PALAEONTOLOGICAL IMPACT ASSESSMENT: DESKTOP STUDY

Proposed Photovoltaic Power Station, Beaufort West Municipality, Western Cape

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1. SUMMARY

EAB-Astrum Energy (Pty) Ltd is proposing to develop a 60 MW photovoltaic (PV) power station some 3 km northeast of the town of Beaufort West in the Great Karoo, Western Cape Province. The study area comprises flat-lying terrain at the foot of the Great Escarpment. The bedrock here is formed by Late Permian fluvial and lacustrine sediments of the Hoedemaker Member (Teekloof Formation, Lower Beaufort Group). This rock unit is known for its rich fossil biota of the *Tropidostoma* Assemblage Zone, including a range of therapsids ("mammal-like reptiles"), pareiasaur reptiles, large amphibians, bony fish as well as plant remains of the Gondwanan *Glossopteris* Flora (*e.g.* fossil wood) and trace fossils such as therapsid and invertebrate burrows. The palaeontological sensitivity of the Beaufort Group sediments is therefore generally high. However, in the study area the potentially fossiliferous Beaufort Group bedrocks are rarely exposed due to the thick cover of superficial deposits - mainly residual (down-wasted) gravels and gravelly to silty alluvium of Pleistocene to Recent age. These superficial deposits are not markedly fossiliferous, although they may contain fossil bones and teeth of mammals and reptiles, ostrich eggshells, and calcretized traces such as rhizoliths (root casts) and termitaria.

Since deep bedrock excavations are unlikely to be required for the proposed development while the superficial sediments here are of low palaeontological sensitivity, it is very unlikely that the proposed PV power station development will pose a serious risk to local fossil heritage. Specialist palaeontological mitigation for this project is therefore not considered necessary.

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 Beaufort West Photovoltaic Power Station project.

2. INTRODUCTION & BRIEF

2.1. Project outline

The company EAB-Astrum Energy (Pty) Ltd is proposing to develop a photovoltaic (PV) power station some 3 km northeast of the town of Beaufort West in the Great Karoo, Western Cape Province. The project is being developed in conjunction with Wind Farm Beaufort West, both of which are situated adjacent to and north of the N1 trunk road on a portion of Portion 1 of the Farm Bulskop No. 163, camp 3, the Farm Lemoenfontein South and Portion 9 of the Farm Kuilspoort (Figs. 1 & 2).

The proposed PV power station will have a peak capacity of 60MW and will occupy a footprint of approximately 150 ha. The main infrastructural components of the development are:

- An array of *c*. 260 000 photovoltaic panels, each with a surface area of 1.68m^2;
- Support structures of PV the panels;
- DC to AC Inverters;
- A transformer;
- An overhead power line (132kV) of approximately 6km length feeding into the Beaufort West Substation (the power line will be shared with the associated wind farm development);
- Underground cabling between the PV panels;
- Internal access roads;
- A workshop area for maintenance and storage.

At the end of its expected 20 year lifespan, the system will be decommissioned and its components, where possible, will be recycled.

2.2. Project implications for palaeontological heritage & relevant legislation

The proposed Beaufort West PV Power Station 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 excavations for the PV panel support structures, buried cables, new internal access roads, power 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 station 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.

2.3. Approach to this palaeontological study

This report provides an assessment of the observed or inferred palaeontological heritage within the Beaufort West study area, with recommendations for any specialist palaeontological mitigation where this is considered necessary. The report is based on (1) a review of the relevant scientific literature, (2) geological maps and (3) several previous palaeontological heritage assessments in the Beaufort West study region (Almond 2006, 2010a, 2010b). These last include a combined desktop and field assessment study of the wind farm development associated with this project (Almond 2010b) during which the proposed PV power station development area was also assessed (See Fig. 2). Additional field assessment of the PV power station footprint was therefore not considered to be necessary. Please note that no assessment of the proposed off-site electrical substation at Beaufort West was undertaken. Should the development go ahead, the substation should be covered by a separate fossil heritage study.

