PALAEONTOLOGICAL SPECIALIST STUDY: COMBINED DESKTOP AND FIELD-BASED ASSESSMENTS

PROPOSED PHOTOVOLTAIC (SOLAR) ENERGY FACILITIES ON BADENHORST DAM FARM NEAR DE AAR, NORTHERN CAPE

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1. SUMMARY

Mulilo Renewable Energy (Pty) Ltd (Mulilo), is proposing to construct four 75 MW alternating current (AC) photovoltaic (PV) solar energy facilities on Badenhorst Dam Farm (Portion 1 of Farm 180), situated on the south-eastern outskirts of the town of De Aar, Northern Cape Province. The total extent of the proposed solar energy facilities would be approximately 1118.68 ha.

The potentially fossiliferous sediments of the Ecca Group and Lower Beaufort Group (Karoo Supergroup) that underlie the Badenhorst Dam study area are almost entirely mantled in a thick layer of superficial deposits of probable Pleistocene to Recent age. In addition they are extensively intruded and baked by the Karoo Dolerite Suite (unfossiliferous igneous rocks of Early Jurassic age). The upper Ecca Group bedrocks in the De Aar area contain sparse to locally common petrified wood as well as low diversity shallow marine trace fossil assemblages typical of the Middle Permian Waterford Formation, rather than the Tierberg Formation as mapped. Ecca / Beaufort boundary beds within the southernmost portion of the study area contain abundant trace fossils as well as fossil plant compressions, including woody material, that are of palaeontological interest. No fossil vertebrate remains were recorded from the Karoo Supergroup rocks here. Based on field assessment the overall palaeontological sensitivity of the Karoo Supergroup successions in the study area is rated as low.

The diverse superficial deposits in the study region, including various soils, gravels and – at least in some areas - a well-developed calcrete hardpan, are also of low palaeontological sensitivity as a whole (Almond & Pether 2008). Calcretized rhizoliths (root casts) and possible invertebrate burrows of probable Quaternary age are recorded in the southern portion of Badenhorst Dam. Sparse, well-preserved but small fragments of reworked Permian silicified fossil wood are widely recorded widely from surface and near-surface gravels overlying Ecca bedrocks in the De Aar study area.

Potential impacts of the proposed solar facility developments on fossil heritage are confined to the development footprint and are only anticipated during the construction phase. As far as fossil heritage is concerned, their impact significance is considered to be LOW for the following reasons:

- The Karoo Supergroup bedrocks here are deeply weathered, locally calcretised and baked, and for the most part only sparsely fossiliferous;
- The development footprints for proposed PV solar energy facility sites are small and largely underlain by superficial deposits of low palaeontological sensitivity;
- Significant fossil material (*e.g.* fossil wood, vertebrate remains) at or near surface level is most likely only very sparsely distributed within the study area; and
- Extensive, deep bedrock excavations are not envisaged during the construction phase.

The Layout Alternative 2, comprising three 150 MW PV facilities on Badenhorst Dam, would also have a low impact significance on local palaeontological resources. However, given the marginally higher magnitude of impacts on fossil heritage anticipated in the extended PV4 project area (low rather than very low), there is a slight preference on palaeontological grounds for the Alternative 1 layout.

The “no go” alternative to the proposed solar plant developments would have a neutral (zero magnitude) impact significance on fossil heritage resources. There is no preference on palaeontological grounds for conventional PV *versus* CPV technology. Likewise there is unlikely to be any significant difference in impact significance between single axis *versus* fixed axis tracking technology.

A substantial number of other alternative energy projects – including both wind energy and solar energy facilities – have been proposed for the De Aar area (*cf* 2010b, 2011, 2012a, 2012b, 2012c). Given the generally low palaeontological sensitivity of the Karoo Supergroup bedrocks and Pleistocene to Recent superficial sediments in the De Aar region as a whole, the cumulative impact of these developments is considered to be of low significance, however.

It is recommended that:

- The ECO responsible for the development should be aware of the possibility of important fossils (*e.g.* petrified wood, mammalian bones, teeth) being present or unearthed on site and should monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;
- In the case of any significant fossil finds (*e.g.* fossil wood, vertebrate teeth, bones, burrows, petrified wood) during construction, these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to the relevant heritage management authority (SAHRA. Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za) so that any appropriate mitigation (*i.e.* fossil recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer’s expense; and
- These recommendations should be incorporated into the EMP for the Badenhorst Dam solar energy facility project.

The palaeontologist involved with mitigation work will need a valid fossil collection permit from SAHRA and any material collected would have to be curated in an approved depository (*e.g.* museum or university collection). All palaeontological specialist work should conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording, fossil collection and curation, final report) should adhere as far as possible to the minimum standards for Phase 2 palaeontological studies recently developed by SAHRA (2013).

2. INTRODUCTION & BRIEF

The company Mulilo Renewable Energy (Pty) Ltd (Mulilo), is proposing to construct four 75 MW alternating current (AC) photovoltaic (PV) solar energy facilities on Badenhorst Dam Farm (Portion 1 of Farm 180), situated on the south-eastern outskirts of the town of De Aar, Northern Cape Province (DEA REF. NOS. 14/12/16/3/3/2/504, 506, 483 & 485) (Figs. 1 & 2, Table 2.1). The total extent of the proposed solar energy facilities would be approximately 879 ha (Alternative 1 layout) or 1816 ha (Alternative 2 layout). Badenhorst Dam farm is *c*. 1815 ha in extent and is currently zoned as agricultural land.

A 100 MW solar energy plant (PV1) on Badenhorst Dam Farm has already received environmental authorization from the Department of Environmental Affairs (DEA) on 9 July 2012.

An alternative proposal entails the construction of a three 150 MW PV facilities on Badenhorst Dam Farm (Table 2.2). As shown in Fig. 4 the layouts of this Alternative 2 more or less overlap with the Alternative 1 layouts, with the exception of PV4. Extended PV2 is approximately the same extent as PV2 and PV5 combined and extended PV3 is similar to the combined layout of PV3 and PV4. The proposed layout for extended PV4 is located at the southern boundary of the farm.

Table 2.1: Footprints, capacities and coordinates of the four proposed PV facilities on Badenhorst Dam (Alternative 1, preferred layout)

Plant	Footprint (ha)	Capacity (MW)	Co-ordinates (middle point)
PV2	240	75	30°40'11.54"S; 24° 2'56.25"E
PV3	252	75	30°40'10.16"S; 24° 4'37.07"E
PV4	186	75	30°41'14.00"S; 24° 4'8.53"E
PV5	201	75	30°41'3.40"S; 24° 2'40.53"E

Table 2.2: Footprints, capacities and coordinates of the three proposed PV facilities on Badenhorst Dam (Alternative 2 layout)

Plant	Site (ha)	Capacity (MW)	Co-ordinates (middle point)
Extended PV2	572	150	30°40'48.69"S; 24°2'37.61"E
Extended PV3	520	150	30°40'55.63"S; 24°4'32.49"E
Extended PV4	723	150	30°42'38.28"S; 24°3'5.45"E

Each of the proposed PV facilities would consist of the following key components:

- **Solar energy facility:** numerous arrays of PV panels and associated support infrastructure to generate up to 75 MW AC *per* PV facility for Alternative 1 and up to 150 MW AC per PV facility for Alternative 2. The PV panel frame supports are fixed on top of steel piles. Due the occurrence of dolerite and siltstone bedrock on site at shallow depths, the steel piles would be embedded into a concrete pile. However, the final design of the foundations will depend on the geotechnical conditions of the site which will be determined at a later stage;

- **Transmission lines:** 132kV overhead transmission lines to connect each facility to the central onsite substation or an existing Eskom substation. The proposed T-shaped transmission line corridor of *c*. 10 km total length as shown in Fig. 4 is 150-350 m wide;
- **Boundary fence:** a fence around each 75 MW PV facility for health, safety and security reasons.

It is also proposed that the following infrastructure be shared among the PV facilities to limit the impact on the surrounding environment, as well as to reduce costs:

- **Central substation**: One central 132kV substation and connection to Eskom grid. This central substation will connect the PV facilities with Eskom's Hydra substation *via* either an existing overhead 132kV Eskom line or by a new 132kV transmission line directly to Hydra substation;
- **Roads:** A main access road (6 m wide and 5.87 km long) and internal access roads for servicing and maintenance of the site (existing roads will be used where possible);
- **Water supply infrastructure:** It is proposed that potable water will be obtained from the Emthanjeni Municipality *via* an underground municipal pipeline (4.61 km long) from the nearest municipal supply point and will be contained onsite in a jo-jo tank;
- **Stormwater infrastructure:** Including drainage channels, berms, detention areas and kinetic energy dissipaters; and
- **Buildings:** Buildings would probably include onsite substations, a connection building, control building, guard cabin and solar resource measuring substation.

Proposed additional infrastructure will include the following components:

- Three **laydown areas** have been identified and would be used during the construction phases of the proposed PV plants;
- **Septic tanks** would be constructed at the site offices; and
- The natural water flow of the site will be interrupted by the proposed roads, and therefore **stormwater infrastructure** will be required to facilitate surface water flow and to prevent erosion.

Aurecon South Africa (Pty) Ltd (Aurecon) has been appointed to undertake the requisite environmental process as required in terms of the National Environmental Management Act (No. 107 of 1998), as amended, on behalf of Mulilo (Contact details: Ms Karen Versfeld. Aurecon South Africa (Pty) Ltd (Aurecon). Aurecon Centre, 1 Century City Drive, Waterford Precinct, Century City, South Africa. Tel: +27 21 526 6022. Cell: +27 86 723 1750. Email: karen.versfeld@aurecongroup.com. Website: aurecongroup.com).

Given the presence of exposures of potentially fossiliferous Karoo Supergroup sediments within the study area, a combined desktop and field-based palaeontological assessment for the project has been commissioned by Aurecon in accordance with the requirements of the National Heritage Resources Act, 1999 (Act No. 25 of 1999) (NHRA). The terms of reference for this study, which builds on the earlier combined desktop and field-based palaeontological heritage assessment for the PV1 site (Almond 2012b), as defined by Aurecon, are briefly as follows:

To undertake a Palaeontology Impact Assessment of the site in accordance with the requirements of Section 38(3) of the NHRA which would include:

- Conducting a detailed desk-top level investigation to identify all palaeontologically significant geological units in the proposed development areas;
- Undertaking field work, if necessary, to verify results of desktop investigation;
- Documenting (GPS coordinates and map) all sites, objects and structures identified on the candidate sites;
- Submitting the relevant application form, as required by the South African Heritage Resources Agency and Northern Cape Provincial Heritage (Boswa ya Kapa Bokone);
- Compilation of a report which would include:

(1) Identification of palaeontologically significant sites within the proposed development areas;
(2) Assessment of the sensitivity and significance of palaeontological resource of the site;
(3) Evaluation of the potential impacts of construction, operation and maintenance of the proposed development on palaeontological resources, in terms of the scale of impact (local, regional, national), magnitude of impact (low, medium or high) and the duration of the impact (construction, up to 10 years after construction (medium term), more than 10 years after construction (long term));
(4) Assessment of cumulative impacts;
(5) Recommendation of mitigation measures to ameliorate any negative impacts on areas of palaeontological importance;
(6) The preparation of a heritage resources management plan which includes recommendations on the management of the objects, sites or features, and also guidelines on procedures to be implemented if previously unidentified palaeontological resources are uncovered during later developments in the area;
(7) Consideration of relevant guidelines.

Cognisance must be taken of the Department of Environmental Affairs and Development Planning guideline: “Guideline for involving heritage specialists in EIA processes”24.

2.1. Project implications for palaeontological heritage & relevant legislation

The proposed solar energy facilities are located in an area of the Main Karoo Basin of South Africa that is underlain by potentially fossiliferous sedimentary rocks of the Karoo Supergroup that are of Permian age. The construction phase of the development will entail excavations into the superficial sediment cover (soils, alluvial gravels *etc*) and perhaps also into the underlying potentially fossiliferous bedrock. These notably include excavations for the PV panel support structures, buried cables, internal access roads, any new 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 solar energy facilities 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 NHRA. The various categories of heritage resources recognised as part of the National Estate in Section 3 of the NHRA include, among others:

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

Minimum standards for the palaeontological component of heritage impact assessment reports have recently been developed by the South African Heritage Resources Authority SAHRA) (2013).

