PALAEONTOLOGICAL IMPACT ASSESSMENT: DESKTOP STUDY

Proposed Photovoltaic Power Facility, Farm Steenrotsfontein 168, Beaufort West Municipality, Western Cape Province

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1. EXECUTIVE SUMMARY

Biotherm Energy (Pty) Ltd in partnership with Aurora Power Solutions (Pty) Ltd (APS) is proposing to develop a Photovoltaic (PV) Solar Facility of 10 MW capacity on Portion 1 of the Farm Steenrotsfontein 168, located approximately 6.5 km south-west of Beaufort West, in the Western Cape Province. Three site options are under consideration.

Bedrock excavations during construction of the proposed solar energy facility will primarily impact continental sediments of the Teekloof Formation (Poortjie Member) of the Lower Beaufort Group (Karoo Supergroup). The Middle to Late Permian sediments of the Lower Beaufort Group are renowned for their outstandingly rich fossil heritage of terrestrial vertebrates (most notably mammal-like reptiles or therapsids), as well as fish, amphibians, molluscs, trace fossils (*e.g.* trackways, burrows) and plants (*e.g.* petrified wood). The Teekloof stratigraphic interval is of special palaeontological significance in that it contains a record of the extinction and recovery of continental biotas during one or more extinction events towards the end of the Mid Permian Period, some 260.4 million years ago. The palaeontological sensitivity of the Beaufort Group sediments in the study area is consequently very high.

Permian vertebrate fossils have been collected in the Beaufort West area since at least the 1820s. Recent palaeontological impact studies in the region southwest of Beaufort West, just outside the present study area, have yielded sparse but scientifically important fossil remains including vertebrate bones and teeth, trace fossils (*e.g.* vertebrate and invertebrate burrows) and plants. However, due to the extensive cover by Recent superficial sediments (*e.g.* alluvium and soil), potentially fossiliferous Beaufort Group bedrocks are very poorly exposed within the study area itself. Because extensive, deep bedrock excavations are not envisaged and the superficial sediment cover is substantial, the overall impact significance of the Beaufort West solar energy project as far as fossil heritage is concerned is considered to be LOW (negative) and, pending new fossil finds, further specialist mitigation is not considered as necessary for this project. The operational and decommissioning phases of the wind energy facility will not involve further significant adverse or other impacts on palaeontological heritage. There is no preference on palaeontological heritage grounds for any one of the three sites under consideration, all of which are of low impact significance.

It is recommended that:

- 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 (Heritage Western Cape) 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 Aurora Biotherm solar power facility near Beaufort West.

2. INTRODUCTION & BRIEF

2.1. Project outline

The company Biotherm Energy (Pty) Ltd in partnership with Aurora Power Solutions (Pty) Ltd (APS) is proposing to develop a Photovoltaic (PV) Solar Facility of 10 MW capacity on Portion 1 of the Farm Steenrotsfontein 168, located approximately 6.5 km south-west of Beaufort West, in the Western Cape Province (Figs. 1 & 2). The study site, currently zoned for agricultural use, lies to the east of the N12 tar road between Beaufort West and Oudtshoorn and north of the Gamka River. The farm Steenrotsfontein is already traversed by several high voltage transmission lines connected to the Droërivier Substation on the western side of the N12 as well as their service roads.

According to the Draft Basic Assessment Report for the Photovoltaic (PV) Power Project prepared by the CSIR (Report No. CSIR/CAS/EMS/ER/2011/0006/B) the main components of the proposed development are as follows:

1. Solar (PV) power facility
This comprises the solar panels and their support structures, electrical inverters, a network of underground cables connected to nearby substations, a control room and facilities for security guards. Two design options are being considered at this stage, these being sun tracking using single axis or dual axis motors. The mounting structure for the solar panels could either be based on a concrete foundation or a deep seated screw.

2. Site Clearing and Preparation
The site will need to be cleared of vegetation and portions of the site will need to be levelled.

3. Civil Works
The main civil works are: Terrain levelling – Levelling will be minimal as the potential sites chosen are relatively flat. Access and inside roads/paths – already existing paths to be used were possible, turning circle of trucks to be taken into consideration, use of roads /paths minimal when plant is in operation. Trenching – all DC and AC wiring within the PV plant must be buried underground. Trenches will have a river sand base, space for pipes, backfill of sifted soil and soft sand and concrete layer where vehicles will pass.

4. Connection to the Grid
Connecting the array to the electrical grid requires transformation of the voltage from 480V to 22kV. The normal components and dimensions of a distribution rated electrical substation will be required. Electricity generated from the panels will be connected to the Droërivier Substation located immediately to the west of the proposed site across the N12 National Road *via* a 22kV line. The length of the power line connection from the PV facility to Droërivier Substation varies from 1km to 3km, depending on which of the three alternatives sites are chosen for the PV plant on Steenrotsfontein Farm.

5. Supporting Infrastructure

A control facility with basic services such as water and electricity would be constructed at the site and would have an approximate footprint 100m². Other supporting infrastructure includes voltage and current regulators and protection circuitry. In terms of project maintenance, approximately 450 m³ of water, mixed with a cleaning agent, would be required per year for the site. The water source has not been determined at this stage.

Three alternative locations for the proposed PV solar facility are under consideration (Fig. 1).The co-ordinates for the three site options are as follows:

Site 1: 32.39840˚ S 22.56294˚ E

Site 2 (Preferred Site): 32.39642˚ S 22.54404˚ E

Site 3: 32.40128˚ S 22.54403˚ E

2.2. Implications of the proposed development for palaeontological heritage and relevant heritage legislation

The proposed Aurora Biotherm PV Power Project is located in an area of the western Karoo that is underlain by potentially fossil-rich sedimentary rocks of the Karoo Supergroup that are of Permian age and are internationally famous for their rich fossil record. The construction phase of the development will entail excavations into the superficial sediment cover (soils, alluvial gravels *etc*) and perhaps also into the underlying fossiliferous bedrock. These notably include site clearance activities as well as excavations for the PV panel support structures, buried cables, any new internal access roads, transmission line pylons and associated infrastructure. All these developments may adversely affect potential fossil heritage within the study area by destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good. Once constructed, the operational and decommissioning phases of the PV power project will not involve further adverse impacts on palaeontological heritage, however.

The extent of the proposed development (over 5000 m^2) falls within the requirements for a Heritage Impact Assessment (HIA) as required by Section 38 (Heritage Resources Management) of the 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.

Heritage Western Cape issued an interim comment (23 May 2011) requesting a palaeontological assessment of the three optional sites for the Beaufort West power project. Given the low levels of bedrock exposure within the study sites, a field assessment was not considered to be worthwhile by the author. The present desktop study was therefore commissioned on behalf of the developers by Ms Renee Rahaman of the CSIR, 11 Jan Celliers Street , Stellenbosch 7599.