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

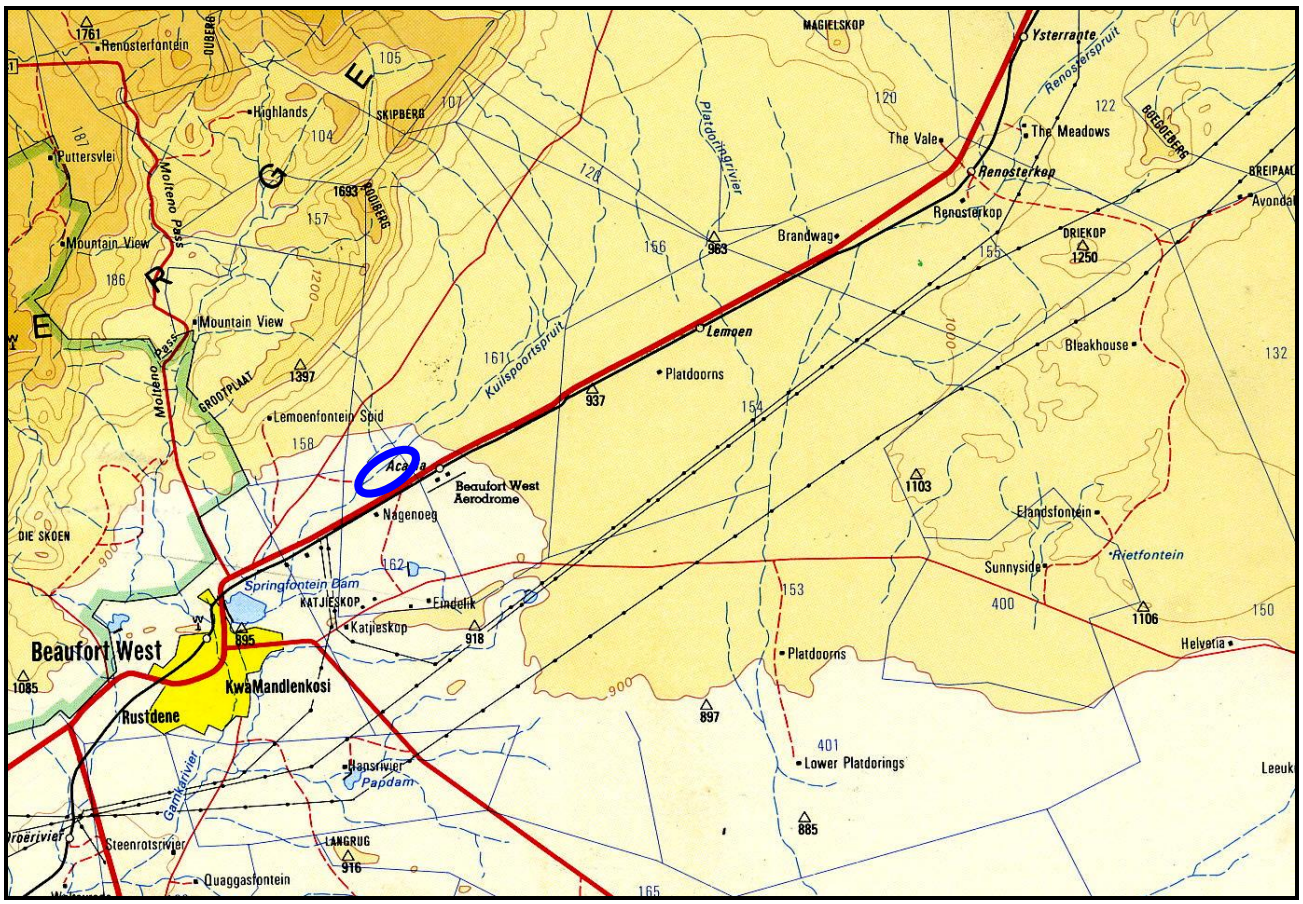

Fig. 1. Extract from 1: 250 000 topographical sheet 3222 Beaufort West showing approximate position (blue oval) of the proposed Beaufort West Photovoltaic Power Station *c.* 3 km northeast of Beaufort West, between the N1 freeway and the Kuilspoortspruit drainage system (Map courtesy of The Chief Directorate, Surveys & Mapping, Mowbray).