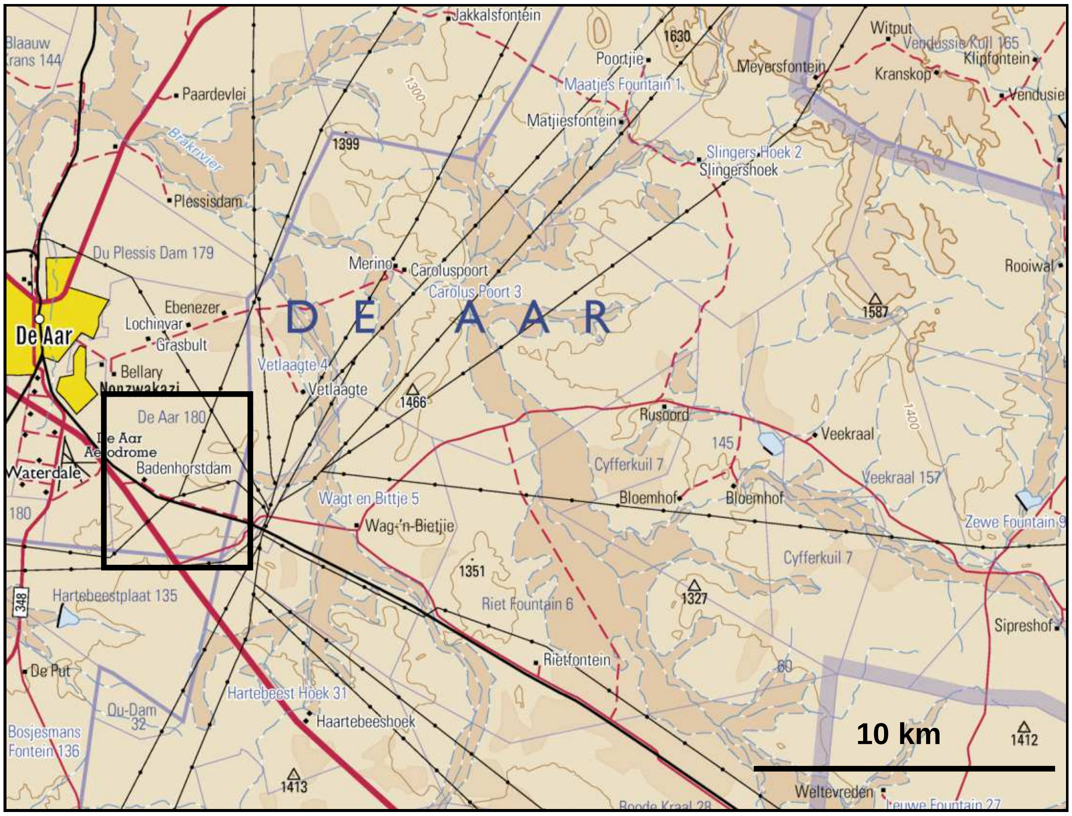

Fig. 1. Extract from 1: 250 000 topographical sheet 3024 Colesberg showing the *approximate* location (black polygon) of the proposed PV facilities' study area on farm Badenhorst Dam (Portion 1 of Farm 180) on the southeastern outskirts of De Aar.

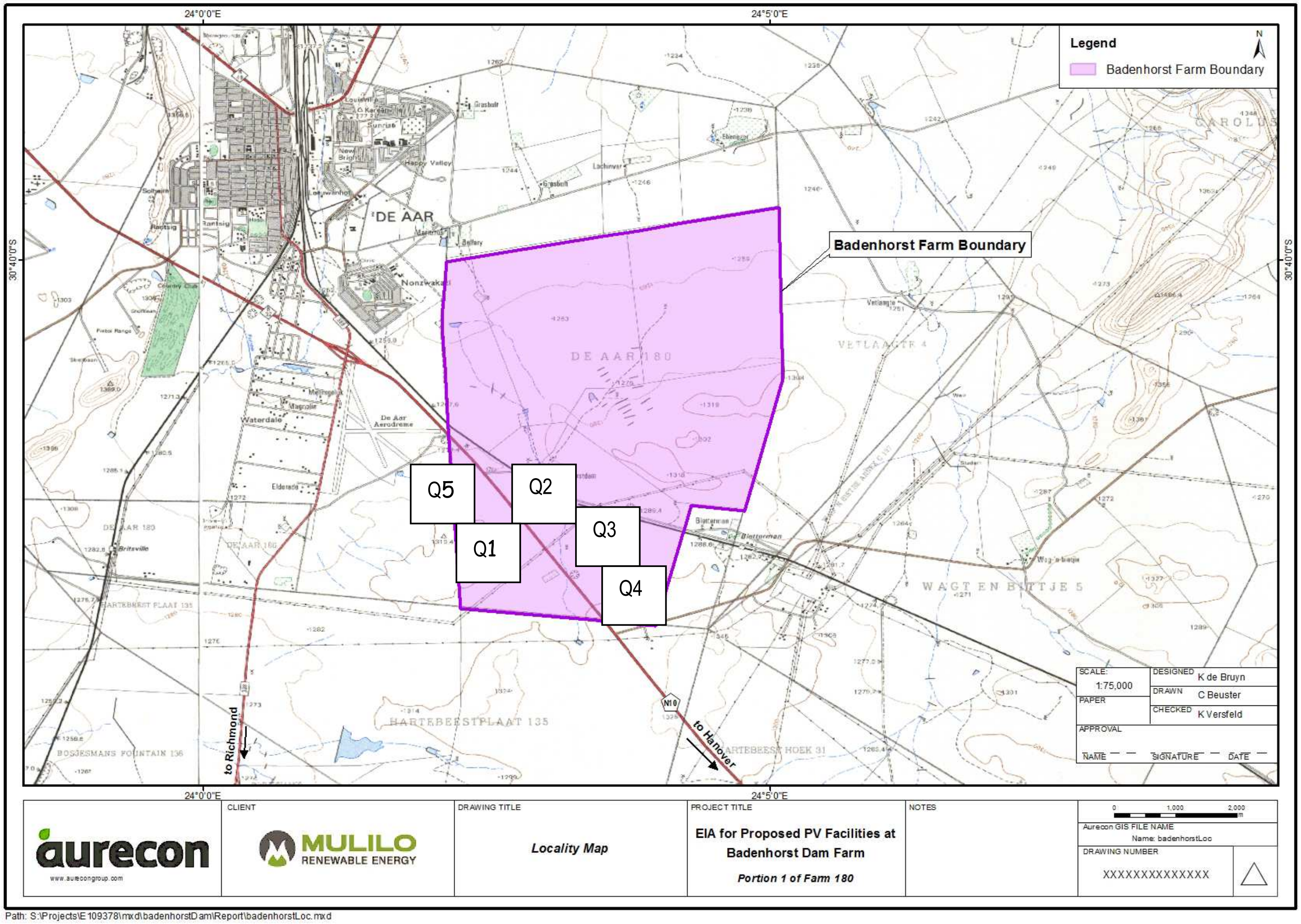

Fig. 2. Badenhorst Dam study area to the southeast of De Aar (yellow polygon) showing grey *vlaktes* underlain by Ecca Group mudrocks in the north, rusty-brown dolerite intrusions and doleritic gravels overlying Karoo Supergroup sediments in the south. Existing quarry sites visited during fieldwork are labled Q1 to Q5.

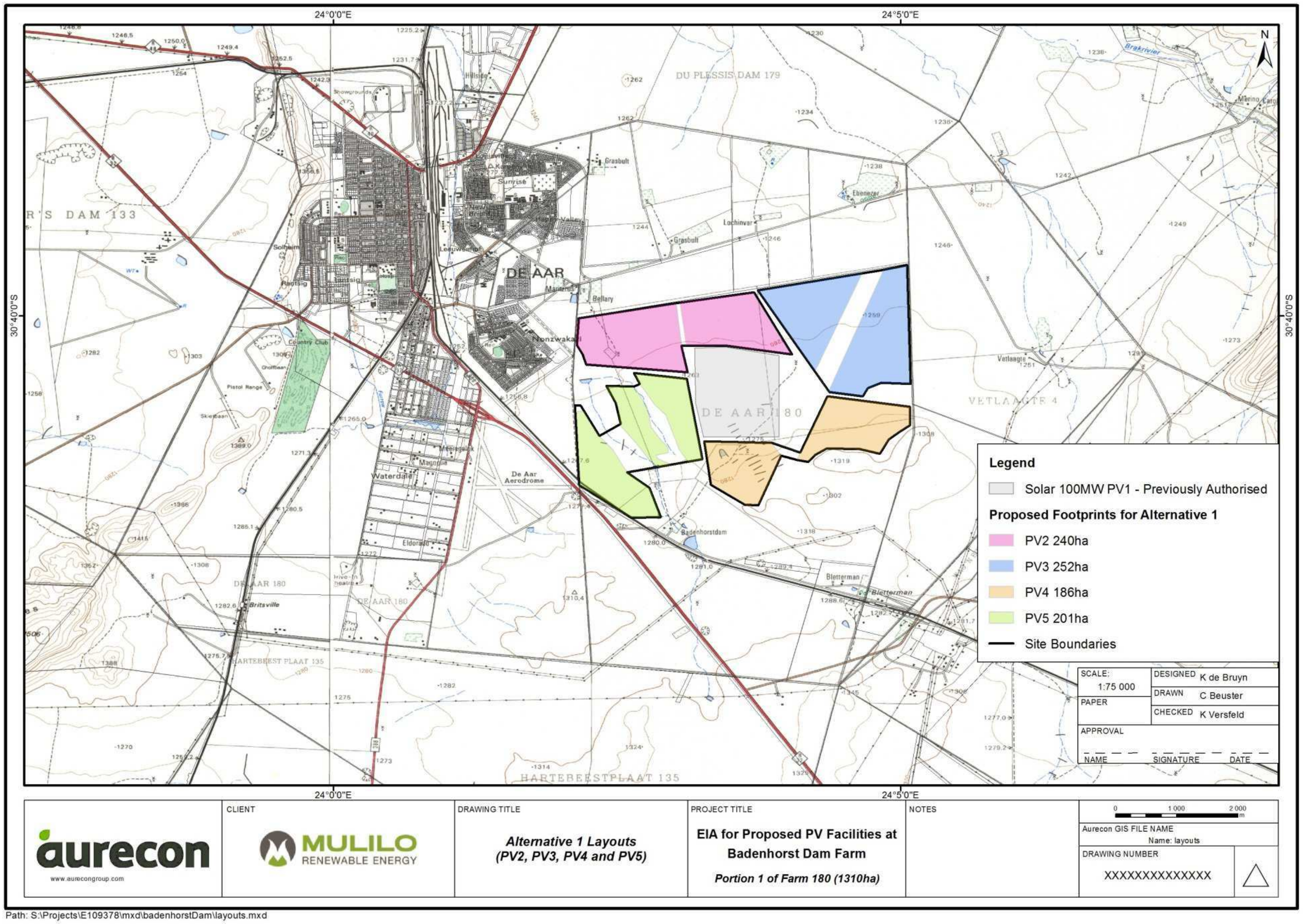

Fig. 3. Map showing preferred layout (Alternative 1) for the four proposed PV solar energy facilities on Badenhorst Dam, to the southeast of De Aar, Northern Cape (Image abstracted from the Draft Scoping Report of April 2013 produced by Aurecon.

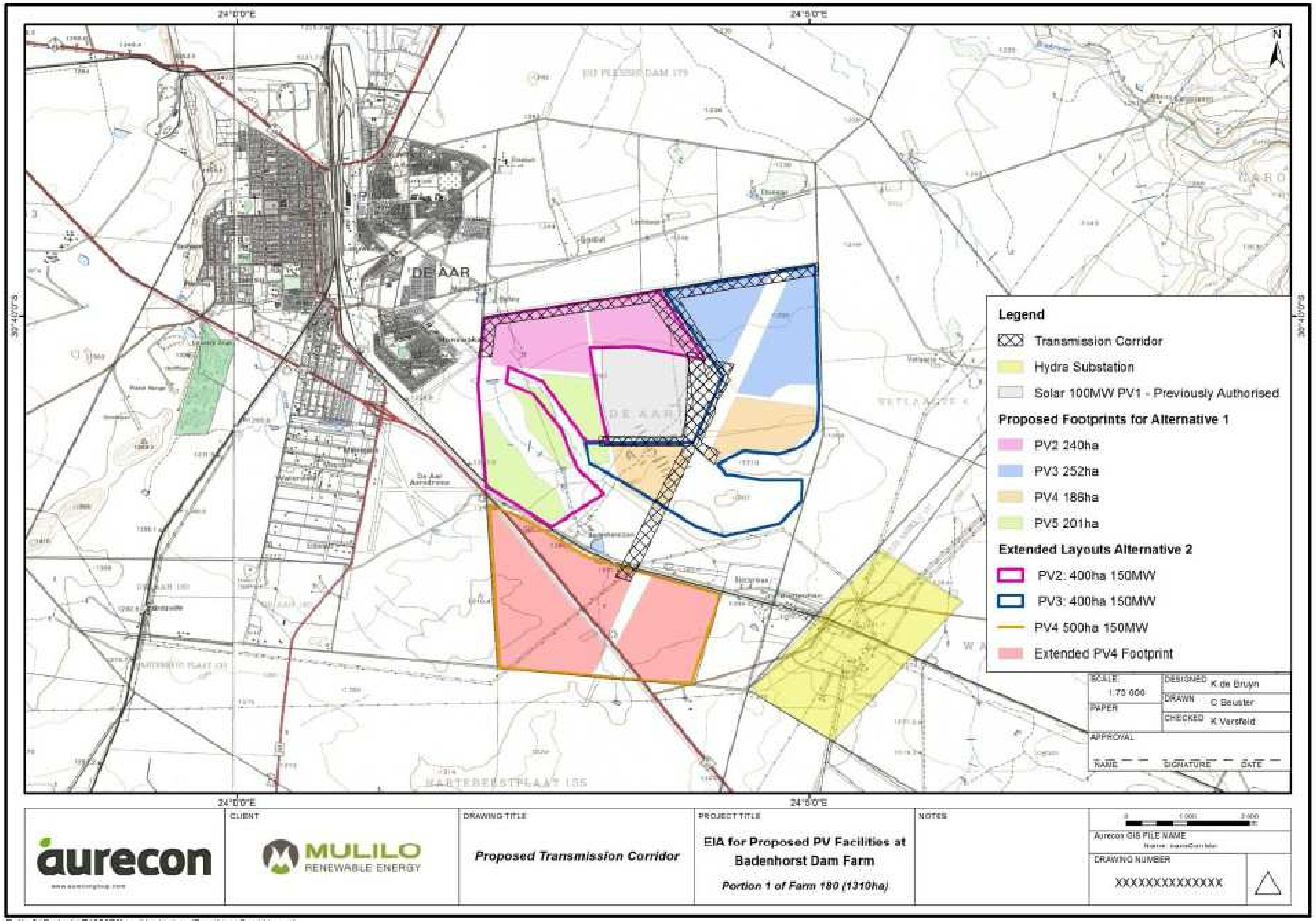

Fig. 4. Map showing the Alternative 2 extended layouts *plus* the proposed T-shaped transmission line corridor for the PV solar energy facilities on Badenhorst Dam (Image abstracted from the Draft Scoping Report of April 2013 produced by Aurecon.