2.3. General approach used for this palaeontological study

This palaeontological assessment report provides an assessment of the observed or inferred palaeontological heritage within the study area, with recommendations for specialist palaeontological mitigation where this is considered necessary. The report is based on (1) a review of the relevant scientific literature, (2) published geological maps and accompanying sheet explanations, (3) previous fossil heritage studies in the area (*e.g.* Almond 2010a, 2010b, 2010c); (4) the author's extensive field experience with the formations concerned and their palaeontological heritage.

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

On the basis of the desktop study, the likely impact of the proposed development on local fossil heritage and any need for specialist mitigation are then determined. Adverse palaeontological impacts normally occur during the construction rather than the operational or decommissioning phase. Mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) – is usually most effective during the construction phase when fresh fossiliferous bedrock has been exposed by excavations. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority (*e.g.* Heritage Western Cape for the Western Cape). It should be emphasized that, *providing appropriate mitigation is carried out*, the majority of developments involving bedrock excavation can make a *positive* contribution to our understanding of local palaeontological heritage.

Fig. 1 (Following page). Map of the Beaufort West region, Western Cape, showing the location of Farm Steenrotfontein 168 some 6.5 km southwest of the town as well as the three optional sites under consideration for the proposed Aurora Biotherm PV power project (Image kindly provided by CSIR, Stellenbosch).

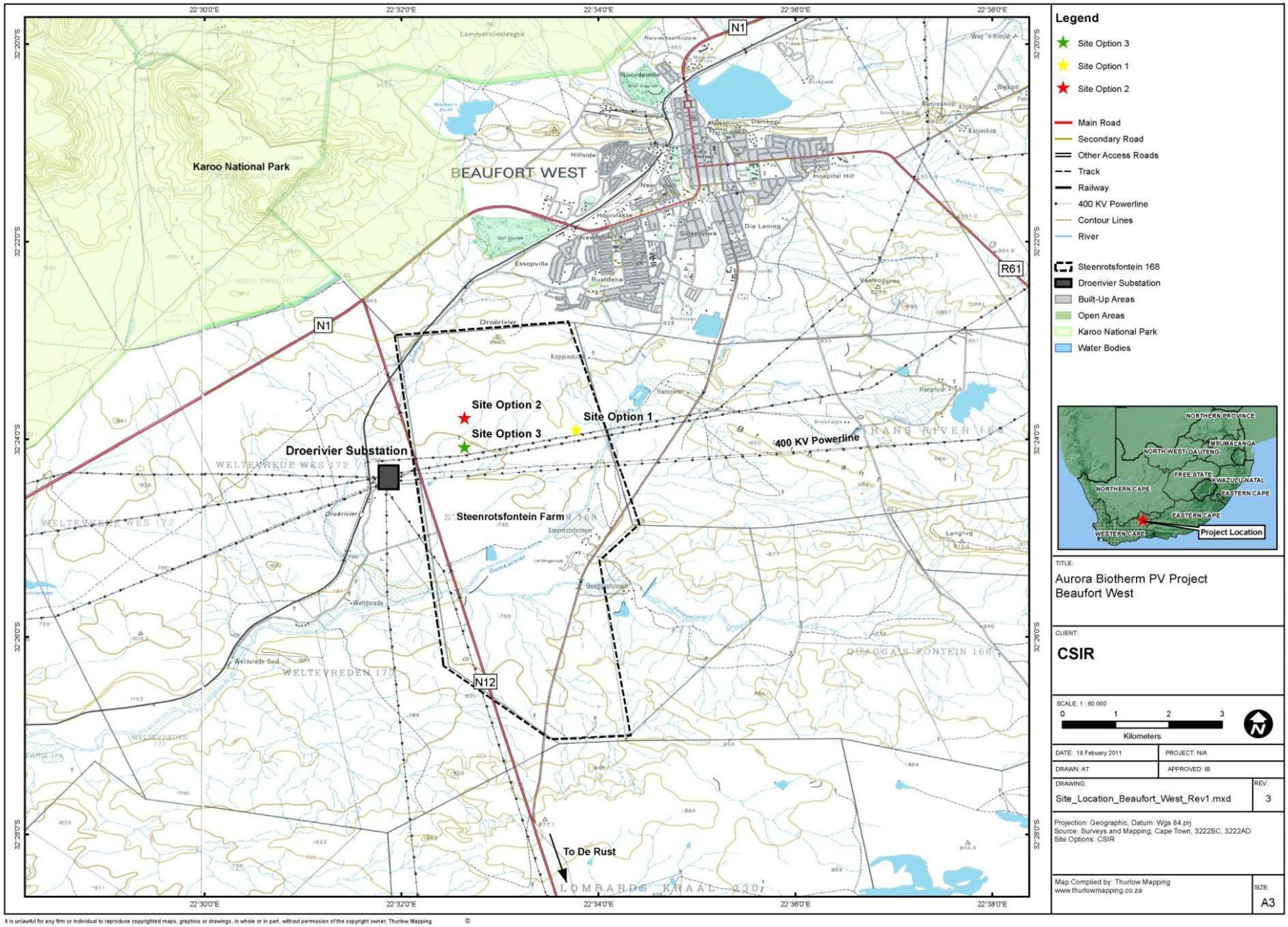

Fig. 2. Google Earth satellite image of the Aurora Biotherm PV Power Project study area on Farm Steenrotsfontein 168 *c.* 6.5 km to the southwest of Beaufort West (red rectangle) and east of the N12 tar road. This area is fairly flat-lying and traversed by small, shallow beds of intermittently-flowing streams. The Gamka River runs across the south-eastern corner of the image. Smooth grey areas represent Lower Beaufort Group mudrocks as well as overlying superficial deposits. Coarser surface gravels of sandstone and dolerite show up as rusty-brown patches. Elevated rocky ridges and plateaux to the north and south are resistant-weathering sandstone packages of the Poortjie Member (Teekloof Formation).

3. GEOLOGICAL BACKGROUND

As seen on satellite images (Fig. 2) and the 1: 50 000 topographical sheet 3222 BC Beaufort West, the study area to the east of the N12 comprises flat to hilly terrain at *c*. 800m amsl situated close to the foot of the Great Escarpment. This impressive mountainous escarpment, referred to in this area as the Nuweveld Mountains, defines the northern edge of the Great Karoo proper. It is built of a thick stack of continental sediments assigned to the **Lower Beaufort Group** (Late Permian Period) that are extensively intruded by dolerite sills and dykes of the Early Jurassic **Karoo Dolerite Suite** (**Jd**). The lower-lying *vlaktes* and hilly areas are traversed by several, shallow, intermittently-flowing tributaries of the Droërivier to the west and the Gamka River to the southeast.