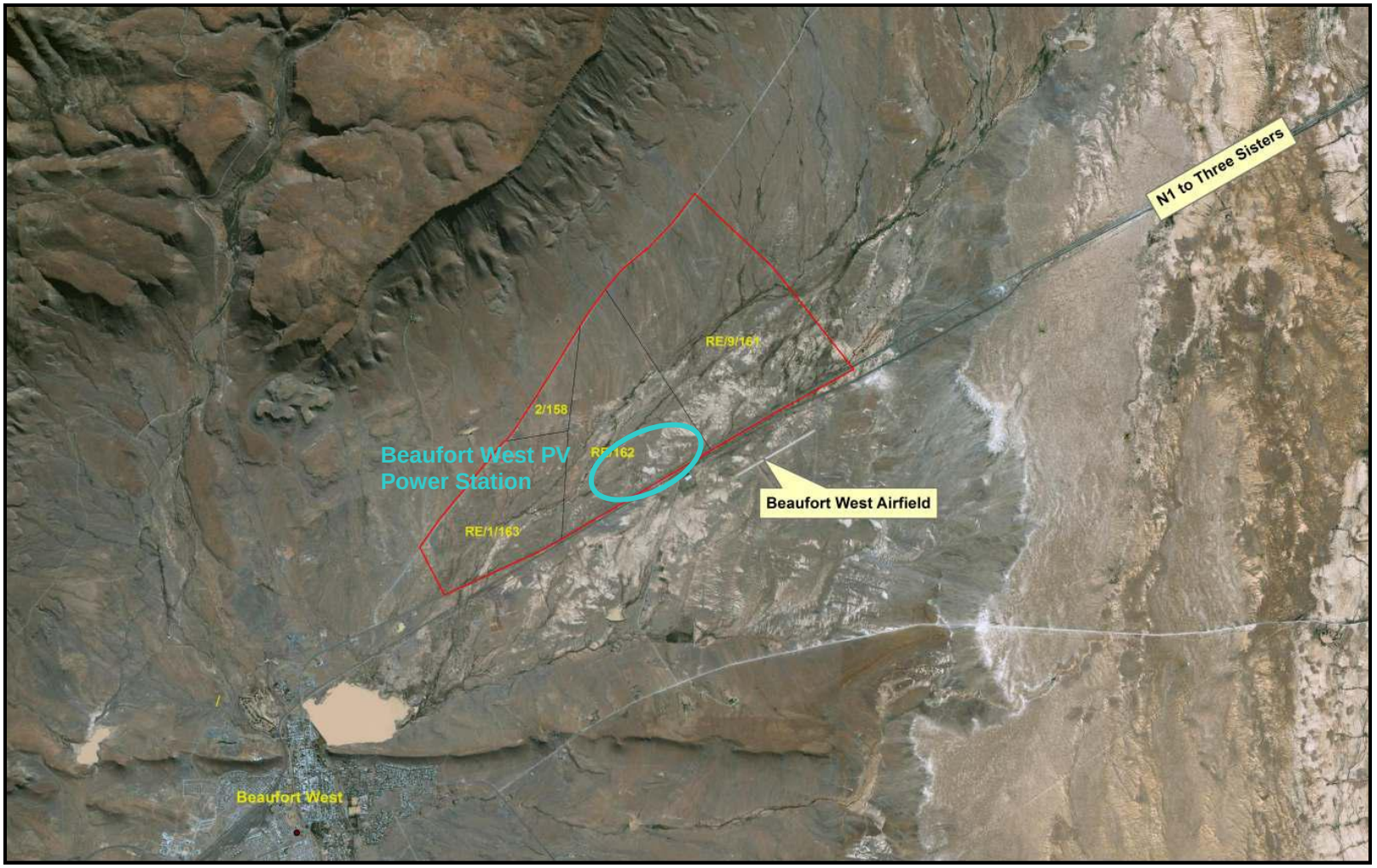

Fig. 2. Satellite image of study area to the north east of Beaufort West and on the north side of the N1 showing its situation on the gently sloping *vlaktes* at the base of the Great Escarpment. The approximate location of the proposed Beaufort West Photovoltaic Power Station development is shown by the blue oval. Land parcels involved with this and the associated Wind Farm Beaufort West development are outlined in red. The network of shallow, vegetated channels (dark) and alluvial sediments (pale grey) associated with the Kuilspoortspruit drainage system are clearly seen here (Modified from a figure kindly provided by Cape Environmental Assessment Practitioners (Pty) Ltd).

3. GEOLOGICAL BACKGROUND

The PV power station study area lies on the north-eastern outskirts of the town of Beaufort West, between the N1 tar road and the main channels of the Kuilspoortspruit drainage system (Figs. 1, 2; 1: 50 000 topographical sheet 3222 BC Beaufort West). As clearly seen on satellite images (Fig. 2), it comprises gently-sloping to flat terrain (*c*. 860-910 m amsl) along the foothills of the Great Escarpment (Fig. 5). 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** (Karoo Supergroup, Adelaide Subgroup, Late Permian Period) that are extensively intruded by thick dolerite sills of the Early Jurassic **Karoo Dolerite Suite** (**Jd**) (Johnson & Keyser 1979). The relatively flat, low-lying *vlaktes* in the study area are traversed by several, shallow, intermittently-flowing watercourses of the Kuilspoortspruit braided drainage system that have their origins in the Great Escarpment and drain southwestwards towards the Springfontein Dam and Gamka River in the neighbourhood of Beaufort West.

3.1. Lower Beaufort Group

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, coprolites or fossil droppings, arthropod, vertebrate and other trace fossils).

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).