2.2. Approach used for this specialist palaeontological study

This report provides an assessment of the observed or inferred palaeontological heritage within the De Aar 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, (3) several previous palaeontological heritage assessments for alternative energy developments in the De Aar region (*e.g.* Almond 2010b, 2011, 2012a, 2012b, 2012c); (4) two one-day field assessments of the study area carried out on 12-13 January, 2012 (see Almond 2012a) and again on 2 June, 2013.

Because the level of natural rock exposure within the flat-lying study areas was generally very poor, the far better exposed stratotype section of the main rock units involved (Tierberg and Waterford Formations) on the farm Swartkoppies, some 47 km north-east of De Aar, was also inspected for fossil remains associated with these formations. Data on fossil heritage within the Ecca and Lower Beaufort Groups near De Aar that was collected during the recent field assessment of a large wind energy project has also been referred to here (cf Almond 2012c).

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps and satellite images. 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 Northern Cape have been compiled by 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 by a professional palaeontologist is usually warranted.

The focus of the field-based assessment work is *not* simply to survey the development footprint or even the development area as a whole (*e.g.* farms or other parcels of land concerned in the development). Rather, the palaeontologist seeks to assess or predict the diversity, density and distribution of fossils within and beneath the study area, as well as their heritage or scientific interest. This is primarily achieved through a careful field examination of one or more representative exposures of all the sedimentary rock units present (*N.B.* Metamorphic and igneous rocks rarely contain fossils). The best rock exposures are generally those that are easily accessible, extensive, and fresh (*i.e.* unweathered) and include a large fraction of the stratigraphic unit concerned (*e.g.* formation). These exposures may be natural or artificial and include, for example, rocky outcrops in stream or river banks, cliffs, quarries, dams, dongas, open building excavations or road and railway cuttings. Uncemented superficial deposits, such as alluvium, scree or wind-blown sands, may occasionally contain fossils and should also be included in the scoping study where they are well-represented in the study area. It is normal practice for impact palaeontologists to collect representative, well-localized (*e.g.* GPS and stratigraphic data) samples of fossil material during scoping studies. All fossil material collected must be properly curated within an approved repository (usually a museum or university collection).

Before fieldwork commenced, a preliminary screening of satellite images and 1: 50 000 maps of the De Aar study area was conducted to identify sites of potentially good bedrock exposure to be examined in the field (See, for example, Fig. 2). The sites included both natural exposures (*e.g.* stream beds, steep escarpment slopes, gullies) as well as artificial exposures such as dams, borrow pits and quarries.

Note that while fossil localities recorded during fieldwork within the study area itself are obviously highly relevant, most fossil heritage here is embedded within rocks beneath the land surface or obscured by surface deposits (soil, alluvium *etc*) and by vegetation cover. In many cases where levels of fresh (*i.e.* unweathered) bedrock exposure are low, the hidden fossil resources have to be *inferred* from palaeontological observations made from better exposures of the same formations elsewhere in the region but outside the immediate study area. Therefore a palaeontologist might reasonably spend far *more* time examining road cuts and borrow pits close to, but outside, the study area than within the study area itself. Field data from localities even further afield (*e.g.* an adjacent province) may also be adduced to build up a realistic picture of the likely fossil heritage within the study area.

On the basis of the desktop and field assessment studies, the likely impact of the proposed development on local fossil heritage and any need for specialist mitigation are then determined. Adverse palaeontological impacts normally occur during the construction rather than the operational or decommissioning phase. 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, although pre-construction recording of surface-exposed material may sometimes be more appropriate. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority (*i.e.* SAHRA, Cape Town). 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.

2.3. Assumptions & limitations

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

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

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

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

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

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

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

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

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

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

In the case of palaeontological field studies in the De Aar region, the main limitations are:

- Very extensive intrusion of the potentially fossiliferous Karoo Supergroup bedrocks by dolerite. Weathered dolerite colluvium (scree) and sheetwash blanket most of the hill slopes in the area, *i.e.* the very regions where fossiliferous bedrocks are usually exposed;

- High levels of bedrock cover by thick alluvial and colluvial soils as well as extensive calcrete hardpans;

- Conflicting views among geologists concerning the stratigraphic subdivision and palaeoenvironmental interpretation of the Ecca – Beaufort transition rocks in the De Aar / Philipstown area.

These limitations were in part addressed through palaeontological surveying of a much larger area beyond the boundaries of the present solar energy facility study area itself (*e.g.* as part of an impact study for a nearby wind energy development; Almond 2012c). Confidence levels in the conclusions presented here are in consequence moderately high.

3. GEOLOGICAL CONTEXT

The geology of the Badenhorst Dam Farm study area near De Aar, where the proposed for PV facilities are to be located, is outlined on the 1: 250 000 geology sheet 3024 Colesberg (Le Roux 1993) (Fig. 5). In this section of the report the geology of the study site is briefly described first, followed by a more detailed, illustrated account of each major rock unit represented here. GPS co-ordinates of numbered localities mentioned in the text are provided in the Appendix.

The Badenhorst Dam Farm study area (1815 ha comprises largely flat-lying to hilly, semi-arid terrain between 1200 – 1300m above mean sea level (amsl) on the south-eastern outskirts of De Aar that is covered with sparse karroid vegetation and grass of the Northern Upper Karoo vegetation type (Figs. 6 & 7). The farm spans the N10 tar road as well as the De Aar – Noupoort railway line. Low rocky dolerite ridges traverse the central region and there are a couple of very shallow, intermittent-flowing water courses in the west. The area is also crossed by several electrical transmission lines from the Hydra Substation located just south-east of the study area. A number of small quarries penetrating into the Karoo Supergroup bedrocks are situated close to the N10 and railway line in or adjacent to the southern portion of the farm (Q1 to Q5 in Fig. 2).

As mapped on the 1: 250 000 Colesberg geology sheet (Fig. 5), the northern half of the study area is largely underlain by dark basinal mudrocks of the **Tierberg Formation** (Pt) mantled with a thin cover of brown soils, alluvial and sheet wash gravels that appear greyish in satellite images (Fig. 2). However, as argued below (Section 3.1), in the author's opinion these rocks rather belong to the **Waterford Formation** at the top of the Ecca Group succession.

The southern half or so of the study area is mapped as being underlain by fluvial Lower Beaufort Group sediments of the **Adelaide Subgroup** (Pa), although convincing field evidence for Beaufort rather than upper Ecca rocks here is only seen at most along the southern margin of the area. The sedimentary bedrocks here are extensively intruded by Early Jurassic dolerite sills (Jd) and a narrow, sinuous dolerite dyke extends SE-NW across the study area towards De Aar. These intrusions of the **Karoo Dolerite Suite** (Jd) weather out at surface as low rocky ridges and *koppies* that show up in rusty-brown colours in satellite images (Fig. 2). They have baked (thermally metamorphosed) the adjacent Karoo Supergroup mudrocks to hornfels, and many sandstones to quartzites. Dolerite colluvial rubble extends well beyond the intrusions themselves to blanket adjacent slopes and *vlaktes*.

The great majority of the Karoo Supergroup and dolerite outcrop area is obscured by superficial sediments of probable Pleistocene to Holocene age, as well as by abundant karroid shrub and grassy vegetation (Figs. 6 and 7). Sedimentary bedrocks are only seen in scattered low exposures (mainly of the more resistant-weathering sandstones) on the *vlaktes* and hillslopes as well as in several quarry exposures close to the N10 (See satellite image Fig. 2). Intrusive dolerites build low *koppies* and ridges, especially in the south-eastern corner of the study area (Fig. 7).

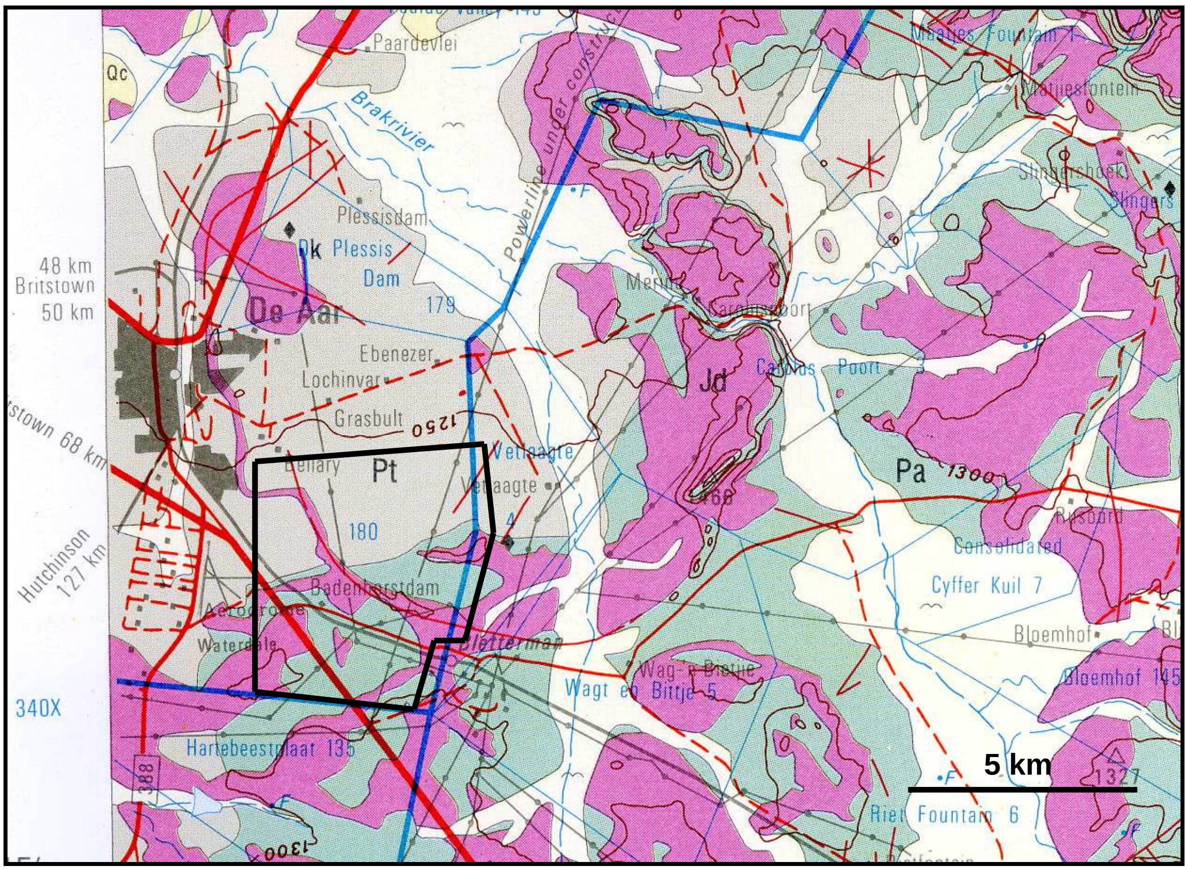

Fig. 5. Geological map of the region east of De Aar, Northern Cape, showing the approximate boundary (black polygon) of the Badenhorst Dam PV solar energy facility study area near De Aar (Abstracted from 1: 250 000 geology sheet 3024 Colesberg, Council for Geoscience, Pretoria). The following rock units are mapped within or close to the PV study areas:
grey (Pt) = Tierberg / Waterford Formation (Ecca Group)
pale green (Pa) = Adelaide Subgroup (Lower Beaufort Group)
pink (Jd) = intrusive dykes and sills of the Karoo Dolerite Suite
dark yellow (T-Qc) = Neogene to Quaternary calcretes
white = Quaternary to Recent superficial deposits (alluvium, colluvium *etc*)
small black diamond symbol = Kimberlite pipe

Fig. 6. Flat terrain blanketed by soil and grassy karroid vegetation in northern part of the Badenhorst study area, view towards the southeast.

Fig. 7. Low *koppies* of intrusive dolerite in the south-eastern corner of the study area. The surrounding Karoo sediments (*e.g.* Ecca sandstones building the low plateau in the middle ground) have been baked.