The geology of the Beaufort West area is depicted in 1: 250 000 geology sheet 3222 Beaufort West (Council for Geoscience, Pretoria; Johnson & Keyser 1979) (Fig. 3). The bedrocks here are assigned to the **Teekloof Formation** (**Pt**) of the Lower Beaufort Group (Adelaide Subgroup, Karoo Supergroup). Geological and palaeoenvironmental analyses of the Lower Beaufort Group sediments in the Beaufort West area have been conducted by a number of workers. Key references within an extensive scientific literature include various papers by Roger Smith (*e.g.*

Smith 1979, 1980, 1986, 1987a, b, 1989, 1990, 1993a, 1993b) and Stear (1978, 1980). In brief, these thick successions of clastic sediments were laid down by a series of large, meandering rivers within a subsiding basin over a period of some ten or more million years within the Late Permian Period (*c*. 265-251 Ma). Sinuous sandstone bodies of lenticular cross-section represent ancient channel infills, while thin (<1.5m), laterally-extensive sandstone beds are crevasse splays deposited during occasional overbank floods. The bulk of the Beaufort sediments are greyish-green to reddish-brown or purplish mudrocks ("mudstones" = fine-grained claystones and slightly coarser siltstones) that were deposited over the floodplains during major floods. Thin-bedded, fine-grained playa lake deposits also accumulated locally where water ponded-up in floodplain depressions and are associated with distinctive fossil assemblages (*e.g.* fish, amphibians, trace fossils such as coprolites or fossil droppings, as well as burrows and trackways of arthropods and vertebrates).

Frequent development of fine-grained pedogenic (soil) limestone or calcrete as nodules and more continuous banks indicates that semi-arid, highly seasonal climates prevailed in the Late Permian Karoo. This is also indicated by the frequent occurrence of sand-infilled mudcracks and silicified gypsum "desert roses" (Smith 1980, 1990, 1993a, 1993b). Highly continental climates can be expected from the palaeogeographic setting of the Karoo Basin at the time – embedded deep within the interior of the Supercontinent Pangaea and in the rainshadow of the developing Gondwanide Mountain Belt. Fluctuating water tables and redox processes in the alluvial plain soil and subsoil are indicated by interbedded mudrock horizons of contrasting colours. Reddish-brown to purplish mudrocks probably developed during drier, more oxidising conditions associated with lowered water tables, while greenish-grey mudrocks reflect reducing conditions in waterlogged soils during periods of raised water tables. However, diagenetic (post-burial) processes also greatly influence predominant mudrock colour (Smith 1990).

Compared with the underlying rocks of the Abrahamskraal Formation the Teekloof Formation generally has a higher ratio of sandstones to mudrock, while reddish mudrocks are more abundant here than below. The Beaufort succession within the study area contains numerous single to multistory channel sandstones that are characteristic of the basal arenaceous **Poortjie Member** of the Teekloof Formation. In addition to its high sandstone: mudrock ratio, the Poortjie Member is also characterized by thin, impersistent lenses of pinkish "cherts" that are probably altered volcanic ashes (Johnson & Keyser 1979, Smith & Keyser 1995b). Several economically interesting uranium ore deposits occur within this member in association with brown-weathering, ferruginous channel sandstones ("*koffieklip*") and transported plant material. Interesting accounts of the sedimentology and palaeontology of the Poortjie Member at the farm Putfontein, to the south of Beaufort West, are given by Stear (1978) as well as by Cole and Smith (2008).

A thin dyke-like intrusion of the **Karoo Dolerite Suite** (**Jd**) striking NW-SE runs south of Beaufort West and is exposed in a small hilltop quarry as well as streambeds and banks in the Droërivier area, to the north of the present study area. The Early Jurassic Karoo dolerites are totally unfossiliferous and will therefore not be considered further here (*cf* Duncan & Marsh 2006).

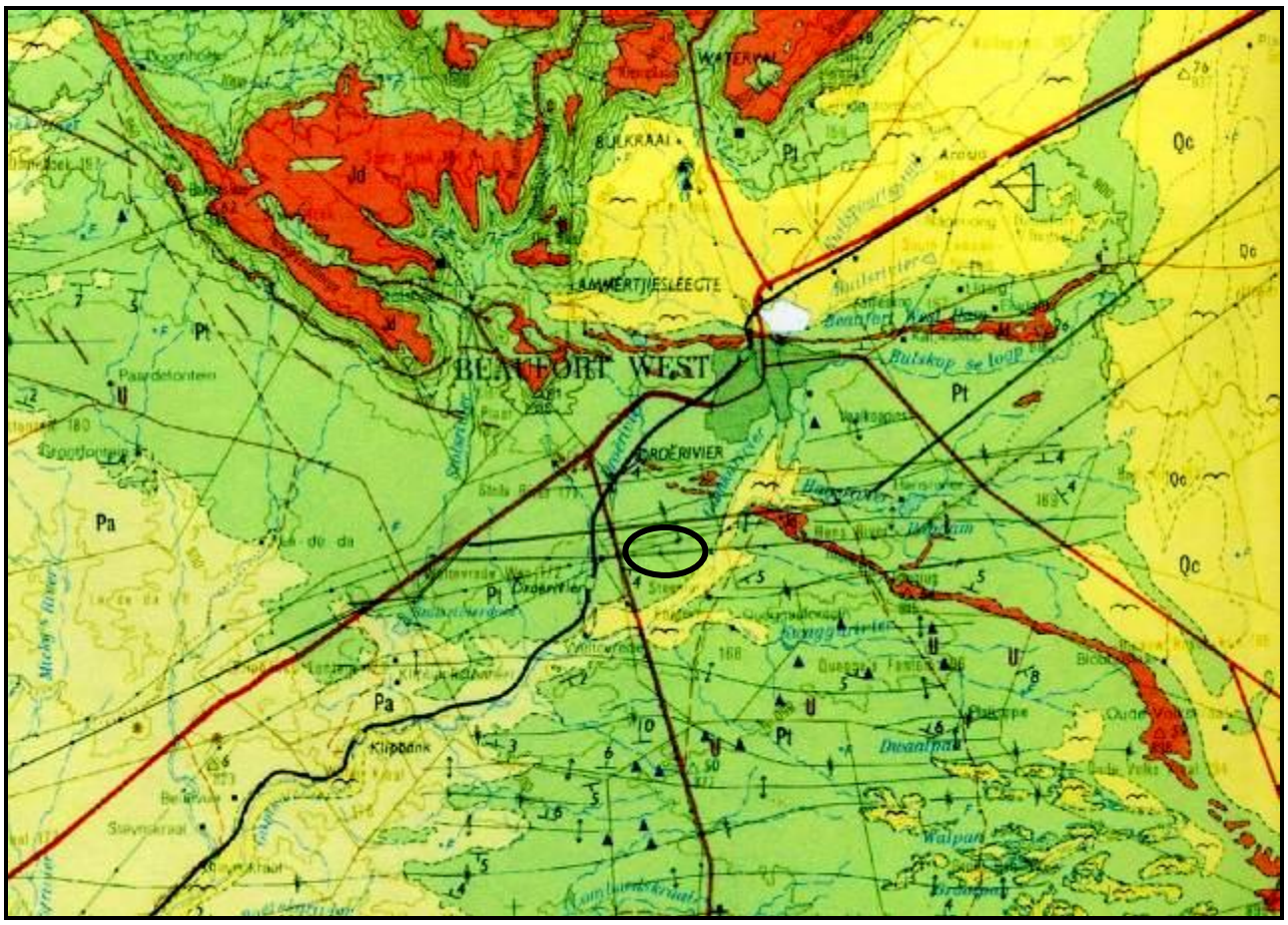

Fig. 3. Extract from 1: 250 000 geology sheet 3222 Beaufort West showing geology of the Beaufort West region. The black ellipse indicates the approximate location of the study area east of the N12 and north of the Gamka River. Note numerous W-E trending fold axes indicated south of Beaufort West.