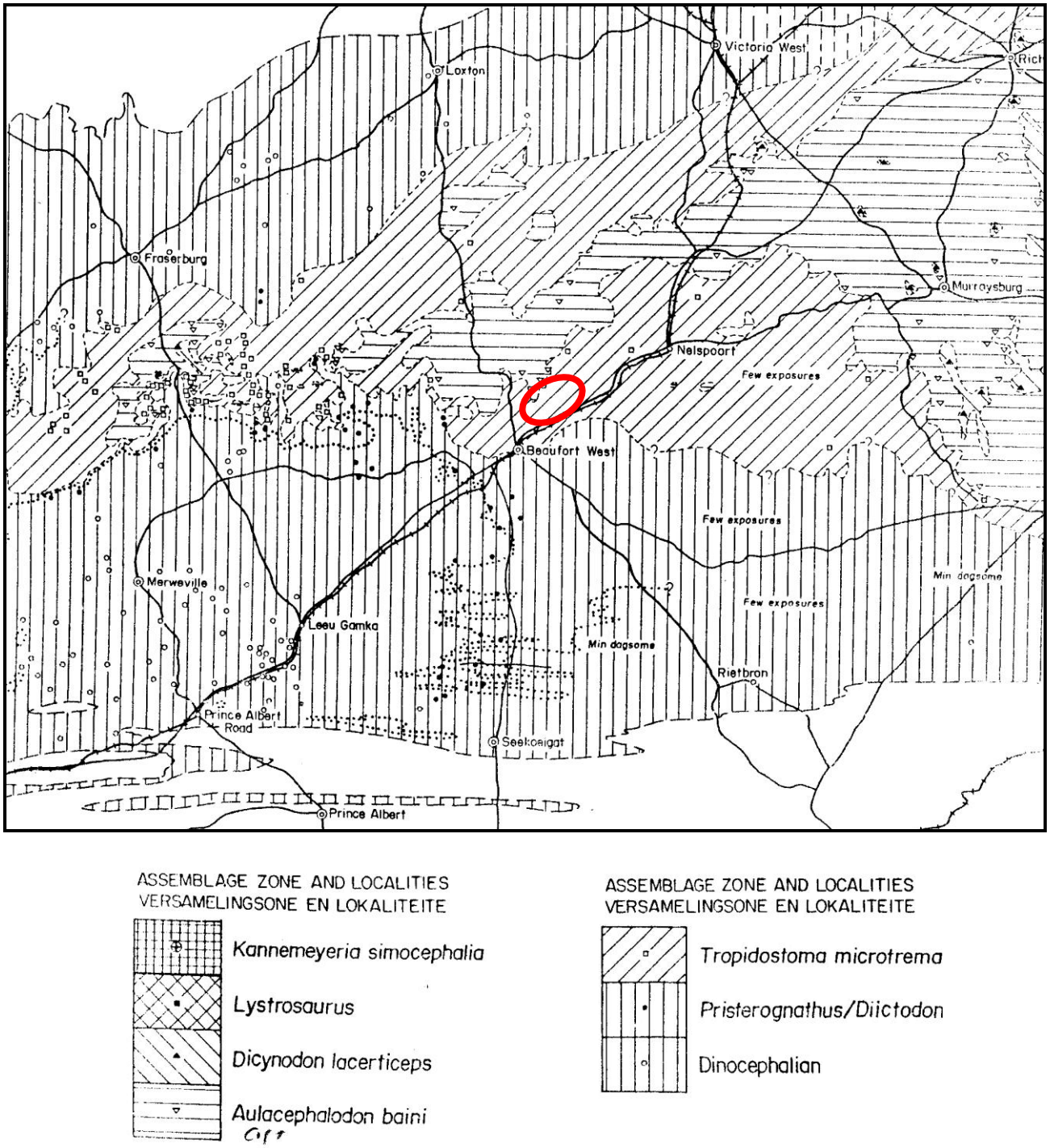

Fig. 3. Biostratigraphical map of the Beaufort Group in the Great Karoo around Beaufort West showing the distribution of the various palaeontological Assemblage Zones, mainly based on tetrapod fossils. The study area northeast of Beaufort West (red ellipse) lies within the Late Permian *Tropidostoma* Assemblage Zone (Map from Keyser & Smith 1977-78).

According to the 1: 250 000 scale geological map 3222 Beaufort West (Council for Geoscience, Pretoria; Johnson & Keyser 1979) and the recent field assessment by Almond 2010b) the study area is almost entirely blanketed in **Quaternary to Recent alluvium** that overlies Late Permian sediments of the **Teekloof Formation** (**Pt**) (Adelaide Subgroup, Beaufort Group, Karoo Supergroup; Johnson *et al*., 2006). The Beaufort Group succession exposed along the Escarpment is approximately one kilometre thick and is more-or-less flat-lying. Low levels of burial metamorphosis and tectonic deformation facilitate sedimentological and palaeontological analysis of key sections. Numerous potentially fossiliferous exposures of Beaufort Group sediments are present in the steep Great Escarpment region itself due to deep dissection by many small, episodic watercourses combined with a semi-arid climate supporting a sparse karroid vegetation. However, in the *vlaktes* at the foot of the Escarpment the Beaufort Group bedrock is largely obscured by a thick blanket of colluvium (gravity slope deposits such as scree), alluvium (river or stream sediments) as well as soil and, to a lesser extent, karroid grasses, shrubs and riverine trees and shrubs (Almond 2010b).

Several subdivisions (known as *members*) of the Teekloof Formation crop out along the Great Escarpment in the Beaufort West area (Fig. 4). In order of decreasing age, corresponding to increasing elevation, these include the Poortjie, Hoedemaker, Oukloof and Steenkampsvlakte Members. These lithostratigraphic units or sedimentary packages differ in the relative proportion and geometry (shape) of sandstone bodies compared to the intervening mudrocks. The Poortjie and Oukloof Members contain a high concentration of relatively resistant sandstone bodies that weather out more prominently as ridges and cliffs on slopes and hilltops. In contrast, the Hoedemaker and Steenkampsvlakte Members consist mainly of more readily-weathered and easily-eroded mudrocks. They therefore form gentler slopes and are largely obscured by colluvium (slope deposits), alluvium and vegetation except on steep slopes and in stream valleys.

