATION**
Gordonia Formation **KALAHARI GROUP** ***plus*** **SURFACE CALCRETE**	**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**
HIGH LEVEL GRAVELS	**alluvial gravels (often calcretised)** **MIOCENE to MID PLEISTOCENE**	**diverse mammalian fossils (bones, teeth), Acheulian stone tools**	**VERY HIGH**	**specialist scoping study**
Prince Albert Formation **ECCA GROUP**	**basinal mudrocks with calcareous concretions** **EARLY PERMIAN**	**marine invertebrates (esp. molluscs, brachiopods), coprolites, palaeoniscoid fish & sharks, trace fossils, various microfossils, petrified wood**	**VERY HIGH IN THIS AREA**	**specialist scoping study**
Mbizane Formation **DWYKA GROUP**	**tillites, interglacial mudrocks, deltaic & turbiditic sandstones, minor thin limestones** **LATE CARBONIFEROUS -EARLY PERMIAN**	**sparse petrified wood & other plant remains, palynomorphs, trace fossils (*e.g.* arthropod trackways, fish trails, U-burrows) possible stromatolites in limestones**	**LOW**	**none recommended** **any substantial fossil finds to be reported by ECO to SAHRA**

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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 APHAP (Association of Professional Heritage Assessment 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 Douglas 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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