Pa (pale yellow) = Abrahamskraal Formation (Adelaide Subgroup, Lower Beaufort Group). Pt (green) = Teekloof Formation. Jd (red) = Karoo Dolerite Suite. Yellow = Quaternary superficial sediments, including alluvium, sheet wash, colluvium, soils, locally cemented by pedocretes such as calcrete (Qc). Diamond symbols indicate fossil localities within the *Tapinocephalus* Assemblage Zone. Triangles indicate fossils within the *Pristerognathus* Assemblage Zone. Squares indicate fossils within the *Tropidostoma* Assemblage Zone (See also Figs 4 and 5).

A range of, mainly unconsolidated, **Quaternary to Recent superficial deposits** or "drift" mantle the Beaufort Group outcrop along the gently sloping foothills (pediplain) of the Great Escarpment (Johnson & Keyser 1979, Cole *et al.,* 2004). Colluvial scree and sheet-wash deposits are found on the steeper slopes while channel-related alluvium predominates in flatter areas away from the Escarpment. Close to the escarpment massive to well-bedded, silty to gravely alluvium attaining thicknesses of several meters is seen in the banks of recently incised streams and rivers (Almond 2010b). Coarser alluvial gravels capping older pediment surfaces (some of which may even be Neogene or Late Tertiary in age) are frequently cemented within the top couple of meters by pedocretes such as calcrete, especially where abundant groundwater carbonate is available from weathering of local dolerite intrusions. The Quaternary or younger age of many of the alluvial deposits is confirmed by the presence within them of reworked stone artefacts no more than 2.5 Ma (Earlier Stone Age) or 250-300 000 years old (Middle Stone Age). Extensive, thin (one to two clasts-thick) mantles of residual surface gravels mainly comprise tougher-weathering lithologies such as quartzite, hornfels and dolerite. Locally they include abundant stone artefacts of the Early to Late Stone Age. Many of the older artefacts show extensive rounding due to transport and also

to weathering. Cole *et al.* (2004) argue that local slopes are too low to ascribe emplacement of these coarser gravels to sheet wash, so an origin by down-wasting of bedrock (and of older gravels) is preferred. A further category of Karoo drift sediments are spring and pan deposits (*cf* Partridge *et al*., 2006).

The fossiliferous Beaufort Group bedrocks in the solar power facility study areas are extensively overlain by rocky colluvium (including sandstone and dolerite) on hill slopes and by fine, silty to gravelly alluvium of Quaternary to Recent age in lower-lying areas. Bedrock exposures are largely limited to small gullies and patches on hill slopes as well as dry streambeds in the *vlaktes*. On satellite images (Fig. 2) the Beaufort Group mudrocks and overlying superficial deposits appear as greyish areas, while coarser sandstone and doleritic gravels have rusty brown hues. Prominent-weathering plateaux and ridges to the north and south of the study area are sandstone packages of Poortjie Member at the base of the Teekloof Formation. CSIR field photographs at all three sites under consideration for the PV power project show relatively flat terrain mantled in silty superficial sediments (sheet wash, alluvium, soil) with sparse surface gravels. No outcrops of Beaufort Group bedrocks are visible here.

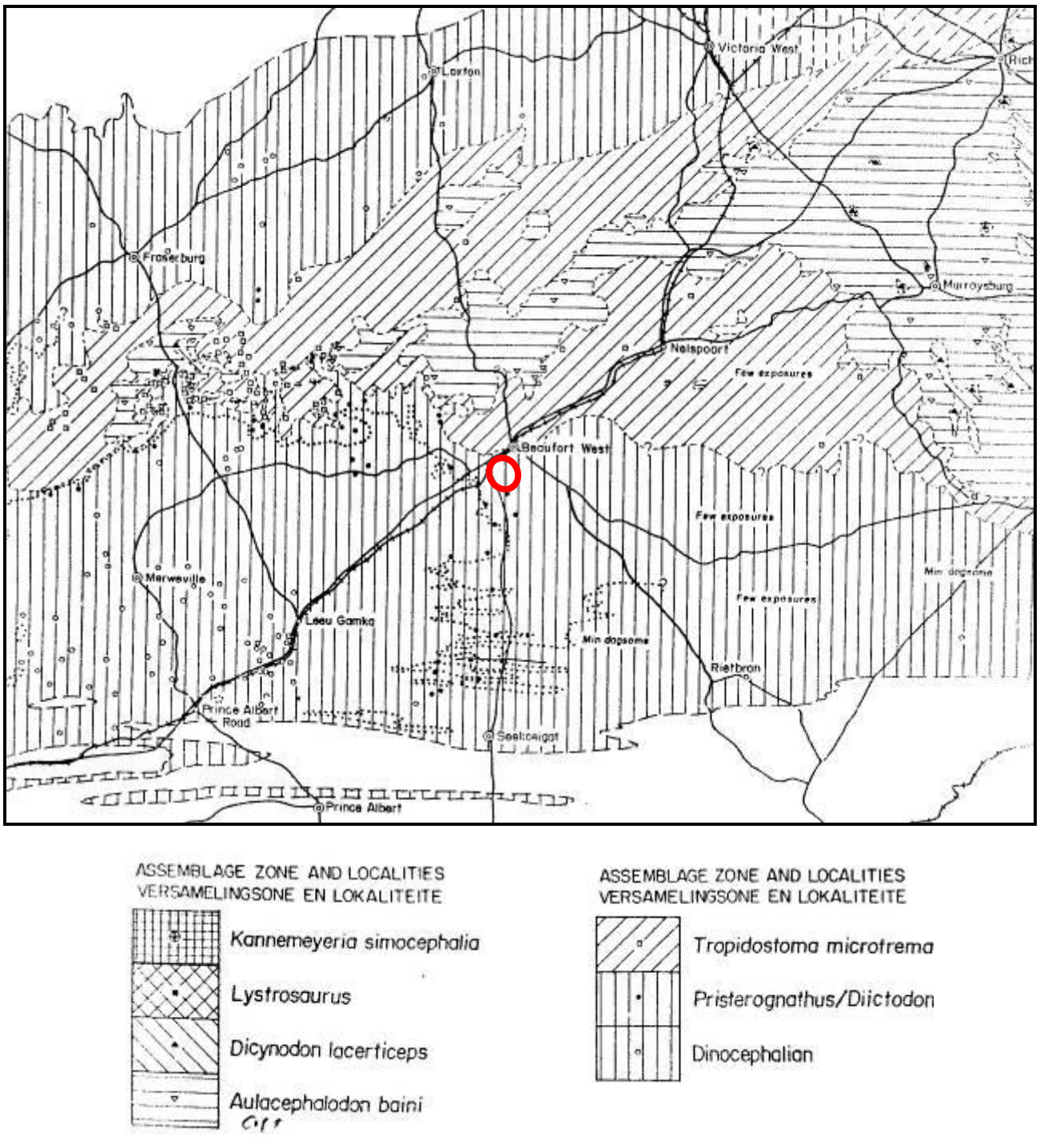

Fig. 4. Biostratigraphical map of the Beaufort Group in the Great Karoo around Beaufort West showing the distribution of the various palaeontological Assemblage Zones, mainly based on tetrapod fossils (Keyser & Smith 1977-78). According to this map the study area southwest of Beaufort West lies within the *Pristerognathus* Assemblage Zone.