In the study region near Beaufort West the sandstone-dominated Poortjie Member forms a prominent east-west ridge running south of the Beaufort West Dam, south of the N1 (Clearly seen on satellite image, Fig. 2). The study area itself lies within the relatively smoothly sloping zone between this Damkop-Katjieskop ridge in the south and the thin, closely-spaced, prominent-weathering sandstones of the Oukloof Member towards the base of the escarpment to the north. It is inferred that the study area is underlain by the mudrock-dominated **Hoedemaker Member**. The geology of the Hoedemaker Member, which is up to 240m thick, is outlined by Smith (1980, 1993a, b) and later by Smith and Keyser (1995) as well as Cole and Smith (2008). The Hoedemaker succession is dominated by greenish-grey to purple-brown overbank mudrocks, with occasional single-storey sheet sandstones. Palaeosol (ancient soil) horizons characterized by calcrete nodules and rhizocretions (root casts) are common, as are also lacustrine (transient to long-lived playa lake) sediments deposited in depressions on the Late Permian floodplain. These last are associated with limestone crusts, gypsum crystals (“desert roses”) as well as a range of fine-scale sedimentary features such as wave rippled sandstones, falling water marks, mudcracks, and trace fossils (Stear 1978, Smith 1980, 1986, 1993a).

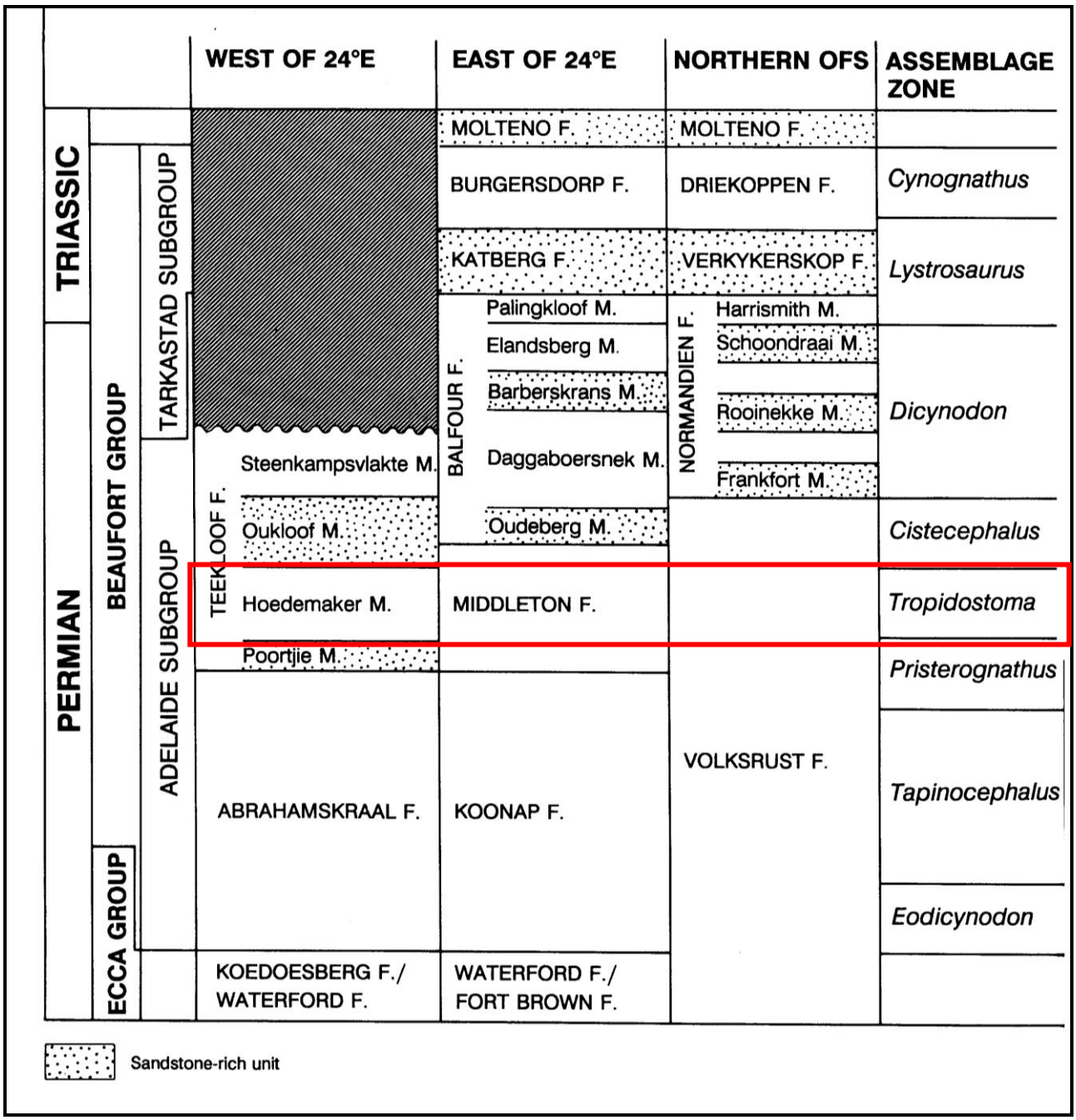

Fig. 4. Chart showing the lithostratigraphic and biostratigraphic subdivisions of the Beaufort Group with units relevant to the present study outlined in red (From Rubidge 1995).

