Palaeontological specialist assessment: combined desktop and field-based study

PROPOSED NOJOLI WIND FARM NEAR COOKHOUSE, BLUE CRANE MUNICIPALITY, EASTERN CAPE

John E. Almond PhD (Cantab.)
***Natura Viva* cc, PO Box 12410 Mill Street,**
Cape Town 8010, RSA
naturaviva@universe.co.za

April 2014

EXECUTIVE SUMMARY

ACED Cookhouse South Wind (Pty) Ltd (being renamed the Nojoli Wind Farm (RF) (Pty) Ltd) is planning to establish a wind energy facility with 44 wind turbines, known as the Nojoli Wind Farm, on a site located 8 to 16 km east and southeast of the small town of Cookhouse, Blue Crane Municipality, Eastern Cape.

The Nojoli Wind Farm project area is almost entirely underlain by potentially fossiliferous fluvial sediments of the Karoo Supergroup of Late Permian age but bedrock exposure levels here are very limited. The Lower Beaufort Group sediments (Middleton and Balfour Formations) underlying the study area contain important fossils of terrestrial animals such as reptiles and therapsids ("mammal-like reptiles") as well as representatives of the Late Permian *Glossopteris* Flora of Gondwana. However, the present two-day field palaeontological field assessment, as well as a number of recent field studies carried out in the Cookhouse – Middleton – Bedford area, suggest that Late Permian vertebrate remains tend to be very sparse in this part of the Eastern Cape, even where bedrock exposure is good. Apart from an isolated, unidentified fragment of fossil bone and occasional low-diversity trace fossil assemblages, the only Permian fossils recorded from the Nojoli Wind Farm study area comprise locally abundant fragments of petrified logs up to 50 cm across. The well-preserved fossil wood probably originates from channel sandstones within the Lower Beaufort Group (*e.g.* the Oudeberg Member of the Balfour Formation) but has not yet been recorded *in situ*. Instead, the resistant wood material been reworked into ancient, partially calcretised alluvial deposits as well as modern stream gravels and colluvial (hillslope) gravels in the larger stream valleys (*e.g.* on Bavians Krantz 151, Klipfonteyn 150). Associated Early and Middle Stone Age artefacts as well as a large fossil horse tooth (perhaps *Equus capensis*) recorded on Klipfonteyn 150 suggest a probable Pleistocene age for the older alluvial deposits here.

The great majority of infrastructure developments (*e.g.* wind turbines, access roads) for the proposed Nojoli Wind Farm are located in elevated plateau or hilly areas where exposure of Beaufort Group bedrocks is poor, due to soil and vegetation cover, and no fossil remains were recorded in these areas during the field assessment. Significant impacts on thick, fossiliferous Pleistocene alluvium in major stream valleys (palaeontologically sensitive green areas on Klipfonteyn 150 outlined in Fig. 53 herein) are not anticipated. The inferred impact significance of the proposed Nojoli Wind Farm project as far as palaeontological heritage is concerned is LOW (negative). Confidence levels for this assessment are moderate, given the limited bedrock exposure within most of the study area.

Unless significant new fossil finds are made during the construction phase of the development, or substantial excavations are made into the potentially sensitive older alluvial deposits indicated in Fig. 53, further specialist palaeontological studies or mitigation of the project are not regarded as warranted here. The cumulative impact on fossil heritage of the Nojoli Wind Farm in conjunction with several other wind energy projects in the Cookhouse - Middleton - Bedford region of the Eastern Cape is probably low.