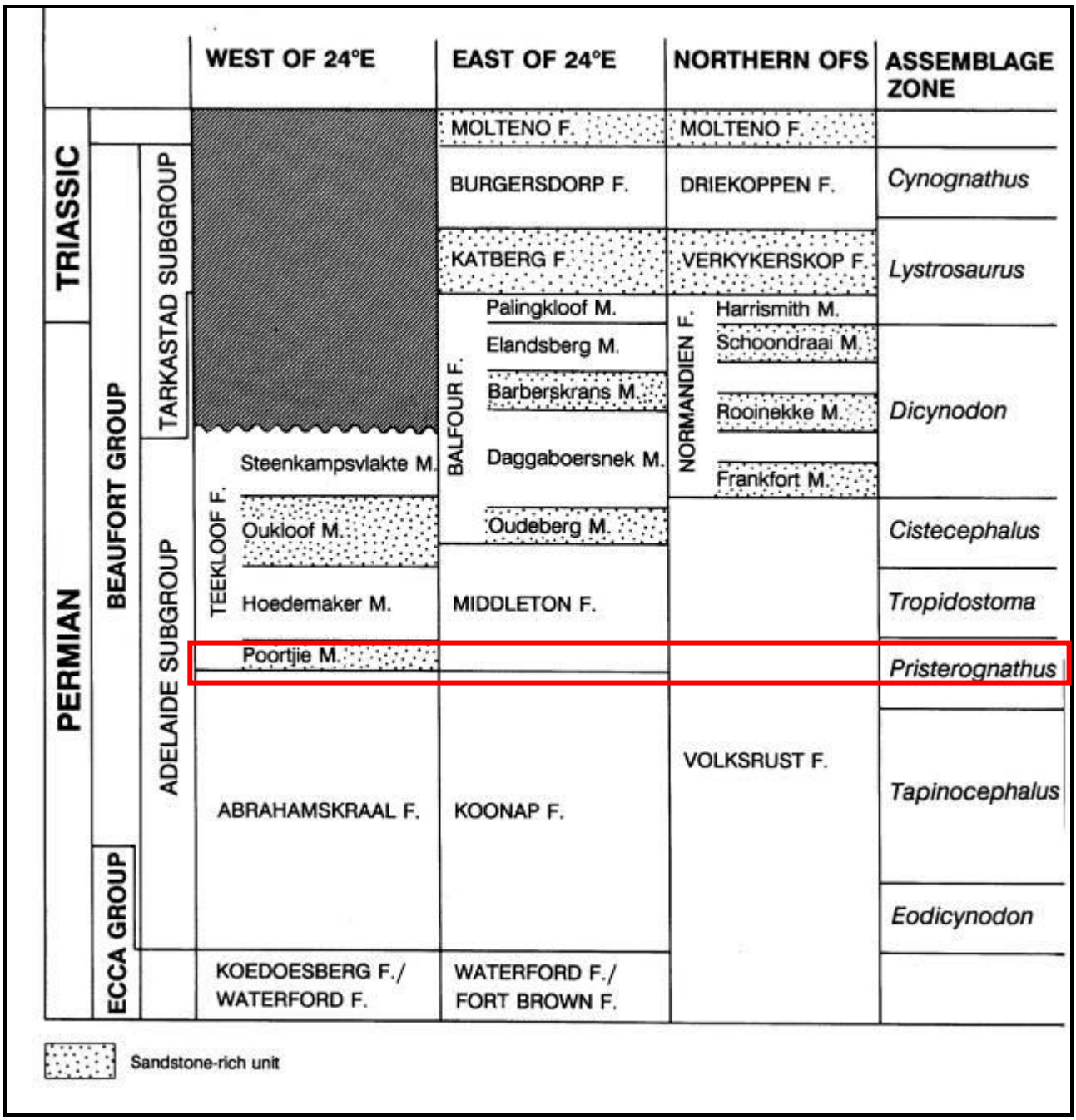

Fig. 5. Chart showing the lithostratigraphic and biostratigraphic subdivisions of the Beaufort Group with the Poortjie Member and *Pristerognathus* Assemblage Zone outlined in red (From Rubidge 1995).

4. PALAEONTOLOGICAL HERITAGE

4.1. Fossil heritage within the Lower Beaufort Group

Fossilised bones and teeth were first recorded from the Beaufort Group in the Beaufort West area in the 1820s. These were the earliest scientific records of such ancient vertebrate fossils from the Great Karoo (MacRae 1999). They represent the start of a strong scientific tradition in vertebrate palaeontology in South Africa that has now persisted for nearly two centuries and has established the Great Karoo as an area of unrivalled importance for understanding the evolution of the oldest known complex ecosystems on land (*cf.* Cluver 1978, MacRae 1999, McCarthy & Rubidge 2005).

The various formations and members of the Beaufort Group are distinguished on the basis of both *lithological* features (*i.e.* rock type and sedimentation patterns) as well as on *palaeontological* grounds (*i.e.* fossil content). A succession of fossil assemblage zones, also termed biozones, has been established by palaeontologists for the Beaufort Group succession and mapped out throughout the main Karoo Basin (Keyser & Smith 1977-78, Rubidge, 1995, MacRae 1999, Rubidge 2005, Van der Walt *et al.*, in press; Figs 4 and 5 herein). Each assemblage zone is characterised by a number of key fossil vertebrate taxa (zone fossils), some of which are restricted to that assemblage zone and are of special biostratigraphic significance – *i.e.* they can be used to identify sedimentary successions of closely comparable age both within and between sedimentary basins.