3.1. Upper Ecca Group

The **Tierberg Formation** (**Pt**) (Ecca Group, Karoo Supergroup) is a recessive-weathering, mudrock-dominated succession – predominantly consisting of dark, well-laminated, carbonaceous shales with subordinate thin, fine-grained sandstones (Prinsloo 1989, Le Roux 1993, Viljoen 2005, Johnson *et al*., 2006). The Tierberg shales are Lower to Mid Permian in age and were deposited in a range of offshore, quiet water environments below wave base. These include basin plain, distal turbidite fan and distal prodelta settings in ascending order (Viljoen 2005, Almond 2008a). Thin coarsening-upwards cycles occur towards the top of the formation with local evidence of soft-sediment deformation, ripples and common calcareous concretions. A restricted, brackish water environment is reconstructed for the Ecca Basin at this time. Close to the contact with Karoo dolerite intrusions the Tierberg mudrocks are baked to a dark grey hornfels with a reddish-brown crust or patina (Prinsloo 1989).

It should be noted here that the stratigraphic as well as palaeoenvironmental interpretation of the Ecca / Beaufort boundary rocks in the De Aar – Philipstown area is more complex and unresolved than that suggested by the brief treatment in the Britstown sheet explanation by Le Roux (1993). For mapping purposes, the base of the first prominent-weathering sandstone within the Ecca / Beaufort boundary succession has been taken as the base of the Beaufort Group in this region (ibid., p. 4, following Nel 1977). The marine / lacustrine, uppermost Ecca Group rocks here, though mapped as offshore / basinal Tierberg Formation, have in fact many features in common with the shallow shelf, storm-dominated, sandstone-rich facies seen at the top of the Ecca succession in the Carnarvon area to the west. These uppermost Ecca Group rocks were previously assigned to the **Carnarvon Formation** that has since been incorporated into the **Waterford Formation** (*e.g.* Johnson *et al.* 2006). The Waterford beds tend to be more sandstone-rich than the overlying Beaufort Group. The "Carnarvon Facies" is characterised by upward-coarsening, yellowish-weathering, sandstone-rich successions containing storm-generated hummocky cross-stratification and wave ripples, large ferruginous carbonate concretions (*koffieklip*), ball-and-pillow load structures, and pervasive low intensity bioturbation by low diversity trace fossil assemblages. The latter have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Siebrits 1987, Prinsloo 1989, Rust *et al.* 1991 and references therein). Petrified wood and other plant remains (*e.g.* leaf compressions) are locally abundant. The inshore shelf (shoreface) Carnarvon facies rocks have a gradational lower contact with the underlying offshore Tierberg mudrocks and are in turn conformably overlain by continental (subaerial), fluvial sediments of the Lower Beaufort Group. For the purpose of the present fossil heritage study, the upper Ecca Group sediments within the study area are assigned to the Waterford Formation, despite their attribution to the Tierberg Formation on the published 1: 250 000 geological map (Fig. 5) and the key SACS publication by Viljoen (2005). It is possible that both the Tierberg / Waterford (*i.e.* offshore basin to prodelta) as well as Ecca / Beaufort (*i.e.* lacustrine / continental) transitions are represented by sedimentary rock successions in the study region.

Good exposures of typical Carnarvon-type facies of the Waterford Formation are seen in several shallow riverine exposures in the De Aar region (*e.g.* Almond 2012b, 2012c). They include tabular-bedded, well-jointed sandstones with wave rippled tops, well-developed low angle cross-lamination (hummocky cross-stratification), abundant bioturbation, convolute lamination (dewatering or load structures) and occasional large *koffieklip* ferruginous carbonate concretions. Locally the grey, thin-bedded Ecca mudrocks underlying the sandstones are also exposed in the river banks.

With the exception of occasional concentrations of excavated blocks of dark grey to grey-green mudrocks and sandstones, for example associated with geotechnical test pits, farm tracks and shallow dams, Ecca Group sediments – most notably the less resistant mudrock facies - are only rarely exposed in the northern sector of the Badenhorst Dam study area (Fig. 8). Here the Karoo Supergroup bedrocks are almost entirely mantled with shallow to deep silty to sandy soils of brownish to orange-brown hues, with rare patches of downwasted surface gravels (sandstone, mudrock, hornfels, quartzite, dolerite) and cream-coloured reworked calcrete.

Isolated low exposures of fine- to medium-grained, tabular-bedded to flaggy, buff to pinkish, horizontally- to ripple cross-laminated sandstones referable to the Waterford Formation (Carnarvon facies) occur in flat areas in the north as well as on the lower hillslopes in the south-eastern part of the study area (e.g. Loc. 284, Fig. 4). Sandstone bedding surfaces often show well-developed current lineation, current ripple cross-lamination (rib-and-furrow structure indicating palaeocurrents towards the south here) or small scale wave ripples of both linear-crested and polygonal interference patterns. Soft-sediment deformation of Ecca sandstones is seen at Loc. 284. Many of the sandstone exposures are secondarily baked and well-jointed with ferruginous spotting. Good examples of thermally metamorphosed quartzitic, vuggy sandstones showing conchoidal fracture are seen at Locs. 274 and 275.

3.2. Lower Beaufort Group (Adelaide Subgroup)

The Adelaide Subgroup (Pa) (Lower Beaufort Group, Karoo Supergroup) was deposited by large-scale meandering river systems flowing northwards from the youthful Cape Fold Belt across the extensive floodplains of the ancient Karoo Basin (Smith 1980, Rubidge 1995, Johnson et al. 2006). The sediments mainly comprise fine-grained overbank mudrocks with subordinate lenticular channel sandstones. The channel sandstones have a basal conglomeratic lag of rolled mudflake pellets and calcrete nodules, the latter reflecting the prevailing semi-arid climates in Middle to Late Permian times. Small, often transient playa lakes were also present on the floodplain. In the Britstown – Williston - Colesberg sheet areas the Lower Beaufort succession consists largely of blocky-weathering, blue-grey and reddish floodplain mudrocks, showing occasional mudcracks. There are also subordinate siltstones, fine-grained, lenticular, current cross-bedded channel sandstones, flat-laminated crevasse-splay sandstones, and occasional playa lake deposits (Prinsloo, 1989, Viljoen 1989, Le Roux 1993). Carbonate concretions, including ferruginous *koffieklip*, as well as calcrete nodules (pedogenic limestones) and silicified gypsum rosettes (“desert roses”) are common.

The precise stratigraphic assignment of the Lower Beaufort Group sediments east of De Aar is unresolved. According to the most recent fossil biozonation map of the Beaufort Group (Van der Walt *et al.* 2010) the sediments here are assigned to the *Pristerognathus* Assemblage Zone that characterises the uppermost Abrahamskraal Formation *plus* the Poortjie Member of the Teekloof Formation west of longitude 24º East, as well as the uppermost Koonap Formation and basal Middleton Formation to the east (Rubidge 1995). De Aar is situated on the (arbitrary) cut-off line between these two stratigraphic schemes. The lowermost Beaufort Group rocks in the region to the east of town contain numerous, closely-spaced sandstones with a yellowish hue, resembling in this respect the Poortjie Member recognised in the western part of the Karoo Basin. An assignation of these rocks to the Poortjie Member is supported by the sparse fossil vertebrate remains recently recorded here, including the rare tortoise-like parareptile *Eunotosaurus* (Almond 2012c, Day *et al.* 2013).

Compared with the underlying Abrahamskraal rocks, the Teekloof Formation has a generally higher proportion of sandstones while reddish mudrocks are more abundant here. Multi-storied sandstones are common in the basal arenaceous Poortjie Member. Thin, impersistent lenses of pinkish “cherts” are probably altered volcanic ashes (Johnson & Keyser 1979, Theron 1983, Smith & Keyser 1995, Rubidge et al. 2010). Several economically interesting uranium ore deposits occur within the Poortjie Member in association with brown-weathering, ferruginous channel sandstones (*koffieklip*) and transported plant material. Interesting accounts of the sedimentology and palaeontology of the Poortjie Member are given by Stear (1978) as well as by Cole and Smith (2008). The Poortjie Member has a thickness of some 200 m while the entire Teekloof succession is *c*. 1000 m thick (Cole et al. 1990, Cole & Voster 1999). Recent, unpublished radiometric dating of zircons from tuff layers within the Poortjie Member gives an age of *c.* 260 – 261 Ma (Rubidge *et al.* 2010, Rubidge *et al.* 2013), placing this stratigraphic unit within the Gaudalupian Epoch (late Middle Permian). Previously the Poortjie Member was considered to be earliest Late Permian or Lopingian in age (*cf* Smith & Keyser 1995, Rubidge 2005).

Sediments currently assigned to the Lower Beaufort Group on the 1: 250 000 geological map (Fig. 5) are well exposed within several quarries in the southern portion of, or just outside, the Badenhorst Dam study area, close to the N10 tar road (Q1 to Q5 in Fig. 2). They comprise grey-green mudrocks interbedded with tabular, thin- to medium-bedded greenish sandstones or wackes with occasional large (meter-sized) ferruginous calcareous concretions. Linear-crested wave-rippled upper bedding planes are seen locally (Fig. 11). The rippled sandstones may have been deposited in a continental setting within playa lakes but, alternatively, these rocks may rather belong to the storm-influenced Carnarvon facies of the uppermost Ecca Group, *i.e.* the Waterford Formation. SE-dipping "Beaufort Group" mudrocks and thin sandstones are exposed in a small quarry close to the N10 (note small dolerite dyke here; Fig. 10).

As suggested earlier, in the author's opinion the transition between the Ecca and Beaufort successions (*i.e.* the ancient shoreline of the Ecca Sea) lies close to the southern edge of the present study area, as suggested by recent unpublished field observations near the De Aar aerodrome on the western edge of Badenhorst Dam. For example good quarry exposures at Locs. 244 to 245 (Quarry Q5 in Fig. 2) include tabular, thin-bedded, wave-rippled heterolithic packages of typical Carnarvon facies with abundant *Cruziana* ichnofacies burrows. These sediments are interbedded with thick-bedded, coarser-grained, massive pinch-and-swell sandstones associated with mudflake breccias and locally abundant fossil plant material (Figs. 13 & 29). These successions may reflect intertonguing of shallow marine and fluvial facies close to the Ecca / Beaufort contact (or perhaps distributary channels in a delta top setting). If correct, the Adelaide Subgroup is represented at most only along the southern margins of Badenhorst Dam, mainly south-west of the N10, *i.e.* only within the extended PV4 footprint and possibly also the south-western portion of the PV5 footprint (See map Figs. 4 & 5).

The "Beaufort Group" mudrocks and sandstones exposed near-surface in the southern portion of Badenhorst Dam are often disrupted to a depth of several meters by a dense network of calcrete veins. Whereas Karoo Supergroup rocks in the De Aar region are normally flat-lying, reflecting the absence of tectonic disturbance here, those seen in Fig. 12 show well-spaced small-scale folds. This phenomenon of buckling and heaving of Karoo beds is a geologically recent (probably Pleistocene) process consequent on stresses induced by extensive secondary mineralization by calcrete, causing both vertical and horizontal expansion of the rock column. Past expression of sandstone anticlinal hinge axes as surface ridges has promoted erosion of mudrocks in intervening synclines and development here of a thick calcrete packet.

Fig. 8. Excavated blocks of Ecca Group mudrocks and sandstones near a shallow dam in northern part of the study area (Hammer = 30 cm).

Fig. 9. Good exposure of baked Ecca sandstones forming a low *krans* on the northern slopes of a dolerite-capped *koppie*, Loc. 282a (Hammer = 30 cm).

Fig. 10. SE-dipping dark mudrocks and thin sandstones mapped as the Lower Beaufort Group (but probably Waterford Formation) exposed in small quarry near the N10 (Q4 in Fig. 2). Note also rusty-brown weathering dolerite dyke beneath hammer (Hammer = 30 cm).

Fig. 11. Wave-rippled upper surface of "Lower Beaufort Group" sandstone bed in quarry exposure, southwestern part of the study area (Q2 in Fig. 2). These rocks are probably better assigned to the Waterford Formation.

Fig. 12. Small-scale folding in "Lower Beaufort Group" sediments, possibly due to extensive near-surface secondary calcrete deposition, small quarry in southwestern part of study area (Q2 in Fig. 2).

Fig. 13. Heterolithic packages of tabular, thin-bedded sandstones and siltstones rich in trace fossils of aquatic invertebrates interbedded with thick-bedded, massive, coarser sandstones with mudflake breccias and transported plant material, Loc. 245 (Q5 in Fig. 2) (Hammer = 30 cm). These beds probably lie close to the Ecca / Beaufort boundary.

3.3. Karoo Dolerites

The **Karoo Dolerite Suite** (**Jd**) is an extensive network of basic igneous bodies (dykes, sills) that were intruded into sediments of the Main Karoo Basin in the Early Jurassic Period, about 183 million years ago (Duncan & Marsh 2006). These dolerites form part of the Karoo Igneous Province of Southern Africa that developed in response to crustal doming and stretching preceding the break-up of Gondwana. Hard cappings of blocky, reddish-brown to rusty-weathering dolerite are a very typical feature of the flat-topped *koppies* in the Great Karoo region. As seen from geological maps (Fig. 4), extensive dolerite intrusion of both the upper Ecca Group as well as the Lower Beaufort Group rocks is observed in the De Aar region. The country rocks adjacent to the intrusions have often been extensively baked or thermally metamorphosed. Mudrocks are altered to flinty hornfels ("lydianite" of some authors), while sandstones are metamorphosed to resistant-weathering, siliceous quartzites. The Karoo rocks within the thermal aureole of the dolerite intrusions are also often chemically altered and they tend to be silicified, more brittle and contain numerous irregular *vugs* (cavities) lined or infilled with secondary minerals.