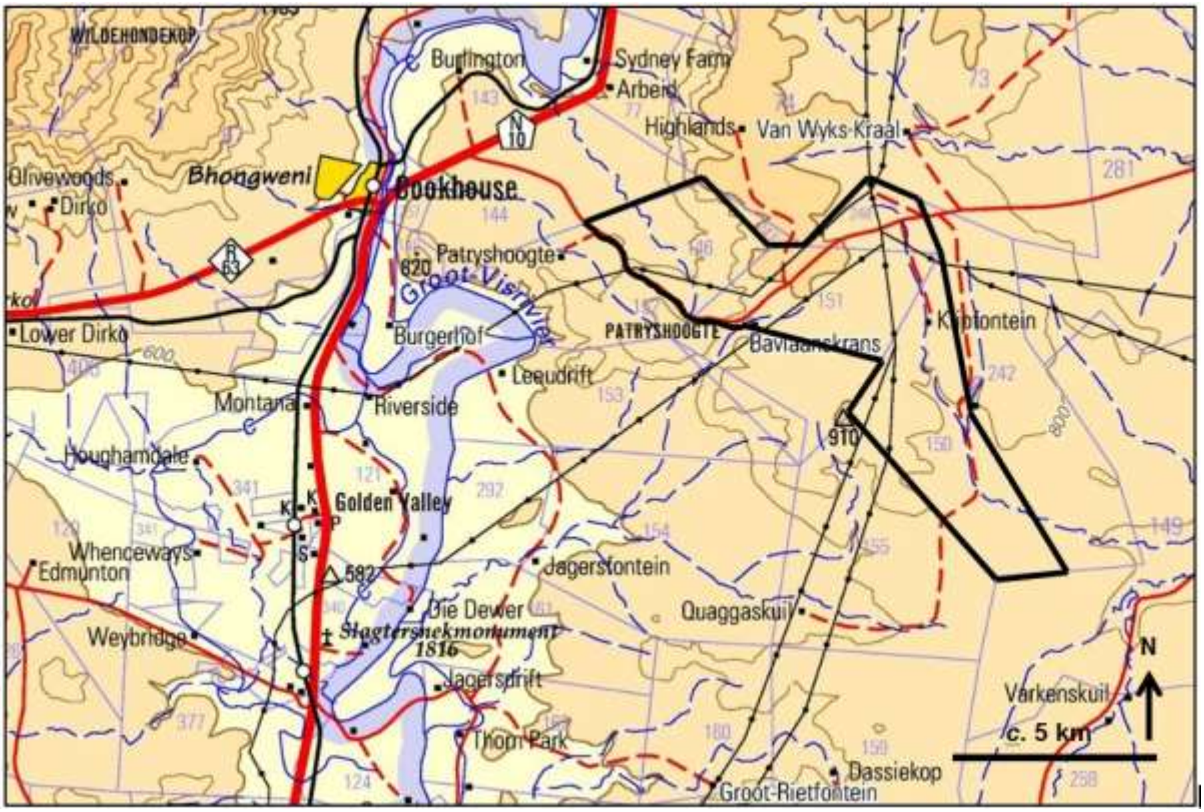
The ECO for the project should be alerted to the potential for, and scientific significance of, new fossil finds during the construction phase of the development. Should either (1) substantial excavations be planned into the older alluvial deposits indicated in Fig. 53, or (2) important new fossil remains such as vertebrate bones and teeth, plant-rich fossil lenses or dense fossil burrow assemblages be exposed during construction, the responsible Environmental Control Officer should alert ECPHRA (*i.e.* The Eastern Cape Provincial Heritage Resources Authority. Contact details: Mr Sello Mokhanya, 74 Alexander Road, King Williams Town 5600; smokhanya@ecphra.org.za) as soon as possible so that appropriate action can be taken in good time by a professional palaeontologist at the owner's expense. Palaeontological mitigation would normally involve the scientific recording and judicious sampling or collection of fossil material as well as of associated geological data (*e.g.* stratigraphy, sedimentology, taphonomy). The palaeontologist concerned with mitigation work will need a valid fossil collection permit from SAHRA (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za) 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).

These recommendations should be incorporated into the EMP for the Nojoli Wind Farm project.

1. INTRODUCTION AND BRIEF

The company ACED Cookhouse South Wind (Pty) (being renamed the Nojoli Wind Farm (RF) (Pty) Ltd) Ltd is planning to establish a wind energy facility, known as the Nojoli Wind Farm, on a site located some 8 to 16 km east and southeast of the small town of Cookhouse, Blue Crane Municipality, Eastern Cape (Figs. 1 & 2). The site extends to the south of the Poseidon Substation and borders the Cookhouse Wind Farm (Cookhouse 1) recently developed by African Clean Energy Developments as a REIPPPP Round 1 Project. Land parcels involved with the Nojoli Wind Farm include the following farms and farm portions:

- Farm Klipfontein 150/ Portion 2;
- Farm Bavians Krantz 151 and 151/ Portion 2;
- Farm 148 and 148[1]/ Portion 1; and
- Farm Rooi Draai 146



[1] previously known as Farm 248

Fig. 1. Extract from 1: 250 000 topographical map 3224 Graaff-Reinet (Courtesy of the Chief Directorate: Surveys & Mapping, Mowbray) showing the outline of the Nojoli Wind Farm study area to the east of Cookhouse (black polygon).