The relationship between the various lithostratigraphic formations and members of the Beaufort Group within the study area on the one hand and the biostratigraphic assemblage zones on the other is outlined in Figure 5. Four successive fossil assemblage zones of Late Permian age are represented in the Beaufort West area: the *Pristerognathus*, *Tropidostoma*, *Cistecephalus* and *Dicynodon* Assemblage Zones (AZ). Comprehensive lists and illustrations of the fossil taxa within each assemblage zone are given in the references cited above (See especially MacRae 1999 for a readable, popular and well-illustrated account, and Rubidge 1995 for a recent authoritative but more technical review). Accessible, more "popular" reviews of Karoo fossils directly relevant to the Beaufort West area are given by Smith (1988, 1989) as well as in the recently upgraded Fossil Trail and the new Interpretive Centre within the Karoo National Park (*Natura Viva* cc, 2005).

On the basis of international faunal correlation, the *Pristerognathus*, *Tropidostoma* and *Cistecephalus* Assemblage Zones / Biozones of the Lower Beaufort Group have until recently all been assigned to the Wuchiapingian Stage of the Late Permian Period, with an approximate age range of 260-254 Ma (Rubidge 2005 and refs. therein). Terrestrial tetrapod faunas of comparable age are known from Russia and China in the northern, Laurasian portion of Pangaea as well as Karoo-type basins to the north of South Africa (Zimbabwe, Zambia, Malawi, Tanzania) and in India within the Gondwanan sector of Pangaea. Recently announced, but as yet unpublished, radiometric dates for the Teekloof Formation (Rubidge *et al.* 2010) assign a late Guadalupian (Capitanian) age to the *Pristerognathus* AZ (261-260.36 Ma), an early Lopingian (Wuchiapingian) age to the *Tropidostoma* AZ (259.3 Ma), and a later Wuchiapingian age to the Cistecephalus AZ (256.6-255.2Ma). This places the Mid / Late Permian boundary and End Guadalupian mass extinction event (if reflected on land) within the Teekloof Formation between the *Pristerognathus* and *Tropidostoma* AZs, rather than at the base of the *Pristerognathus* AZ as previously assumed.

Late Permian age vertebrate fossil assemblages of the lower Beaufort Group are dominated by a variety of small to large true reptiles and – more especially – by a wide range of therapsids. The latter are also commonly, but misleadingly, known as "mammal-like reptiles" or protomammals (*e.g.* Cluver 1978, MacRae 1999, Rubidge 1995). By far the most abundant group among the Late Permian therapsids are the dicynodonts, an extinct group of two-tusked herbivorous therapsids. Aquatic animals include large, crocodile-like temnospondyl amphibians and various primitive bony fish (palaeoniscoids). Note that fossil dinosaurs are *not* found within the Beaufort West area; this group only evolved some thirty million years *after* the lower Beaufort Group sediments were deposited.

A high proportion of the tetrapod (*i.e.* four-limbed, terrestrial vertebrate) fossils from the Teekloof Formation are found within the overbank mudrocks. They are very commonly encased within calcrete or pedogenic limestone that often obscures their anatomy and makes such fossils difficult to recognise in the field, even for experienced palaeontologists (Smith 1993a,b). Rarer fossil specimens preserved within the Beaufort Group sandstones are usually disarticulated and fragmentary due to extensive, pre-burial transport. Occasionally vertebrate fossils are found embedded within baked (thermally metamorphosed) mudrocks or hornfels in the vicinity of dolerite intrusions. However, such fossils are extremely difficult to prepare out in the laboratory and so are generally of limited scientific value.

Key studies on the *taphonomy* (pre-burial history) of Late Permian vertebrate remains in the Great Karoo have been carried out in the Beaufort West area and have yielded a wealth of fascinating data on Late Permian terrestrial wildlife and palaeoenvironments (*e.g.* Smith 1980, 1993a). Therapsid fossils are most abundant and best preserved (well-articulated) within muddy and silty overbank sediments deposited on the proximal floodplain (*i.e.* close to the river channel). Here they are often associated with scoured surfaces and mature palaeosols (ancient soils), these last indicated by abundant calcrete nodules. In the distal floodplain sediments (far from water courses), fossils are rarer and mostly disarticulated. Channel bank sediments usually contain few fossils, mostly disarticulated, but occasionally rich concentrations of calcrete-encrusted remains, some well-articulated, are found. These dense bone assemblages may have accumulated in swale fills or chute channels which served as persistent water holes after floods (Smith 1993a). Such detailed interdisciplinary field studies re-emphasise how essential it is that fossil collecting be undertaken by experienced professionals with a good grasp of relevant sedimentology as well as palaeontology, lest invaluable scientific data be lost in the process.

Plant fossils in the lower Beaufort Group are poorly represented and often very fragmentary (*cf*. Anderson & Anderson 1985, dealing primarily with material from the eastern Karoo Basin, Gastaldo *et al*. 2005, dealing with Permo-Triassic boundary floras in the Main Karoo Basin). They belong to the *Glossopteris* Flora typical of Permian Gondwana and include reedy sphenophytes or "horsetails" (Arthrophyta, now recognised as a fern subgroup) and distinctive tongue-shaped leaves of the primitive, tree-sized gymnosperm *Glossopteris*. Well-preserved petrified wood ("*Dadoxylon*") occurs widely and may prove of biostratigraphic and palaeoecological value in future (*e.g.* Bamford 1999, who records only the genus *Australoxylon* from Lower Beaufort beds stratigraphically equivalent to those examined here). Elongate plant root casts or *rhizoliths* are frequently found associated with calcrete nodule horizons. Transported plant debris preserved within channel sandstones is often associated with secondary iron ("*kofffieklip*") and uranium mineralization, as seen for example within the Abrahamskraal Formation and Poortjie Member Member in the Beaufort West area (Cole & Smith 2008 and refs. therein).

Late Permian invertebrate fossils from the western Karoo Basin comprise almost exclusively relatively featureless, thin-shelled freshwater bivalves, while fairly low diversity insect faunas are recorded from plant-rich horizons further east. The most prominent vertebrate trace fossils in the Lower Beaufort Group are well-preserved tetrapod trackways attributed to various groups of reptiles and therapsids (Smith 1993b), as well as substantial, inclined to helical scratch burrows that were probably constructed by smaller therapsids as an adaptation to the highly seasonal, and occasionally extreme, continental climates at high palaeolatitudes of 60-70º S. (Smith 1987b). Invertebrate trace fossils from the Karoo National Park at Beaufort West include the locally abundant scratch burrows of the ichnogenus *Scoyenia* that are generally attributed to infaunal arthropods such as insects. A diverse freshwater ichnofauna (trace fossil assemblage) from the Beaufort West townlands with trails, burrows and trackways generated by fish, snails, arthropods, worms and other animals has been recorded by Smith (1993a).

A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Kitching (1977), Keyser and Smith (1979), Rubidge (1995) and Van der Walt *et al.* in press (Fig. 4).