Rocky ridges and low *koppies* of well-jointed, masonry-like dolerite, as well as zones of dolerite corestones emerging from the soil, are seen in central and south-eastern portion of the Badenhorst Dam study area reflecting both intrusive dykes and sills (Figs. 14 & 15). Thick calcrete development overlying deeply-weathered dolerite (corestones, onionskin weathering *etc*) is seen in several quarries to the south (Fig. 20).

3.4. Superficial deposits

Quaternary to Recent superficial deposits ("drift") cover all but the steepest slopes of the Karoo *koppies* as well as most of the plains at their feet, including dry river courses such as the Brak River in the broader De Aar study region. Various types of superficial deposits of geologically young, Late Caenozoic (Miocene / Pliocene to Recent) age (< 5 Ma = million years ago) occur throughout the Great Karoo region (Prinsloo 1989, Le Roux 1993, with more extensive discussion in Holmes & Marker 1995, Cole *et al.* 2004, Partridge *et al.* 2006). They include pedocretes (*e.g.* calcretes), colluvial slope deposits (dolerite, sandstone and hornfels scree *etc*), sandy, gravelly and bouldery river alluvium, as well as spring and pan sediments. These colluvial and alluvial deposits may be extensively calcretised (*i.e.* cemented with soil limestone), especially in the neighbourhood of dolerite intrusions (*e.g.* Loc. 282b, Fig. 19).

Thin (usually < 1 m) horizons of fine to coarse, angular gravels mantle the Palaeozoic and Mesozoc bedrocks over much of the study area. Gravel clasts mostly consist of locally-derived Ecca / Lower Beaufort Group sandstones, mudrocks, hornfels (sometimes flaked), quartzite, ferruginous carbonate nodule fragments and rare silicified wood as well as weathered to fresh dolerite, including small to large, rounded dolerite corestone boulders (*e.g.* Locs. 278, 281, 283, 284). In areas with a well-developed calcrete hardpan the surface gravels are rich in reworked calcrete clasts. Buried gravel lenticles and layers are present at the bedrock / soil interface in many areas, as seen elsewhere in the De Aar area.

Quarry sections in the southern portion of the Badenhorst Dam study area show that a large proportion of the Karoo and dolerite bedrocks are mantled with a thick (up to 4 m, though often much less), irregular and variable layer of secondary calcrete (Figs. 21 to 23). This may be massive or multi-layered, and contains lenticular to laterally persistent horizons of gravels (quartzite, hornfels, siltstone, sandstone, dolerite). The thickest calcrete horizons probably infill depressions in the pre-Holocene landscape and are often associated directly or indirectly with weathered dolerite. For the most part they are likely to be Pleistocene in age. The calcrete hardpan is often cavernous weathering. Possible irregular, subvertical soil-filled zones may be solution hollows (Makondos, dolines), as seen in both coastal limestones as well as Precambrian carbonate rocks of the interior. Calcretes seen in the study area are very variable in character and in many or most cases are composite horizons that have developed in several phases over thousands or tens of thousands of years. Veins, networks and sheets of calcrete extend downwards from the main hardpan into the underlying superficial sediments or bedrock.

Semi-consolidated, blocky-weathering, coarse sandy and gritty deposits locally underlying the calcrete hard pan and overlying bedrock or gravel layers may be ancient alluvial soils, of possible Pleistocene age. They contain sparse coarse gravel clasts and are often permeated by a network of pale calcrete veins. Unconsolidated orange-brown to brown surface soils, overlying the calcrete hardpan, may be of alluvial, sheet wash or even in part aeolian origin. These superficial soils are probably Holocene in age. They contain, or are locally overlain by, downwasted surface gravels, concentrated by downwasting and sheetwash processes.

Fig. 14. Well-jointed, blocky outcrop of a large dolerite intrusion in central part of Badenhorst Dam study area, viewed from the south.

Fig. 15. Dolerite *koppie* in the south-eastern corner of the study area showing bouldery colluvial gravels of dolerite corestones in the foreground.

Fig. 16. Orange-brown sandy soils, perhaps in part of aeolian origin, with sparse fine surface gravels mantle many flatter-lying portions of the Badenhorst Dam study area.

Fig. 17. Bare patches exposing fine surface gravels yield sparsely scattered, mostly small fragments of silicified wood, reworked by sheetwash processes (*e.g.* Locs. 283, 284).

Fig. 18. Downwasted surface gravels dominated by angular clasts of brown ferruginous carbonate concretions, Loc. 281 (Hammer = 30 cm).

Fig. 19. Calcretised breccio-conglomerate of polymict colluvial gravels (mainly Ecca sandstone and dolerite) exposed on the lower slopes of a *koppie*, Loc. 282b (Hammer = 30 cm).

Fig. 20. Several meter - thick calcrete hardpan overlying weathered dolerite (in foreground) in quarry exposure close to the railway line (Q3 in Fig. 2).

Fig. 21. Thick calcrete hardpan forming low cliff in the background, underlain by extensively calcretised grey-green mudrocks of the "Lower Beaufort Group", quarry exposure in the southern part of the study area (Q2 in Fig. 2) (Hammer = 30 cm).

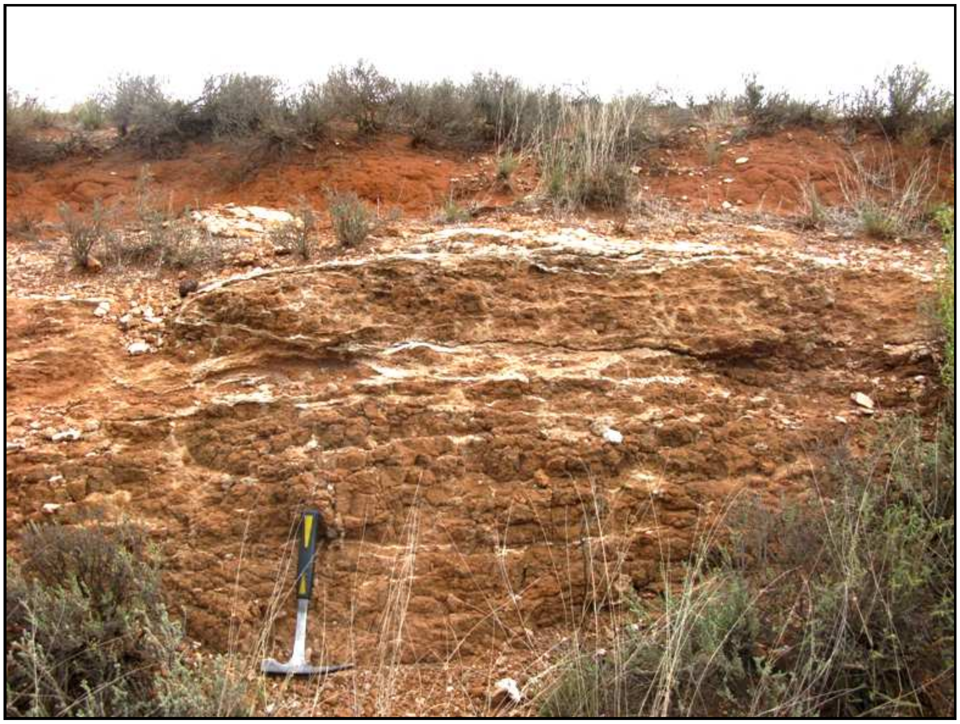

Fig. 22. Well-consolidated, calcretised older alluvial soils overlain by unconsolidated orange-brown younger soils, quarry exposure in southern part of the study area (Q1 in Fig. 2) (Hammer = 30 cm).

Fig. 23. Composite, multi-layered calcrete hardpan with coarse gravel horizon adjacent to hammer, quarry exposure near N10 (Q4 in Fig. 2) (Hammer = 30 cm).

4. PALAEONTOLOGICAL HERITAGE

Fossil biotas recorded from each of the main stratigraphic units mapped in the study area are briefly reviewed in this section. Bedding dips of the Karoo Supergroup sediments in the study region are generally horizontal to very shallow. Low levels of tectonic deformation and cleavage development are expected here, favouring good fossil preservation. However, extensive dolerite intrusion has compromised fossil heritage in the Karoo Supergroup sediments due to resulting thermal metamorphism. In addition, pervasive calcretisation of many near-surface bedrocks has further compromised their original fossil heritage.

4.1. Upper Ecca Group

The fossil record of the **Tierberg Formation** has been reviewed in detail by Almond (2008a). Rare body fossil records include disarticulated microvertebrates (*e.g.* fish teeth and scales) from calcareous concretions in the Koffiefontein sheet area (Zawada 1992) and allochthonous plant remains (drifted leaves, petrified wood). The latter become more abundant in the upper, more proximal (prodeltaic) facies of the Tierberg (*e.g.* Wickens 1984). Prinsloo (1989) records numerous plant impressions and unspecified "fragmentary vertebrate fossils" within fine-grained sandstones in the Britstown sheet area. Dark carbonaceous Ecca mudrocks are likely to contain palynomorphs (*e.g.* pollens, spores, acritarchs).

The commonest fossils by far in the Tierberg Formation are sparse to locally concentrated assemblages of trace fossils that are often found in association with thin event beds (*e.g.* distal turbidites, prodeltaic sandstones) within more heterolithic successions. A modest range of ten or so different ichnogenera have been recorded from the Tierberg Formation (*e.g.* Abel 1935, Anderson 1974, 1976, Wickens 1980, 1984, 1994, 1996, Prinsloo 1989, De Beer *et al*., 2002, Viljoen 2005, Almond 2008a). These are mainly bedding parallel, epichnial and hypichnial traces, some preserved as undertracks. Penetrative, steep to subvertical burrows are rare, perhaps because the bottom sediments immediately beneath the sediment / water interface were anoxic. Most Tierberg ichnoassemblages display a low diversity and low to moderate density of traces. Apart from simple back-filled and / or lined horizontal burrows (*Planolites, Palaeophycus*) they include arthropod trackways (*Umfolozia*) and associated resting impressions (*Gluckstadtella*), undulose fish swimming trails (*Undichna*) that may have been generated by bottom-feeding palaeoniscoids, horizontal epichnial furrows (so-called *Scolicia*) often attributed to gastropods (these are also common in the co-eval Collingham Formation; Viljoen 1992, 1994), arcuate, finely striated feeding excavations of an unknown arthropod (*Vadoscavichnia*), beaded traces ("*Hormosiroidea*" or "*Neonereites*"), small sinusoidal surface traces (*Cochlichnus*), small star-shaped feeding burrows (*Stelloglyphus*) and zigzag horizontal burrows (*Beloraphe*), as well as possible narrow (<1 cm) *Cruziana* scratch burrows. The symmetrical, four-pronged trace *Broomichnium* (= *Quadrispinichna* of Anderson, 1974 and later authors) often occurs in groups of identical size (*c*. 3.5 cm wide) and similar orientation on the bedding plane. This trace has frequently been misinterpreted as a web-footed tetrapod or arthropod trackway (*e.g.* Van Dijk *et al*. 2002 and references therein). However, Braddy and Briggs (2002) present a convincing case that this is actually a current-orientated arthropod resting trace (cubichnion), probably made by small crustaceans that lived in schools of similar-sized individuals and orientated themselves on the seabed with respect to prevailing bottom currents. Distinctive broad (3-4 cm), strap-shaped, horizontal burrows with blunt ends and a more-or-less pronounced transverse ribbing occur widely within the Tierberg mudrocks. They have been described as "fucoid structures" by earlier workers (*e.g.* Ryan 1967) by analogy with seaweeds, and erroneously assigned to the ichnogenera *Plagiogmus* by Anderson (1974) and *Lophoctenium* by Wickens (1980, 1984). Examples up to one metre long were found in Tierberg mudrocks near Calvinia in 1803 by H. Lichtenstein, who described them as "eel fish". These are among the first historical records of fossils in South Africa (MacRae 1999). These as yet unnamed burrows are infilled with organized arrays of faecal pellets (Werner 2006). Sandstone sole surfaces with casts of complex networks of anastomosing (branching and fusing) tubular burrows have been attributed to the ichnogenus *Paleodictyon* (Prinsloo 1989) but may more appropriately assigned to *Megagrapton* (Almond 1998). These so-called graphoglyptid burrows are associated with turbidite facies from the Ordovician to Recent times and have been interpreted as gardening burrows or *agrichnia* (Seilacher, 2007). Microbial mat textures, such as *Kinneyia*, also occur in these offshore mudrocks but, like the delicate grazing traces with which they are often associated, are generally under-recorded.

As discussed previously (Section 3.1) it is considered likely that the Ecca Group rocks in the study area belong to the **Waterford Formation** rather than the Tierberg Formation as mapped. Rare fragments of poorly-preserved tetrapod bone are recorded in channel lags within the upper Waterford Formation in the Williston sheet area (Viljoen 1989) and the southern Great Karoo. These probably belong to aquatic temnospondyl amphibians ("labyrinthodonts") but large fish and terrestrial therapsids might also be represented. Scattered palaeoniscoid fish scales and fish coprolites are common in the Waterford Formation, and several genera of non-marine bivalves have been described from the southern Karoo (Bender *et al*. 1991, Cooper & Kensley 1984).