3.2. Superficial sediments

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, including the PV power station study area (Johnson & Keyser 1979, Cole *et al.,* 2004) (Figs. 5 & 6). Colluvial (scree) and sheet-wash deposits are found on the steeper slopes while channel-related alluvium predominates in flatter areas away from 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 (Fig. 6). 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) (Almond 2010b). 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).

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 and numerous refs. therein; Fig.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 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.

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 ("*koffieklip*") and uranium mineralization, as seen for example within the Hoedemaker Member in the Karoo National Park (Cole & Smith 2008 and refs. therein).

Late Permian **invertebrate fossils** from the western Karoo Basin comprise almost exclusively inadequately studied, 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 (1993b).

4.1.1. Fossil biotas of the *Tropidostoma* Assemblage Zone

A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Kitching (1977), Keyser and Smith (1979) and Rubidge (1995) (Fig. 3). Selected fossil tetrapod localities from these and other sources are marked on the 1: 250 000 Beaufort West geology sheet (*e.g.* fossil sites located along the base of the Great Escarpment a few kilometres north and northwest of the PV solar power study area). These sources establish that the study area lies within the ***Tropidostoma* Assemblage Zone** (AZ) that characterizes the Hoedemaker Member of the Teekloof Formation (Smith & Keyser, 1995). Fossils from this assemblage zone collected in the Karoo National Park at Beaufort West are illustrated by Almond (2006) and displayed at the park itself (Fossil Trail and Interpretive Centre).

The following major categories of fossils might be expected within *Tropidostoma* AZ sediments in the study area (Kitching 1977, Keyser & Smith 1977-78, Anderson & Anderson 1985, Smith & Keyser 1995, MacRae 1999, Cole *et al*., 2004, Almond *et al*. 2008):

- isolated petrified bones as well as rare articulated skeletons of **terrestrial vertebrates (tetrapods)** such as true **reptiles** (notably large herbivorous pareiasaurs) and **therapsids** or "mammal-like reptiles" (*e.g.* diverse herbivorous dicynodonts, flesh-eating gorgonopsians, and insectivorous therocephalians)

- aquatic vertebrates such as large **temnospondyl amphibians** (*Rhinesuchus* spp., usually disarticulated), and **palaeoniscoid bony fish** (*Atherstonia*, *Namaichthys*, often represented by scattered scales rather than intact fish)
- freshwater **bivalves** (*e.g. Palaeomutela*)
- **trace fossils** such as worm, arthropod and tetrapod burrows and trackways, coprolites (fossil droppings), fish swimming trails
- **vascular plant remains** including leaves, twigs, roots and petrified woods ("*Dadoxylon*") of the *Glossopteris* Flora (usually sparse, fragmentary), especially glossopterid trees and arthrophytes (horsetails).

According to Smith and Keyser (1995) the tetrapod fauna of the *Tropidostoma* Assemblage Zone is dominated by the small burrowing dicynodont *Diictodon* that constitutes some 40% of the fossil remains recorded here. There are several genera of toothed dicynodonts (*e.g. Emydops, Pristerodon*) as well as medium-sized forms like *Rachiocephalus* and *Endothiodon* (*cf* Cluver & King 1983, Botha & Angielczyk 2007 for more details about these genera). Carnivores are represented by medium-sized gorgonopsians (*e.g. Lycaenops, Gorgonops*) as well as smaller, insectivorous therocephalians such as *Ictidosuchoides*. Among the large (2.3-3m long), lumbering pareiasaur reptiles the genus *Pareiasaurus* replaces the more primitive *Bradysaurus* seen in older Beaufort Group assemblages.

As far as the biostratigraphically important tetrapod remains are concerned, the best fossil material within the Hoedemaker Member succession is generally found within overbank mudrocks, whereas fossils preserved within channel sandstones tend to be fragmentary and water-worn (Rubidge 1995, Smith 1993b). Many vertebrate fossils are found in association with ancient soils (palaeosol horizons) that can usually be recognised by bedding-parallel concentrations of calcrete nodules. Smith and Keyser (1995) report that in the *Tropidostoma* Assemblage Zone / Hoedemaker Member most tetrapod fossils comprise isolated disarticulated skulls and post-cranial bones, although well-articulated skeletons of the small dicynodont *Diictodon* are locally common, associated with burrows (See also Smith 1993b for a benchmark study of the taphonomy of vertebrate remains in the Hoedemaker Member).

As a consequence of their proximity to large dolerite intrusions in the Great Escarpment zone, the Beaufort Group sediments in the study area might 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.

According to the recent palaeontological field assessment of the broader study area by Almond (2010b) the potentially fossiliferous Beaufort Group bedrocks here are rarely exposed due to the thick cover of superficial deposits. During the palaeontological field survey no fossil vertebrate remains were recorded from the Beaufort Group. Low diversity trace fossil assemblages were observed in association with rippled sandstone palaeosurfaces (*i.e.* preserved ancient land surfaces or lake beds on the Permian floodplain) to the north of the PV power station development area.

4.2. Fossil heritage within superficial sediments

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). 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.