4.1.1. Teekloof Formation (Poortjie Member)

The arenaceous Poortjie Member as well as the uppermost beds of the underlying Abrahamskraal Formation are characterised palaeontologically by fossils of the ***Pristerognathus* Assemblage Zone** (Smith & Keyser 1995b). This important terrestrial biota is dominated by various therapsids ("mammal-like reptiles") such as the moderate-sized therocephalian carnivore *Pristerognathus* as well as several gorgonopsian predators / scavengers (*e.g. Gorgonops*) and herbivorous dicynodonts (Fig. 6). The commonest genus by far is the small burrowing dicynodont *Diictodon* (Keyser and Smith 1977-78, Smith & Keyser 1995b, MacRae 1999, Cole *et al*., 2004, Rubidge 2005, Day & Rubidge 2010). There are also large, rhino-sized herbivorous reptiles (*Bradysaurus* spp.), the curious turtle-like insectivore *Eunotosaurus*, large crocodile-like temnospondyl amphibians (*Rhinesuchus*), palaeoniscoid fish, vascular plant fossils of the *Glossopteris* Flora (fossil woods such as *Australoxylon*, leaves *etc*; Bamford 1999) and various trace fossils. These last include a range of invertebrate burrows (*e.g. Scoyenia*), vertebrate scratch burrows, many of which are attributed to dicynodonts (Smith 1987b), and tetrapod trackways (Smith 1993a).

Until recently the fossil biota of the *Pristerognathus* AZ was interpreted as an impoverished post-extinction recovery fauna following the catastrophic End-Guadalupian (= End Mid Permian) mass extinction event of 260.4 million years ago (Retallack *et al.,* 2006). This mass extinction is now correlated with the top of the *Pristerognathus* biozone (see above), suggesting that these low diversity faunas may have lived *between* two successive Mid Permian extinctions.

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

As a consequence of their proximity to large dolerite intrusions in the Great Escarpment zone, some Beaufort Group sediments in the study area have been thermally metamorphosed or "baked" (*i.e*. recrystallised, impregnated with secondary minerals). Embedded fossil material of phosphatic composition, such as bones and teeth, is frequently altered by baking – bones may become blackened, for example - and can be very difficult to extract from the hard matrix by mechanical preparation (Smith & Keyser, p. 23 *in* Rubidge 1995). Thermal metamorphism by dolerite intrusions therefore tends to reduce the palaeontological heritage potential of Beaufort Group sediments.

No fossil sites are marked within the study area on the south-western outskirts of Beaufort West either on the 1: 250 000 geological map 3222 Beaufort West (Fig. 3) nor on the Karoo biozone maps published by Kitching (1977) and Keyser and Smith (1977-78) (Fig. 4) but there are a few *Pristerognathus* AZ fossil sites just to the south. Important collections of pristerognathids and *Diictodon* assemblages have been collected from the Poortjie Member near Beaufort West over the years by Dr R. Smith and colleagues at Iziko Museums, Cape Town (*e.g.* from the farm La de Da. See also faunal lists in Kitching 1977). Fossils in the Poortjie Member in the Karoo National Park, just northwest of the present study area, are mentioned by Cole and Smith (2008; see also impact study by Almond 2006). The type area of the *Pristerognathus* Assemblage Zone is on the farm Lombardskraal 330, only some 15km south of Beaufort West (Smith & Keyser 1995b), while another important fossiliferous locality in the Poortjie Member is on the farm Putfontein, also due south of Beaufort West (Cole & Smith 2008 and refs. therein). A small range of vertebrate fossils, trace fossils (including vertebrate scratch burrows) and plants (*e.g* sphenophytes) have been recorded from the Poortjie Member just west and south of Beaufort West by the author (Almond 2010a). Recently skull and postcranial remains of a large dinocephalian therapsid were collected from a locality on farm Steenrotsfontein 168 about one kilometre north of the present study site (Almond 2010c). This is currently the only known dinocephalian specimen from the Poortjie Member and the youngest representative of the Dinocephalia ever recorded (Saniye Güven, Mike Day and John Almond, work in progress). Other fossils recorded in the same area include

vertebrate scratch burrows, several small dicynodonts (probably *Diictodon*) as well as silicified wood (*ibid*.).

Given the very low levels of bedrock exposure within the study area it is unlikely that significant fossil remains occur at surface here, although transported bone and silicified wood specimens might occur. As outlined above, important Beaufort Group fossil remains are already recorded in the vicinity and may be encountered in fresh excavations made during the construction phase of development.

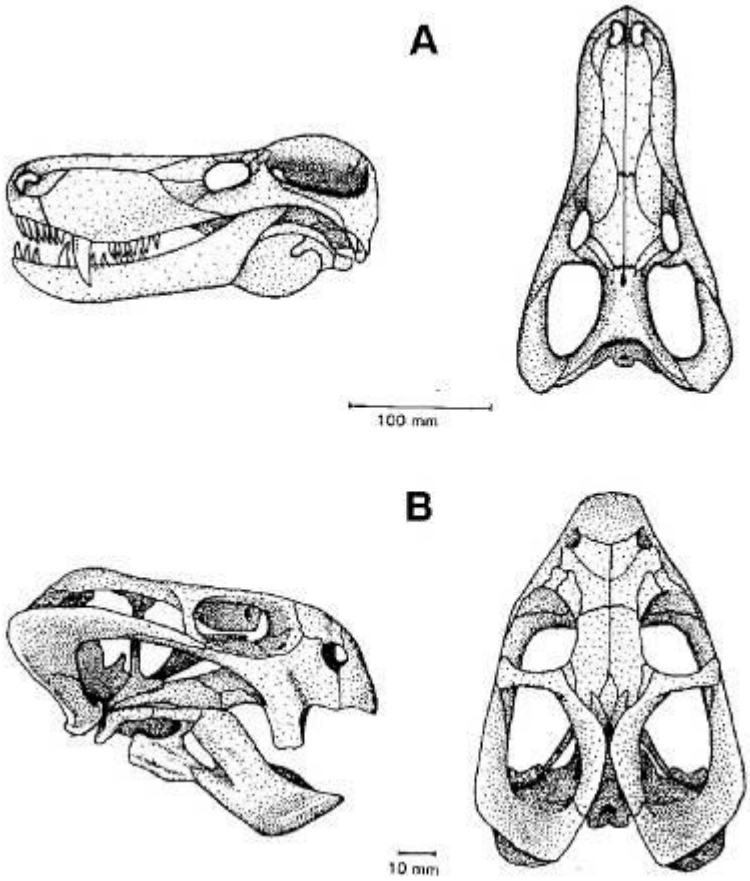

Fig. 6. Skulls of typical therapsids from the *Pristerognathus* Assemblage Zone: A. the dog-sized carnivorous therocephalian *Pristerognathus* and B. the small herbivorous dicynodont *Diictodon* (From Smith & Keyser 1995b).

4.2. Fossil heritage within Quaternary to Recent alluvium

The Quaternary to Recent superficial or “drift” deposits have been comparatively neglected in palaeontological terms for the most part. However, they may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals (*e.g.* Skead 1980, Klein 1984, MacRae 1999, Partridge & Scott 2000, Partridge *et al.* 2006). These may include ancient human remains of considerable palaeoanthropological significance (*e.g*. Grine *et al.,* 2007). Other late Caenozoic fossil biotas from these superficial deposits include non-marine molluscs (bivalves, gastropods), ostrich egg shells, trace fossils (*e.g.* calcretised termitaria, coprolites, rhizoliths), and plant remains such as peats or palynomorphs (pollens) in fine-grained, organic-rich alluvial horizons. Quaternary alluvial sediments may contain reworked Stone Age artifacts that are useful for constraining their maximum age.