Upper delta platform facies of the Waterford Formation (including the Koedoesberg Formation of earlier authors) contain abundant, low diversity trace assemblages of the *Scoyenia* ichnofacies. They are dominated by the rope-like, horizontal and oblique burrows of the ichnogenus *Scoyenia* that has been attributed to small arthropods (possibly insects) and / or earthworms. These tubular, meniscate back-filled scratch burrows characterise intermittently moist, firm substrates such as channel and pond margins on the upper delta platform (Smith & Almond 1998, Buatois & Mángano 2004, 2007). Good examples, often associated with wave-rippled surfaces, are recorded from Waterford thin-bedded sandstones and siltstones in the Roggeveld Escarpment zone by Wickens (1984, 1996) and Viljoen (1989). Offshore delta platform facies of the Waterford Formation have very impoverished, poorly-preserved ichnofaunas due to rapid sedimentation rates with abundant soft-sediment deformation and perhaps also to fluctuating salinities.

Petrified wood and other plant material of the *Glossopteris* Flora (*e.g. Glossopteris, Phyllotheca*) is also common in the Waterford Formation (Theron 1983, Anderson & Anderson 1985, Viljoen 1989, Wickens 1984, 1996, Rubidge *et al*. 2000). Leaves and stems of arthrophytes (horsetails) such as *Schizoneura* have been observed in vertical life position. Substantial fossil logs (so-called "*Dadoxylon*") showing clearly developed seasonal growth rings are mostly permineralised with silica but partially or completely calcified material is also known (Viljoen 1989). At least two different genera of gymnospermous woods, *Prototaxoxylon* and *Australoxylon,* have been identified so far (Bamford 1999, 2004).

The storm-dominated shelf sediments of the Carnarvon-type facies of the Waterford Formation, as seen near De Aar, are typically associated with pervasive low intensity bioturbation by low diversity trace fossil assemblages. The latter have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Rust *et al.* 1991 and references therein). Good examples of these traces are illustrated by Siebrits (1987), Prinsloo (1989) and Rust *et al.* (1991). Prominent trace fossil taxa include cm-sized horizontal to oblique burrows with striated walls (*cf Palaeophycus striatus*) and vertical spreiten burrows of the ichnogenus *Teichichnus*. Possible arthropod feeding traces of the ichnogenera *Rusophycus* and *Cruziana* are also reported here. Petrified wood ("*Dadoxylon*") showing well-developed seasonal growth lines and other plant remains (*e.g.* leaf compressions) are locally abundant.

Low diversity ichoassemblages dominated by *Teichichnus*, *Palaeophycus striatus* and unidentified horizontal burrows were recorded from the tops of wave-rippled Ecca sandstones exposed in the De Aar area (Almond 2012b, 2012c). Assemblages of small- to medium-sized traces, including *Cruziana*, "*Plagiogmus*" – type strap burrows, *Teichichnus* and various other horizontal burrows, were recorded from *in situ* Ecca sandstones as well as sandstone float blocks on Du Plessis Dam Farm just to the north of the present study area (Almond, unpublished palaeontological heritage report, 2013). Tierberg-like dark grey flaggy mudrocks in the same area also contain numerous narrow strap-shaped horizontal burrows (possibly "*Plagiogmus*"). On Badenhorst Dam Farm the Ecca Group sandstones are occasionally highly bioturbated (*e.g.* Loc. 279) (Fig. 24) and low diversity ichnoassemblages of typical Carnarvon-type are also represented here. Sparse, poorly-preserved horizontal burrows were recorded, for example, in sandstone float blocks at Loc. 280

(Fig. 25). In contrast, locally abundant *Cruziana* ichnofacies traces, including a small range of hypichnial and epichnial burrows (*e.g.* small-scale *Cruziana*), are well-represented in thin-bedded heterolithic packages within the uppermost Ecca Group at the quarry site Locs. 244-245, just west of the Badenhorst Dam study area (Fig. 26).

Sheetwash and other surface gravels onBadenhorst Dam Farm contain sparse small cherty fragments of silicified woods reworked from the underlying Ecca Group bedrocks (*e.g.* Locs. 283, 284) (Fig. 27). The fossil woods typically show well-developed seasonal growth rings and preservation of original the original woody microstructure appears to be good. No other Ecca Group body fossils were observed within the study area. Reworked clasts of cherty silicified wood within downwasted surface or near-surface gravels are of widespread occurrence and locally quite common in the De Aar area (Almond 2012b, 2012c).

Fig. 24. Highly bioturbated, grey-green sandstones of the Ecca Group, Loc. 279 (Hammer = 30 cm).

Fig. 25. Poorly-preserved horizontal burrows in Ecca sandstone float block, Loc. 280 (Scale in cm).

Fig. 26. Sandstone sole surface with numerous small-scale invertebrate burrows of the *Cruziana* ichnofacies, Loc. 244 (Scale in cm and mm).

Fig. 27. Moderate-sized piece of silicified Ecca wood downwasted into surface gravels at Loc. 284 (Scale in cm).

4.2. Adelaide Subgroup

The overall palaeontological sensitivity of the Lower Beaufort Group sediments is high (Rubidge 1995, Almond & Pether 2008). These fluvial and lacustrine sediments have yielded one of the richest fossil records of land-dwelling plants and animals of Permo-Triassic age anywhere in the world. Well-preserved tetrapod fossils, from isolated skulls and post-cranial bones to fully articulated skeletons, are mainly found in overbank mudrocks, often in association with pedogenic calcretes (palaeosol horizons). Disarticulated, water-worn bones occur in the channel lag conglomerates and sandstones (Smith 1980, 1993). Playa lake deposits may be associated with disarticulated amphibian bones and a range of trace fossils (*e.g. Scoyenia*). Fossils embedded within metamorphosed sediments (quartzites, hornfels) adjacent to dolerite intrusions may be well-preserved, but are very difficult to prepare out from the matrix and therefore usually of limited scientific value.

A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Kitching (1977), Keyser and Smith (1979) and Rubidge (1995). The first two articles do not specify an assemblage zone for the Badenhorst Dam Farm area. As mentioned earlier (Section 3.2) the sediments here are assigned to the *Pristerognathus* Assemblage Zone according to the most recent fossil biozonation map of the Beaufort Group published by Van der Walt *et al*. (2010). This assignation is supported by recent fossil vertebrate finds in the region to the east of De Aar (Almond 2012c, Day *et al.* 2013). The paucity of fossil data for the Lower Beaufort succession in the Colesberg sheet explanation (Le Roux 1993) also suggests that this region is palaeontologically under-explored; any new fossil finds here are consequently of palaeontological significance. This is emphasized by the absence of fossil records from the De Aar area in the recent maps of Karoo vertebrate fossil sites produced by Nicolas (2007).

Fossils of the *Pristerognathus* Assemblage Zone characterize the arenaceous Poortjie Member as well as the uppermost beds of the underlying Abrahamskraal Formation in the western Main Karoo

Basin as well as the laterally equivalent beds spanning the Koonap / Middleton Formation boundary in the eastern Karoo (Smith & Keyser 1995). This important terrestrial biota is dominated by various therapsids ("mammal-like reptiles"), such as the moderate-sized therocephalian carnivore *Pristerognathus* as well as several gorgonopsian predators / scavengers and herbivorous dicynodonts (Fig. 28). The commonest genus by far is the small burrowing dicynodont *Diictodon* (Keyser and Smith 1977-78, Smith & Keyser 1995b, MacRae 1999, Cole *et al*., 2004, Rubidge 2005, Almond 2010, Nicolas 2007, Nicolas & Rubidge 2010). There are also large, rhino-sized herbivorous pareiasaur reptiles (*Bradysaurus* spp.), crocodile-like temnospondyl amphibians (*Rhinesuchus*), palaeoniscoid fish, vascular plant fossils of the *Glossopteris* Flora (fossil wood, leaves *etc*) and various trace fossils, including invertebrate and therapsid burrows as well as tetrapod trackways. The comparatively low number of specimens and major taxa represented in fossil collections from this biozone has been highlighted by Nicolas (2007). The fossil biota of the *Pristerognathus* Assemblage Zone is of special interest because it *possibly* represents an impoverished post-extinction recovery fauna following a late Mid Permian extinction event that preceded the well-known end-Guadalupian biotic crisis (*cf* Benton 2003, Retallack *et al.,* 2006, Lucas 2009). Recent radiometric dates of *c*. 261-260 Ma for the *Pristerognathus* AZ suggest that this faunal assemblage does in fact *precede* the end-Guadalupian extinction event (Rubidge *et al.* 2013).

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

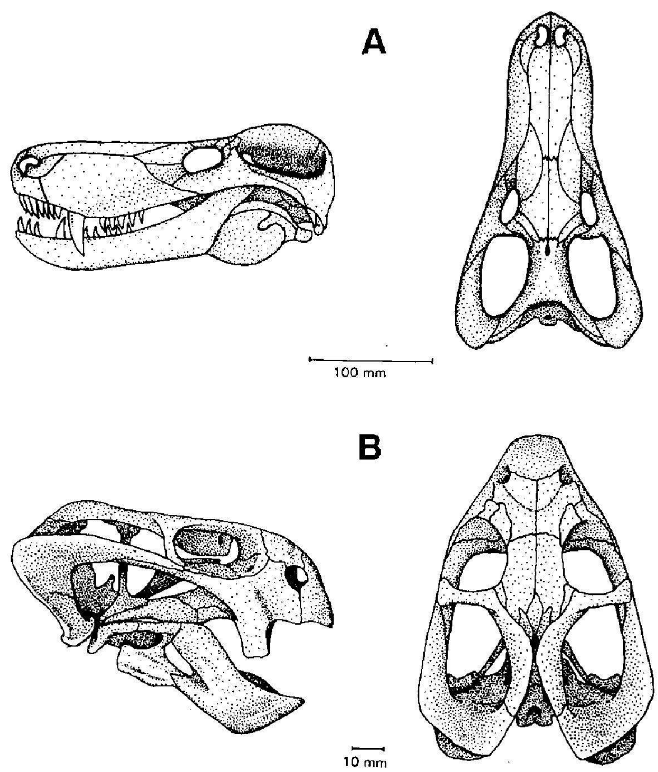

Fig. 28. Skulls of typical therapsids from the *Pristerognathus* Assemblage Zone: A. the dog-sized carnivorous therocephalian *Pristerognathus* and B. the small herbivorous dicynodont *Diictodon* (From Smith & Keyser 1995).

Fig. 29. Concentration of plant stem compressions within grey-green sandstone, possibly within the Lower Beaufort Group, quarry Loc. 245 (Scale in cm).

Apart from vague trace fossils (horizontal burrows) observed on weathered upper surfaces of sandstones, no fossils were observed in the "Lower Beaufort Group" bedrocks within the Badenhorst Dam study area. Sparse skulls and postcranial remains of small-bodied therapsids (probably *Diictodon* and a slightly larger form) as well as the tortoise-like parareptile *Eunotosaurus* have recently been collected from Poortjie Member sediments in the escarpment area to the east of De Aar (Almond 2012c, Day *et al.* 2013). Flaggy buff, medium-grained sandstones exposed in the quarry site just outside and west of the study area (Loc. 245, Q5 in Fig. 2) contain locally abundant drifted plant compression fossils, some of which clearly relate to woody material (Fig. 29), supporting a nearshore depositional setting for these beds (delta distributaries or paralic rivers).

4.3. Karoo Dolerite Suite

The dolerite outcrops at Badenhorst Dam Farm are in themselves of no palaeontological significance. These are high temperature igneous rocks emplaced at depth within the Earth's crust so they do not contain fossils. However, as a consequence of their proximity to large dolerite intrusions in the Great Escarpment zone, some of the Ecca and Beaufort Group sediments in the study area will have been thermally metamorphosed or "baked" (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 1995). Thermal metamorphism by dolerite intrusions therefore tends to reduce the palaeontological heritage potential of Beaufort Group sediments. In some cases (*e.g.* fossil moulds of mesosaurid reptiles and palaeoniscoid fish) baking may enhance the quality of preservation of Ecca fossils while other fossil groups (*e.g*. carbonaceous remains of plants, organic-walled palynomorphs) are more likely to be compromised.

4.4. Quaternary to Recent superficial deposits

The central Karoo drift deposits have been comparatively neglected in palaeontological terms. However, they may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals as well as remains of reptiles like tortoises. Good examples are the Pleistocene mammal faunas at Florisbad, Cornelia and Erfkroon in the Free State and elsewhere (Wells & Cooke 1942, Cooke 1974, Skead 1980, Klein 1984, Brink, J.S. 1987, Bousman *et al.* 1988, Bender & Brink 1992, Brink *et al*. 1995, MacRae 1999, Meadows & Watkeys 1999, Churchill *et al*. 2000 Partridge & Scott 2000, Brink & Rossouw 2000, Rossouw 2006). Other late Caenozoic fossil biotas from these superficial deposits include non-marine molluscs (bivalves, gastropods), ostrich egg shells, tortoise remains, trace fossils (*e.g.* calcretised termitaria, coprolites), and plant material such as peats or palynomorphs (pollens) in organic-rich alluvial horizons (Scott 2000) and diatoms in pan sediments. In Quaternary deposits, fossil remains may be associated with human artefacts such as stone tools and are also of archaeological interest (*e.g.* Smith 1999 and refs. therein). Ancient solution hollows within extensive calcrete hardpans such as seen here may have acted as animal traps in the past. As with coastal and interior limestones, they might occasionally contain mammalian bones and teeth (perhaps associated with hyaena dens) or invertebrate remains such as snail shells.