The main infrastructural components of the proposed Nojoli Wind Farm include:

- 44 wind turbines;
- Foundations to support the turbine towers and hard standing areas next to each turbine;
- Underground medium voltage cables at about 1 m depth connecting the wind turbines and the electricity substation, except where a technical assessment of the proposed design suggests that overhead lines are more appropriate, such as over rivers and gullies. Where overhead power lines are to be constructed, tower structures will be used;
- An electricity substation (maximum footprint of 200 x 250 m /50000 m²) within the development site, which is then connected to the national grid *via* an overhead cable on towers;
- Internal access gravel roads up to 5 m wide connecting the site with the main road;
- An internal road network to the turbines and other infrastructure, including turning circles for large trucks, passing points and culverts over gullies and rivers if required, and existing roads that will be upgraded;
- A temporary construction and laydown area;
- A warehouse and administration building (O&M building) within the substation area of 220 x 250 m.

The Nojoli Wind Farm project area is underlain by potentially fossiliferous sediments of the Karoo Supergroup of Permian age as well as much younger (Pleistocene – Holocene) superficial deposits that may also contain scientifically important fossil remains. Fossil heritage preserved within these rocks is protected by law (National Heritage Resources Act of 1999). A brief desktop palaeontological study covering the Nojoli Wind Farm as well adjacent wind farm project areas to the east of Cookhouse was completed by Almond (2009). The review comment in response to this report by SAHRA (South African Heritage Resources Agency; File No. 9/2/034/0002, dated 20 February 2012) was as follows:

> A palaeontological impact assessment inclusive of a site visit must be undertaken before any construction activities for any of the two wind energy facilities start. The report must be submitted to SAHRA for comments. Monitoring may be necessary for excavations in the Balfour Formation, however a site visit before any construction activities start will confirm this.