5. IDENTIFICATION OF ISSUES

The sedimentary bedrocks of the Teekloof Formation (Lower Beaufort Group) underlying the study area are potentially fossiliferous and important vertebrate fossil sites are already recorded close to (but outside) this area (Section 4). The construction phase of the proposed solar energy development near Beaufort West may therefore compromise fossil heritage present at or below the ground surface within the development footprint. This applies especially to components of the solar power facility - such as PV panel mounting structures and underground cables - that may involve fresh excavations, some of which may penetrate fresh bedrock. However, it should be noted that extensive, deep excavations are *not* envisaged for this project.

The operational and decommissioning phases of the project are unlikely to have any significant impact on palaeontological heritage resources.

6. PERMIT REQUIREMENTS

It should be noted that all South African fossil heritage is protected by law (South African Heritage Resources Act, 1999) and fossils cannot be collected, damaged or disturbed without a permit. Therefore, should fossils be exposed during development, these should be safeguarded, preferably *in situ*, and reported by the ECO as soon as possible to the relevant heritage management authority (Heritage Western Cape) so that any appropriate mitigation by a palaeontological specialist can be implemented.

Mitigation action by a professional palaeontologist will need to be supported by a fossil collection permit from SAHRA.

7. ASSESSMENT OF IMPACTS AND IDENTIFICATION OF MANAGEMENT ACTIONS

7.1. Assessment of impact significance

The proposed Aurora Biotherm solar power facility near Beaufort West is located in an area of the western Karoo that is underlain by potentially fossil-rich sedimentary rocks of Late Permian and younger age (Section 4). The construction phase of the development will entail several small excavations into the superficial sediment cover and perhaps also into the underlying bedrock. These notably include excavations for the PV panel mountings, buried cables and new gravel access roads, among others. Additional areas of bedrock may be sealed-in or sterilized by infrastructural developments. All of these developments may adversely affect local fossil heritage within the study area by destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good.

All three sites under consideration for the solar energy facility show very low levels of bedrock exposure due to superficial sediment cover (soil, alluvium *etc*) so fossils are unlikely to be present at surface. However, buried fossil remains may be present near-surface in these areas. In general, Beaufort Group fossils are scattered and sparse, but local concentrations of well-preserved material (*e.g.* articulated skeletons) may occur. Important vertebrate fossil remains have been recorded from the study region near Beaufort West, just outside the present study area.

The inferred impact of the proposed solar power development on fossil heritage is analysed in Table 1 below, which applies equally to all three sites under consideration. During construction the destruction, damage or disturbance out of context of fossils that are preserved at the ground surface or below ground represents a direct *negative* impact that is limited to the development footprint and cannot be fully rectified (*i.e.* permanent). Because of the generally sparse occurrence of fossils within the Teekloof Formation, as inferred from better exposed localities elsewhere, and the extensive occurrence of overlying superficial sediments (soil *etc*) within the study area, the

impact significance of the construction phase of the proposed solar energy project is rated as LOW (negative).

Should fossils be discovered before or during construction and reported by the responsible ECO to the responsible heritage management authority (Heritage Western Cape) for professional recording and collection, as recommended here, the overall impact significance of the project would change to low (*positive*). This is a positive outcome because any new, well-recorded and suitably curated fossil material from these Karoo bedrocks would constitute a useful addition to our scientific understanding of the palaeontological heritage of the region.

The operational and decommissioning phases of the wind energy facility will not involve further significant adverse or other impacts on palaeontological heritage.

Confidence levels for this assessment are moderate but not high because of the low levels of bedrock exposure in the study area and the known occurrence of important vertebrate fossils within the outcrop area of the Teekloof Formation on the farm Steenrotsfontein 168 and elsewhere.

There is no preference on palaeontological heritage grounds for any one of the three sites under consideration, all of which are of low impact significance.

7.2. Recommended management actions

It is recommended that:

- 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 (Heritage Western Cape) 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 Aurora Biotherm solar power facility near Beaufort West.

Specimens of Beaufort Group fossils from the Beaufort West area are on display at the Karoo National Park (Fossil Trail and Interpretive Centre). These displays could be usefully examined by the ECO to gain experience in the recognition of Karoo fossil material (See also illustrations in MacRae 1999, McCarthy & Rubidge 2005).

The palaeontologist concerned with mitigation work will need a valid 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 to the minimum standards for Phase 2 palaeontological studies currently being developed by SAHRA.

TABLE 1: Palaeontological impact assessment of the proposed Aurora Biotherm solar power facility near Beaufort West, Western Cape (This table applies equally to all three sites under consideration)

Nature of impact	Status (Negative or positive)	Extent	Duration	Intensity	Probability	Significance (no mitigation)	Mitigation/Management Actions	Significance (with mitigation)	Confidence level
Construction Phase									
Destruction, disturbance or sealing-in of surface or buried fossils during bedrock excavations and construction work	**Negative** (without mitigation) **Positive** (with mitigation)	**Local, restricted to immediate develop-ment footprint**	**Permanent**	**Generally Low**, **but locally HIGH**	**Improbable**	**LOW (negative)**	ECO should alert Heritage Western Cape if substantial fossils (*e.g.* bones, teeth, petrified wood) are found during construction.	**Low** and **positive** since any mitigation measures, *e.g.* recording and collection of newly exposed fossils, will reduce negative impacts further and contribute usefully to scientific understanding of local fossil heritage	**Moderate**, based on fieldwork by specialist Karoo palaeontologists as well as present author
Operational Phase									
NO significant impacts anticipated during operational phase	**n/a**	**Solar energy facility**	**n/a**	**n/a**	**n/a**	**n/a**	ECO should alert Heritage Western Cape if substantial fossils (*e.g.* bones, teeth, petrified wood) are found during construction	New fossil records will contribute usefully to scientific understanding of local fossil heritage	**High**

TABLE 2: Recommended mitigation and monitoring for the proposed Aurora Biotherm solar power facility near Beaufort West, Western Cape

Impact	Mitigation / Management Action	Monitoring		
		Methodology	Frequency	Responsibility
Destruction, disturbance or sealing-in of buried fossils during bedrock excavations and construction work	1. General monitoring of bedrock excavations	Any significant fossil finds to be reported to Heritage Western Cape for possible mitigation	Throughout construction	ECO
	2. Monitoring of excavations in palaeontologically sensitive areas	Recording and sampling of fossils and relevant geological data. Phase 2 report to Heritage Western Cape.	During construction, following alert from ECO / Heritage Western Cape	Professional palaeontologist

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QUALIFICATIONS & EXPERIENCE OF THE AUTHOR

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

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