Assemblages of possible calcretized rhizoliths (solid plant root casts) up to 5 cm across as well as hollow subhorizontal root moulds and / or invertebrate burrows are exposed below the calcrete hardpan in a quarry near the N10, close to the southern boundary of the Badenhorst Dam Farm (Figs. 30 & 31). Identifiable embedded stone artefacts (useful for dating purposes) were not seen within coarse subsurface gravel layers, although good examples (MSA flaked hornfels) have been observed elsewhere in the De Aar region (Almond, recent field obs., 2012-2013). As already mentioned in Section 4.1, sparse reworked clasts of resistant-weathering, cherty fossil wood of Permian age occur widely both within subsurface gravels as well as among sheetwash gravels at the soil surface (Fig. 27).

Fig. 30. Irregular, subvertical calcretised rhizoliths (plant root casts) in calcrete hardpan exposed in quarry near N10 (Q4 in Fig 2) (Hammer = 30 cm).

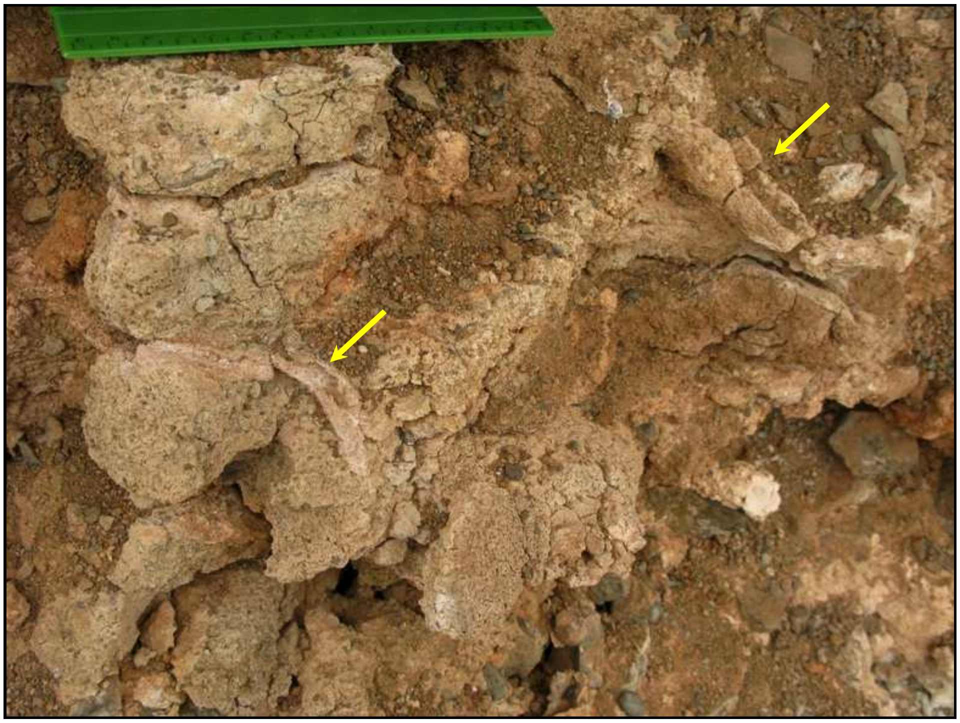

Fig. 31. Hollow calcrete root moulds or invertebrate burrows (arrowed) within calcrete hardpan exposed in quarry near N10 (Q4 in Fig. 2) (Scale in cm).

Table 4.1: Palaeontological record and sensitivity of rocks units represented in the broader De Aar study region

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Superficial deposits (“drift”)	Alluvium, colluvium (scree), pan sediments, surface gravels, calcrete hardpans *etc* NEOGENE / QUATERNARY TO RECENT	Sparse remains of mammals (bones, teeth), reptiles, ostrich egg shells, molluscs shells, trace fossils (calcretized termitaria, rhizoliths), plant remains, palynomorphs, diatoms; reworked Karoo-age silicified wood clasts and stone artefacts in surface or subsurface gravels	LOW	Any substantial fossil finds to be reported by ECO to SAHRA
Kimberlite pipes (diamond symbol)	Ultramafic kimberlite CRETACEOUS	None within pipe itself	ZERO	None
Karoo Dolerite Suite (Jd)	Intrusive dolerite sills & dykes EARLY JURASSIC	NONE	ZERO	None
Adelaide Subgroup (Pa) BEAUFORT GROUP	Floodplain mudrocks with lenticular channel sandstones, tabular crevasse splay sandstones, minor playa lake sediments LATE MIDDLE PERMIAN	Important but low diversity terrestrial vertebrate fauna (esp. therapsids) of Pristerognathus Assemblage Zone, petrified wood, plant remains (incl. fossil wood, leaf & stem impressions), freshwater molluscs, trace fossils (trackways, burrows, coprolites)	HIGH	Any substantial fossil finds to be reported by ECO to SAHRA

Tierberg and Waterford Formations (Pt) **ECCA GROUP**	**Dark basinal, prodelta and submarine fan mudrocks with minor sandstones (Tierberg Fm) OR** **Storm-influenced coastal sandstones and mudrocks (Carnarvon facies of Waterford Fm)** **EARLY TO MIDDLE PERMIAN**	**Locally abundant trace fossils, petrified wood, plant debris, microvertebrates**	**MEDIUM**	**Any substantial fossil finds to be reported by ECO to SAHRA**

5. ASSESSMENT OF SIGNIFICANCE OF PALAEONTOLOGICAL HERITAGE IMPACTS

In this section of the report potential impacts on fossil heritage within each of the proposed PV facilities on Badenhorst Dam are assessed, followed by an assessment of the cumulative impacts in a local and regional context. The impact significance of the various alternative solar energy facility proposals for Badenhorst Dam Farm is then briefly addressed. Please note that the operational and decommissioning phases of the solar energy facilities will not involve further significant adverse or other impacts on palaeontological heritage.

5.1. Assessment of individual PV facilities and proposed mitigation

The inferred overall impact of each of the proposed PV facilities on Badenhorst Dam (Alternative 1 and Alternative 2 layouts) on local fossil heritage is analysed in Table 5.1 below according to the impact assessment methodology developed by Aurecon. Given the very similar terrain and underlying geology represented within all of the proposed PV facilities, their impact ratings are almost identical.

The construction phase of the proposed PV facilities will not entail very substantial (*i.e.* deep and voluminous) excavations into the superficial sediment cover (soils, surface gravels *etc*). In most cases the underlying bedrocks will not be directly impacted. Shallow excavations, including surface clearance, will be required in the case of solar panel emplacements, underground cables, new internal access roads, onsite transmission line pylons, pipelines, stormwater infrastructure, septic tanks and foundations for associated infrastructure such as on-site substations and the workshop / administration building. In addition, sizeable areas may be sealed-in or sterilized by infrastructure such as lay down areas and access roads. However, all these developments may adversely affect potential fossil heritage exposed at the ground surface or preserved below the surface within the study area by damaging, destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good. Once constructed, however, the operational and decommissioning phases of the PV facilities will not involve further adverse impacts on palaeontological heritage.

In general, the destruction, damage or disturbance out of context of fossils preserved at the ground surface or below ground that may occur during construction represents a *negative* impact that is limited to the development footprint (*site specific*). Such impacts can usually be mitigated but cannot be fully rectified (*i.e. long term, irreversible*). Most of the sedimentary formations represented within the study area contain fossils of some sort, so impacts on fossil heritage are *probable*. However, because of (1) the generally sparse occurrence of fossils within all the bedrock units concerned here as well as within the overlying superficial sediments (soil, alluvium, colluvium *etc*) as well as (2) the high level of weathering, calcretisation and (in some cases) baking of the bedrocks, the magnitude of these impacts in most cases is conservatively rated as *very low* (with or without mitigation). The exception is the PV5 study area (Alternative layout 1) – and likewise the extended PV4 study area (Alternative layout 2) - where the impact magnitude is rated as *low* (with or without mitigation) as motivated below.

No areas or sites of exceptional fossil heritage sensitivity or significance are identified within the Badenhorst Dam Farm. The fossil remains identified in this study – *viz.* (1) low diversity trace fossil assemblages within Ecca Group sandstones and mudrocks, (2) sparse, reworked silicified wood fragments within surface gravels, and (3) concentrations of transported plant material in Ecca / Beaufort boundary successions - are of widespread occurrence within the rock units concerned (*i.e.* not unique to the study area). Abundant trace fossils and fossil plant remains are recorded from Ecca / Beaufort boundary beds at a quarry site adjacent to the N10 near the De Aar aerodrome, just *outside* the Badenhorst Dam study area (Q5 in Fig. 2, Locs. 244-245). Since it is likely that similar trace fossil / plant assemblages of palaeontological interest underlie the PV5 study area as well as the extended PV4 study area, impact magnitudes are rated as low in these two cases.

There are no fatal flaws in the proposed Badenhorst Dam Farm PV development as far as fossil heritage is concerned. Extensive, deep bedrock excavations are not envisaged during the construction phase. Due to the general scarcity of fossil remains within the bedrocks and superficial deposits represented here, the high levels of bedrock weathering, the comparatively small development footprints, as well as the extensive superficial sediment cover observed within and close to the study area, the overall impact significance of the construction phase of all the proposed PV energy plant projects is assessed as LOW with regard to palaeontological heritage resources.

It should be noted that should new fossil remains be discovered before or during construction and reported by the responsible ECO to the responsible heritage management authority (SAHRA) for professional recording and collection, as recommended here, the overall impact significance of the project would remain *low*. Residual negative impacts from loss of fossil heritage would be partially offset by an improved palaeontological database as a direct result of appropriate mitigation. This is a *positive* outcome because any new, well-recorded and suitably curated fossil material from this palaeontologically under-recorded region would constitute a useful addition to our scientific understanding of the fossil heritage here.

Because of the generally very low levels of bedrock exposure within the study area, and the potential on Badenhorst Dam for unrecorded buried fossiliferous deposits, such as petrified wood or rare amphibian remains, confidence levels for this palaeontological heritage assessment following a two-day field assessment of representative rock exposures are only moderate (*unsure*).

Given the low impact significance of the proposed PV facilities as far as palaeontological heritage is concerned, no further specialist palaeontological heritage studies or mitigation are considered necessary for this project, pending the discovery or exposure of significant new fossil remains during development.

During the construction phase all substantial bedrock excavations should be monitored for fossil remains by the responsible ECO. Should significant fossil remains such as vertebrate bones and teeth, shells, plant-rich fossil lenses, sizeable petrified wood specimens or dense fossil burrow assemblages be exposed during construction, the responsible Environmental Control Officer should safeguard these, preferably *in situ*, and alert SAHRA (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za) as soon as possible so that appropriate action can be taken by a professional palaeontologist at the developer's expense. Mitigation would normally involve the scientific recording and judicious sampling or collection of fossil material as well as associated geological data (*e.g.* stratigraphy, sedimentology, taphonomy).

These mitigation recommendations should be incorporated into the Environmental Management Plan (EMP) for the Badenhorst Dam PV developments.

Provided that the recommended mitigation measures are carried through, it is likely that any potentially negative impacts of the proposed solar energy facilities on local fossil resources will be substantially reduced and, furthermore, they will partially offset by the *positive* impact represented by increased understanding of the palaeontological heritage of the Northern Cape.

Please note that:

- All South African fossil heritage is protected by law (NHRA) and fossils cannot be collected, damaged or disturbed without a permit from SAHRA or the relevant Provincial Heritage Resources Agency;
- The palaeontologist concerned with mitigation work will need a valid fossil collection permit from SAHRA and any material collected would have to be curated in an approved depository (*e.g.* museum or university collection);
- All palaeontological specialist work would have to conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording fossil collection and curation,

final report) should adhere as far as possible to the minimum standards for Phase 2 palaeontological studies recently developed by SAHRA (2013).

5.2. Assessment of cumulative impacts

In this section the cumulative impact of the proposed PV facilities is assessed in the context of other alternative energy projects planned or proposed for the De Aar study region.

A number of wind and solar energy projects have been proposed for the De Aar region, in addition to the Mulilo PV solar plants proposed for Badenhorst Dam (See map Fig. 32 and also proposed Mulilo windfarm development on the Eastern Plateau assessed by Almond 2012c). Potential impacts on palaeontological heritage resources for several of these other projects have been assessed by the author on the basis of desktop as well as field studies (*e.g.* Almond 2010b, 2011, 2012a, 2012b, 2012c). The geology of the bedrocks as well as of the superficial deposits throughout the De Aar region is very similar as far as palaeontology is concerned and in all cases the impact significance of the proposed alternative energy developments was assessed as LOW.

The cumulative impacts of the four new PV solar energy facilities on Badenhorst Dam in terms of both local (< 10 km radius) as well as regional (> 10 km radius) fossil heritage resources is likewise assessed as LOW (Table 5.2) because of:

- The low palaeontological sensitivity of most of the relevant bedrocks (Ecca Group, Karoo dolerite) throughout the De Aar region, with the exception of the Lower Beaufort Group sediments in the southernmost portion of the Badenhost Dam study area. These last are unlikely to be very significantly impacted by the proposed developments;
- Weathering, calcretisation and local baking of the near-surface bedrocks, further decreasing their palaeontological sensitivity;
- The very sparse occurrence of fossils within the extensive mantle of superficial sediments (soils, gravels, calcretes *etc*) in the De Aar region; and
- The limited amount of substantial (deep, voluminous) bedrock excavations envisaged and comparatively small development footprints in the case of the solar energy facility projects in particular.