Superficial sediments within the PV power station development area comprise silty, sandy and gravelly alluvium related to the Kuilspoortspruit drainage system as well as a thin, impersistent mantle of down-wasted surface gravels (Almond 2010b; Figs. 5 & 6). Apart from embedded stone artifacts, no fossils were recorded within these Pleistocene to Recent deposits. However, they might contain fossil bones and teeth of mammals and reptiles, ostrich eggshells, and calcretized traces such as rhizoliths (root casts) and termitaria.

Fig. 5. General view of the study region north east of Beaufort West showing the flat, low-lying *vlaktes* mantled by fine alluvium and a thin veneer of residual surface gravels. The Nuweveld Mountains in the background are built of subhorizontal bedded sediments of the Lower Beaufort Group intruded by dolerite sills (prominent cliffs on skyline) (Image from Almond 2010b).

Fig. 6. Vertical profile (*c*. 1.5m) through crudely-bedded alluvial gravels, finer-grained alluvium and soils in the banks of a tributary of the Kuilspoortspruit drainage system. Note larger, poorly-rounded gravel clasts that have been eroded out of the older alluvial gravels as well as fine-grained nature of the most recent alluvium (bottom right) (Image from Almond 2010b).

6. CONCLUSIONS & RECOMMENDATIONS

The overall palaeontological sensitivity of the Beaufort Group sedimentary bedrocks in the Beaufort West area is *high* (Almond *et al*. 2008). These continental sediments have yielded one of the richest fossil records of land-dwelling plants and animals of Permo-Triassic age anywhere in the world. However, due to the extensive drift cover, potentially fossiliferous Beaufort Group bedrocks are at present hardly exposed at all within the broader study region to the north east of Beaufort West (Almond 2010b). Rare exceptions are occasional shallow dams and borrow pits outside and to the north of the PV power station study area where low diversity trace fossil assemblages are recorded in association with sandstone palaeosurfaces and overbank mudrocks.

Deep bedrock excavations are unlikely to be required for wind PV panel support structures, electricity power lines, underground cables and ancillary developments such as access roads. Given the extensive and moderately thick cover of superficial sediments (alluvium, surface gravels) of low palaeontological sensitivity within the study area, the proposed alternative energy development does not pose a serious risk to local fossil heritage. Specialist palaeontological mitigation for this project is therefore not considered necessary.

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 Beaufort West Photovoltaic Power Station project.

The palaeontologist concerned with mitigation work will need a valid collection permit from Heritage Western Cape. 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.

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8. REFERENCES

ALMOND, J.E. 2006. Karoo National Park, Beaufort West: palaeontological scoping of proposed tourist route, 27 pp plus plates. *Natura Viva* cc, Cape Town.

ALMOND, J.E. 2010a. Eskom Gamma-Omega 765Kv transmission line: Phase 2 palaeontological impact assessment, 95pp. Natura Viva cc.

ALMOND, J.E. 2010b. Proposed windfarm development, Beaufort West Municipality, Western Cape: combined palaeontological desktop and field assessment, 34 pp. Natura Viva cc, Cape Town.

ALMOND, J.E. & PETHER, J. 2008. Palaeontological heritage of the Western Cape. Interim technical report for Heritage Western Cape, 20 pp.

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

BAMFORD, M. 1999. Permo-Triassic fossil woods from the South African Karoo Basin. Palaeontologia africana 35, 25-40.

BOTHA, J. & ANGIELCZYK, K.D. 2007. An integrative approach to distinguishing the Late Permian dicynodont species *Oudenodon bainii* and *Tropidistoma microtrema* (Therapsida: Anomodontia). Palaeontology 50, 1175-1209.

CLUVER, M.A. 1978. Fossil reptiles of the South African Karoo. 54pp. South African Museum, Cape Town.

CLUVER, M.A. & KING, G.M. A reassessment of the relationships of Permian Dicynodontia (Reptilia, Therapsida) and a new classification of dicynodonts. Annals of the South African Museum 91, 195-273.

COLE, D.I., NEVELING, J., HATTINGH, J., CHEVALLIER, L.P., REDDERING, J.S.V. & BENDER, P.A. 2004. The geology of the Middelburg area. Explanation to 1: 250 000 geology Sheet 3124 Middelburg, 44 pp. Council for Geoscience, Pretoria.

COLE, D. & SMITH, R. 2008. Fluvial architecture of the Late Permian Beaufort Group deposits, S.W. Karoo Basin: point bars, crevasse splays, palaeosols, vertebrate fossils and uranium. Field Excursion FT02 guidebook, AAPG International Conference, Cape Town October 2008, 110 pp.

GASTALDO, R.A., ADENDORFF, R., BAMFORD, M., LABANDEIRA, C.C., NEVELING, J. & SIMS, H. 2005. Taphonomic trends of macrofloral assemblages across the Permian-Triassic boundary, Karoo Basin, South Africa. Palaios 20, 479-497.

GRINE, F.E., BAILEY, R.M., HARVATI, K., NATHAN, R.P., MORRIS, A.G., HENDERSON, G.M., RIBOT, I. & PIKE, A.W.G. 2007. Late Pleistocene human skull from Hofmeyr, South Africa, and modern human origins. Science 315, 226-229.