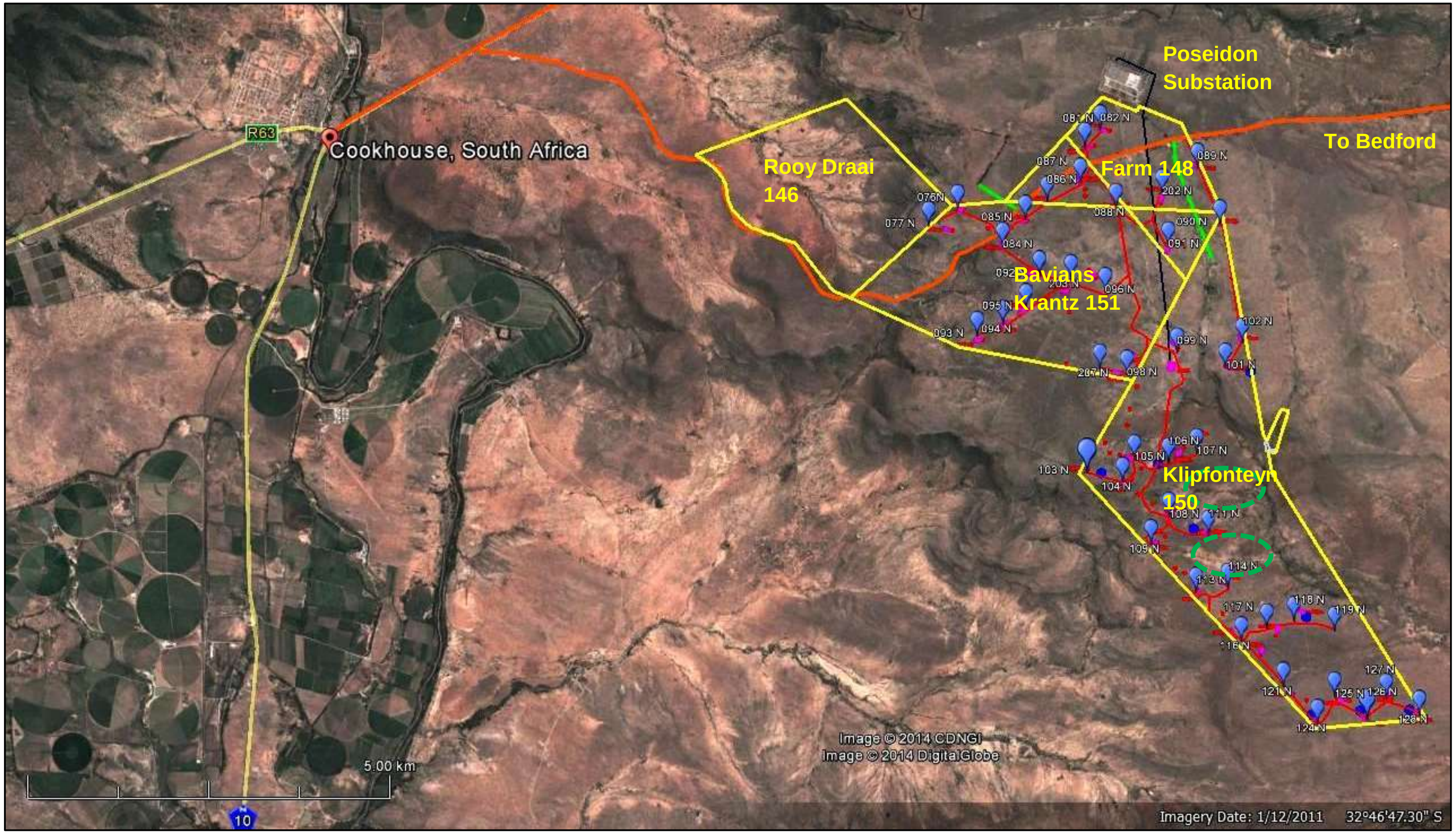


Fig. 2. Google earth© satellite image of the Nojoli Wind Farm study area situated in hilly terrain of the Patryshoogte area to the east of Cookhouse, Eastern Cape (yellow polygon). Proposed wind turbine sites are indicated by blue symbols and internal access roads by red lines. The orange line is an existing public road between Cookhouse and Bedford.

The present combined desktop and field-based assessment of the Nojoli Wind Farm study area has accordingly been commissioned as part of the broad-based Heritage and Environmental Impact Assessment that is being co-ordinated by Savannah Environmental (Pty) Ltd, Woodmead (Contact details: Ms Lusani Rathanya. Savannah Environmental (Pty) Ltd. 1st Floor, Block 2, 5 Woodlands Drive Office Park, Woodlands Drive, Woodmead, 2191. Tel: +27 11 656 3237. Fax: +27 86 684 0547. Cell: +27 72 079 7715. Postal address: P.O. Box 148, Sunninghill, 2157).

1.2. Legislative context for palaeontological assessment studies

The Nojoli Wind Farm near Cookhouse is located in an area that is underlain by potentially fossil-rich sedimentary rocks of Late Palaeozoic and younger, Late Tertiary or Quaternary, age (Section 3). The construction phase of the proposed development will entail substantial excavations into the superficial sediment cover and locally into the underlying bedrock as well. These notably include excavations for turbine foundations, new internal access roads, underground cables, the new substation and associated building infrastructure. In addition, substantial areas of bedrock may be sealed-in or sterilized by infrastructure such as hard standing areas for each wind turbine, any lay down areas, as well as the new gravel road system. All these developments may adversely affect potential fossil heritage within the study area by destroying, disturbing or permanently sealing-in fossils at or beneath the surface of the ground that are then no longer available for scientific research or other public good. The decommissioning phase of the wind farm development is unlikely to involve further adverse impacts on local palaeontological heritage, however.

The present combined desktop and field-based palaeontological heritage report falls under Sections 35 and 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999), and it will also inform the Environmental Management Plan for this project.

The various categories of heritage resources recognised as part of the National Estate in Section 3 of the National Heritage Resources Act include, among others:

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

According to Section 35 of the National Heritage Resources Act, dealing with archaeology, palaeontology and meteorites:

(1) The protection of archaeological and palaeontological sites and material and meteorites is the responsibility of a provincial heritage resources authority.

(2) All archaeological objects, palaeontological material and meteorites are the property of the State.

(3) Any person who discovers archaeological or palaeontological objects or material or a meteorite in the course of development or agricultural activity must immediately report the find to the responsible heritage resources authority, or to the nearest local authority offices or museum, which must immediately notify such heritage resources authority.

(4) No person may, without a permit issued by the responsible heritage resources authority—

(a) destroy, damage, excavate, alter, deface or otherwise disturb any archaeological or palaeontological site or any meteorite;

(b) destroy, damage, excavate, remove from its original position, collect or own any archaeological or palaeontological material or object or any meteorite;

(c) trade in, sell for private gain, export or attempt to export from the Republic any category of archaeological or palaeontological material or object, or any meteorite; or

(d) bring onto or use at an archaeological or palaeontological site any excavation equipment or any equipment which assist in the detection or recovery of metals or archaeological and palaeontological material or objects, or use such equipment for the recovery of meteorites.