Table 5.1a: Evaluation of impacts on local fossil heritage resources of proposed the PV2 to PV5 photovoltaic solar energy facilities on farm Badenhorst Dam near De Aar (Alternative 1, preferred layout).

Project	Key impacts	No mitigation / Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
PV2	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
PV3	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
PV4	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
PV5	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.

Table 5.1b: Evaluation of impacts on local fossil heritage resources of proposed the extended PV2, PV3 and PV4 photovoltaic solar energy facilities on farm Badenhorst Dam near De Aar (Alternative 2 layout) as well as the No-go option

Project	Key impacts	No mitigation / Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
Extended PV2	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
Extended PV3	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
Extended PV4	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
No-go Option	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Zero	Long term	Neutral	Probable	Sure	n/a	n/a
		Mitigation	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 5.2: Evaluation of cumulative impacts on local fossil heritage resources of the proposed photovoltaic energy plants on farm Badenhorst Dam near De Aar

	Key impacts	No mitigation /Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
Baden-horst Dam	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Low to Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Low to Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
Local extent	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Low to Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Low to Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.
Regional extent	Disturbance, damage or destruction of fossils preserved at or below the ground surface during the construction phase	No mitigation	Site specific	Low to Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	
		Mitigation	Site specific	Low to Very low	Long term	Low (negative)	Probable	Unsure	Irreversible	Monitoring of all substantial bedrock excavations for fossil

	Key impacts	No mitigation /Mitigation	Extent	Magnitude	Duration	SIGNIFICANCE	Probability	Confidence	Reversibility	Mitigation measures
										remains by ECO Significant fossil finds to be safeguarded and reported to SAHRA for possible mitigation.

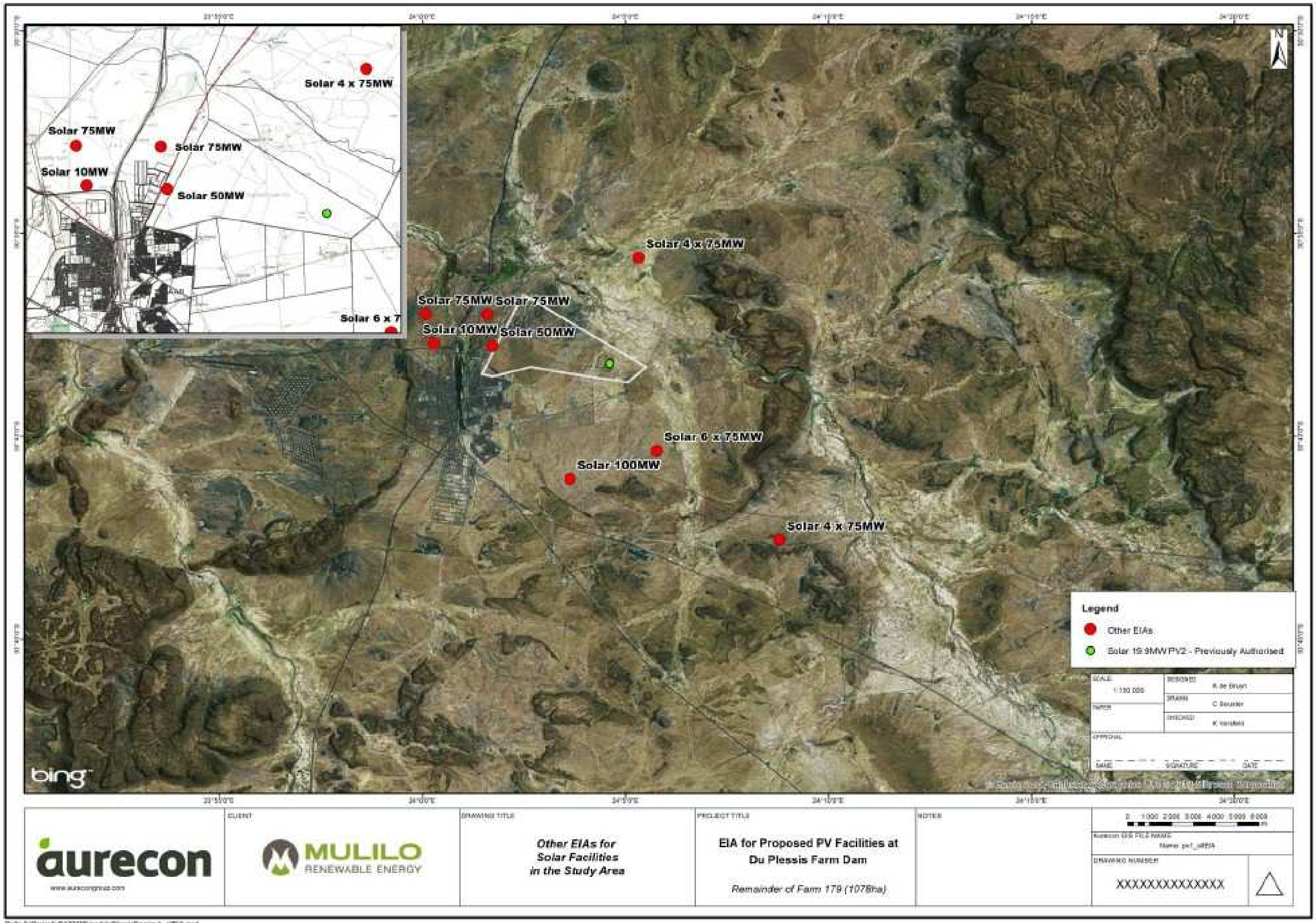

Fig. 32. Solar energy developments currently planned or proposed for the De Aar region, Northern Cape (Image abstracted by the Draft Scoping Report by Aurecon South Africa (Pty) Ltd, April 2013).

5.3. Assessment of project alternatives for Badenhorst Dam

A range of project alternatives have been considered at the EIA stage for the Badenhorst Dam PV facilities project, as summarized in the following table (See also map Fig. 4):

Table 5.3: Project alternatives for the proposed Badenhorst Dam Farm solar energy facility development

Alternative Type	**Description**
Location alternatives	**One location for the proposed Badenhorst Dam Farm (Portion 1 of Farm 180)**
Activity alternatives	• **Solar energy generation *via* a PV plant** • **"No-go" alternative to solar energy production**
Site layout alternatives	• **Four 75 MW AC PV facilities (Layout Alternative 1)** • **Three 150 MW PV facilities (Layout Alternative 2)**
Technology alternatives	• **Solar panels: Conventional PV *vs.* CPV technology** • **Mounting: Single Axis *vs.* Fixed Axis PV tracking technology**
Transmission line routing	• **One transmission line corridor**

The "no go" alternative to the proposed solar plant developments would have a neutral (zero magnitude) impact significance on fossil heritage resources (Table 5.2a).

The Layout Alternative 2, comprising three 150 MW PV facilities (Fig. 4), would also have a similar low impact significance on fossil heritage resources to that of the preferred Layout Alternative 1 (four PV sites) that is considered in more detail above. However, given the marginally higher magnitude of impacts on fossil heritage anticipated in the extended PV4 project area (low rather than very low), as discussed in Section 5.1, there is a slight preference on palaeontological grounds for the Alternative 1 layout.

There is no preference on palaeontological heritage grounds for conventional PV *versus* CPV technology. Likewise there is unlikely to be any significant difference in impact significance between single axis *versus* fixed axis tracking technology, or between the alternative transmission line routes under consideration.

6. CONCLUSIONS & RECOMMENDATIONS

The potentially fossiliferous sediments of the Ecca Group and Lower Beaufort Group (Karoo Supergroup) that underlie the Badenhorst Dam study area are almost entirely mantled in a thick layer of superficial deposits of probable Pleistocene to Recent age. In addition they are extensively intruded and baked by the Karoo Dolerite Suite (unfossiliferous igneous rocks of Early Jurassic age). The upper Ecca Group bedrocks in the De Aar area contain sparse to locally common petrified wood as well as low diversity shallow marine trace fossil assemblages typical of the Middle Permian Waterford Formation, rather than the Tierberg Formation as mapped. Ecca / Beaufort boundary beds within the southernmost portion of the study area contain abundant trace fossils as well as fossil plant compressions, including woody material, that are of palaeontological interest. No fossil vertebrate remains were recorded from the Karoo Supergroup rocks here. Based on field assessment the overall palaeontological sensitivity of the Karoo Supergroup successions in the study area is rated as low.

The diverse superficial deposits in the study region, including various soils, gravels and – at least in some areas - a well-developed calcrete hardpan, are also of low palaeontological sensitivity as a whole (Almond & Pether 2008). Calcretized rhizoliths (root casts) and possible invertebrate burrows of probable Quaternary age are recorded in the southern portion of Badenhorst Dam. Sparse, well-preserved but small fragments of reworked Permian silicified fossil wood are widely recorded widely from surface and near-surface gravels overlying Ecca bedrocks in the De Aar study area.

Potential impacts of the proposed solar facility developments on fossil heritage are confined to the development footprint and are only anticipated during the construction phase. As far as fossil heritage is concerned, their impact significance is considered to be LOW for the following reasons:

- The Karoo Supergroup bedrocks here are deeply weathered, locally calcretised and baked, and for the most part only sparsely fossiliferous;
- The development footprints for proposed PV facilities are small and largely underlain by superficial deposits of low palaeontological sensitivity;
- Significant fossil material (*e.g.* fossil wood, vertebrate remains) at or near surface level is most likely only very sparsely distributed within the study area; and
- Extensive, deep bedrock excavations are not envisaged during the construction phase.

The Layout Alternative 2, comprising three 150 MW PV facilities on Badenhorst Dam, would also have a low impact significance on local palaeontological resources. However, given the marginally higher magnitude of impacts on fossil heritage anticipated in the extended PV4 project area (low rather than very low), there is a slight preference on palaeontological grounds for the Alternative 1 layout. The “no go” alternative to the proposed solar plant developments would have a neutral (zero magnitude) impact significance on fossil heritage resources. There is no preference on palaeontological grounds for conventional PV *versus* CPV technology. Likewise there is unlikely to be any significant difference in impact significance between single axis *versus* fixed axis tracking technology.

A substantial number of other alternative energy projects – including both wind energy and solar energy facilities – have been proposed for the De Aar area (*cf* 2010b, 2011, 2012a, 2012b, 2012c). Given the generally low palaeontological sensitivity of the Karoo Supergroup bedrocks and Pleistocene to Recent superficial sediments in the De Aar region as a whole, the cumulative impact of these developments is not considered to be of high significance, however.

It is recommended that:

- The ECO responsible for the development should be aware of the possibility of important fossils (*e.g.* petrified wood, mammalian bones, teeth) being present or unearthed on site and should monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;
- In the case of any significant fossil finds (*e.g.* fossil wood, vertebrate teeth, bones, burrows, petrified wood) during construction, these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to the relevant heritage management authority (SAHRA. Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za) so that any appropriate mitigation (*i.e.* fossil recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer’s expense; and
- These recommendations should be incorporated into the EMP for the Badenhorst Dam solar energy facility project.

The palaeontologist concerned with mitigation work will need a valid fossil collection permit from SAHRA and any material collected would have to be curated in an approved depository (*e.g.* museum or university collection). All palaeontological specialist work should conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording, fossil collection and curation, final report) should adhere as far as possible to the minimum standards for Phase 2 palaeontological studies recently developed by SAHRA (2013).

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APPENDIX A: GPS LOCALITY DATA FOR SITES LISTED IN TEXT

All GPS readings were taken in the field using a hand-held Garmin GPSmap 60CSx instrument. The datum used is WGS 84.

Only those localities mentioned in the text are listed here.

Badenhorst Dam Farm 2 June 2013

Location number	South	East	Comments
244	S30 41 37.3	E24 02 09.1	Quarry exposure of Waterford Fm sediments with abundant trace fossils
245	S30 41 36.4	E24 02 07.6	Quarry exposure of interbedded Waterford & Lower Beaufort Facies with abundant trace fossils and fossil plant material
274	S30 41 39.7	E24 02 50.1	Low exposure of baked Ecca sandstones
275	S30 41 30.8	E24 02 47.0	Low exposure of baked Ecca sandstones
276	S30 41 30.9	E24 02 44.2	Extensive exposure of current ripple cross-laminated Ecca sandstones
277	S30 41 29.8	E24 02 45.7	Shallow dam excavated into soil
278	S30 41 17.5	E24 02 39.9	Sheet wash surface gravels
279	S30 40 17.1	E24 02 07.9	Bioturbated grey-green Ecca sandstone
280	S30 40 23.5	E24 02 29.3	Ecca sandstone float blocks with sparse trace fossils
281	S30 40 14.3	E24 05 05.5	Surface gravels, including fragmentary ferruginous carbonate concretions
282a	S30 41 10.5	E24 04 34.8	Ecca sandstone *krans* on N face of dolerite-capped *koppie*
282b	S30 41 14.0	E24 04 48.0	Polymict colluvial gravels of dolerite and sandstone on *koppie* slopes. Calcretised colluvial breccio-conglomerates at edge of plateau.
283	S30 41 11.1	E24 03 33.9	Sheetwash surface gravels with sparse fossil wood clasts
284	S30 41 15.7	E24 03 28.3	Ecca sandstones showing soft sediment deformation. Sheetwash surface gravels with sparse fossil wood clasts.