JOHNSON, M.R. & KEYSER, A.W. 1979. The geology of the Beaufort West area. Explanation of geological Sheet 3222, 14 pp. Council for Geoscience, Pretoria.

JOHNSON, M.R., VAN VUUREN, C.J., VISSER, J.N.J., COLE, D.I., WICKENS, H. DE V., CHRISTIE, A.D.M., ROBERTS, D.L. & BRANDL, G. 2006. Sedimentary rocks of the Karoo Supergroup. Pp. 461-499 *in* Johnson. M.R., Anhaeusser, C.R. & Thomas, R.J. (eds.) The geology of South Africa. Geological Society of South Africa, Johannesburg & the Council for Geoscience, Pretoria.

KEYSER, A.W. & SMITH, R.M.H. 1977-78. Vertebrate biozonation of the Beaufort Group with special reference to the Western Karoo Basin. Annals of the Geological Survey of South Africa 12: 1-36.

KITCHING, J.W. 1977. The distribution of the Karroo vertebrate fauna, with special reference to certain genera and the bearing of this distribution on the zoning of the Beaufort beds. Memoirs of the Bernard Price Institute for Palaeontological Research, University of the Witwatersrand, No. 1, 133 pp (incl. 15 pls).

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.

MCCARTHY, T. & RUBIDGE, B. 2005. *The story of Earth and life: a southern African perspective on a 4.6-billion-year journey.* 334pp. Struik, Cape Town.

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.

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.

RUBIDGE, B.S. (Ed.) 1995. Biostratigraphy of the Beaufort Group (Karoo Supergroup). South African Committee for Biostratigraphy, Biostratigraphic Series No. 1., 46 pp. Council for Geoscience, Pretoria.

RUBIDGE, B.S. 2005. Re-uniting lost continents – fossil reptiles from the ancient Karoo and their wanderlust. 27th Du Toit Memorial Lecture. South African Journal of Geology 108, 135-172.

SKEAD, C.J. 1980. Historical mammal incidence in the Cape Province. Volume 1: The Western and Northern Cape, 903pp. Department of Nature and Environmental Conservation, Cape Town.

SMITH, R.M.H. 1979. The sedimentology and taphonomy of flood-plain deposits of the Lower Beaufort (Adelaide Subgroup) strata near Beaufort West, Cape Province. Annals of the Geological Survey of South Africa 12, 37-68.

SMITH, R.M.H. 1980. The lithology, sedimentology and taphonomy of flood-plain deposits of the Lower Beaufort (Adelaide Subgroup) strata near Beaufort West. Transactions of the Geological Society of South Africa 83, 399-413.

SMITH, R.M.H. 1986. Trace fossils of the ancient Karoo. Sagittarius 1 (3), 4-9.

SMITH, R.M.H. 1987a. Morphological and depositional history of exhumed Permian point bars in the southwestern Karoo, South Africa. Journal of Sedimentary Petrology 57, 19-29.

SMITH, R.M.H. 1987b. Helical burrow casts of therapsid origin from the Beaufort Group (Permian) of South Africa. Palaeogeography, Palaeoclimatology, Palaeoecology 60, 155-170.

SMITH, R.M.H. 1988. Fossils for Africa. An introduction to the fossil wealth of the Nuweveld mountains near Beaufort West. Sagittarius 3, 4-9. SA Museum, Cape Town.

SMITH, R.M.H. 1989. Fossils in the Karoo – some important questions answered. Custos 17, 48-51.

SMITH, R.M.H. 1990. Alluvial paleosols and pedofacies sequences in the Permian Lower Beaufort of the southwestern Karoo Basin, South Africa. Journal of Sedimentary Petrology 60, 258-276.

SMITH, R.M.H. 1993a. Sedimentology and ichnology of floodplain paleosurfaces in the Beaufort Group (Late Permian), Karoo Sequence, South Africa. Palaios 8, 339-357.

SMITH, R.M.H. 1993b. Vertebrate taphonomy of Late Permian floodplain deposits in the southwestern Karoo Basin of South Africa. Palaios 8, 45-67.

SMITH, R.M.H. & KEYSER, A.W. 1995. Biostratigraphy of the *Tropidostoma* Assemblage Zone. Pp. 18-22 *in* Rubidge, B.S. (ed.) *Biostratigraphy of the Beaufort Group (Karoo Supergroup).* South African Committee for Stratigraphy, Biostratigraphic Series No. 1. Council for Geoscience, Pretoria.

SMITH, R.M.H. & ALMOND, J.E. 1998. Late Permian continental trace assemblages from the Lower Beaufort Group (Karoo Supergroup), South Africa. Abstracts, Tercera Reunión Argentina de Icnologia, Mar del Plata, 1998, p. 29.

STEAR, W.M. 1978. Sedimentary structures related to fluctuating hydrodynamic conditions in flood plain deposits of the Beaufort Group near Beaufort West, Cape. Transactions of the Geological Society of South Africa 81, 393-399.

STEAR, W.M. 1980. Channel sandstone and bar morphology of the Beaufort Group uranium district near Beaufort West. Transactions of the Geological Society of South Africa 83: 391-398.

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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 Beaufort West Photovoltaic Power Station 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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