(5) When the responsible heritage resources authority has reasonable cause to believe that any activity or development which will destroy, damage or alter any archaeological or palaeontological site is under way, and where no application for a permit has been submitted and no heritage resources management procedure in terms of section 38 has been followed, it may—

(a) serve on the owner or occupier of the site or on the person undertaking such development an order for the development to cease immediately for such period as is specified in the order;

(b) carry out an investigation for the purpose of obtaining information on whether or not an archaeological or palaeontological site exists and whether mitigation is necessary;

(c) if mitigation is deemed by the heritage resources authority to be necessary, assist the person on whom the order has been served under paragraph *(a)* to apply for a permit as required in subsection (4); and

(d) recover the costs of such investigation from the owner or occupier of the land on which it is believed an archaeological or palaeontological site is located or from the

person proposing to undertake the development if no application for a permit is received within two weeks of the order being served.

Minimum standards for the palaeontological component of heritage impact assessment reports (PIAs) have recently been published by SAHRA (2013).

1.3. Approach to the palaeontological heritage study

The approach to this palaeontological heritage study is briefly as follows. Fossil bearing rock units occurring within the broader study area are determined from geological maps and satellite images. Known fossil heritage in each rock unit is inventoried from scientific literature, previous assessments of the broader study region, and the author's field experience and palaeontological database. Based on this data as well as field examination of representative exposures of all major sedimentary rock units present, the impact significance of the proposed development is assessed with recommendations for any further studies or mitigation.

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 field assessment during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development (provisional tabulations of palaeontological sensitivity of all formations in the Western, Eastern and Northern Cape have already been compiled by J. Almond and colleagues; *e.g.* Almond *et al.* 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 significantly the extent of fresh bedrock excavation envisaged. When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a Phase 1 field assessment study by a professional palaeontologist is usually warranted to identify any palaeontological hotspots and make specific recommendations for any mitigation required before or during the construction phase of the development.

On the basis of the desktop and Phase 1 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. Phase 2 mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) may be required (a) in the pre-construction phase where important fossils are already exposed at or near the land surface and / or (b) during the construction phase when fresh fossiliferous bedrock has been exposed by excavations. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority, *i.e.* ECPHRA (The Eastern Cape Provincial Heritage Resources Authority. Contact details: Mr Sello Mokhanya, 74 Alexander Road, King Williams Town 5600; smokhanya@ecphra.org.za). 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.

1.4. Assumptions & limitations

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

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

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

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

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

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

In the case of palaeontological desktop studies without supporting 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 the RSA have not been studied palaeontologically, a palaeontological desktop study usually entails *inferring* the presence of buried fossil heritage within the study area from relevant fossil data collected from similar or the same rock units elsewhere, sometimes at localities far away. Where substantial exposures of bedrocks or potentially fossiliferous superficial sediments are present in the study area, the reliability of a palaeontological impact assessment may be significantly enhanced through field assessment by a professional palaeontologist. In the present case, site visits to the various loop and borrow pit study areas in some cases considerably modified our understanding of the rock units (and hence potential fossil heritage) represented there.

In the case of the present study area in the Cookhouse region of the Eastern Cape exposure of potentially fossiliferous bedrocks is mainly limited to river banks, erosion gullies and steep hill slopes, as well as artificial excavations such as road cuttings and borrow pits, due to extensive cover by superficial sediments and vegetation. Comparatively few academic palaeontological studies have been carried out in the region so any new data from impact studies here are of scientific interest.

1.5. Information sources

The information used in this desktop study was based on the following:

1. A brief project outline kindly supplied by Savannah Environmental (Pty) Ltd;

2. A short desktop palaeontological assessment report for a broader study area to the east of Cookhouse by the author (Almond 2009);

3. A review of the relevant scientific literature, including published geological maps and accompanying sheet explanations (*e.g.* Hill 1993) as well as several previous fossil heritage assessments in the Cookhouse – Middleton – Bedford area (*e.g.* Almond 2009, De Klerk 2010, Almond 2011, Durand 2012, Almond 2013a, 2013b, 2013c);

4. The author's previous field experience with the formations concerned and their palaeontological heritage (*cf* Almond *et al.* 2008);

5. A short two-day field assessment of the study area during the period 23-25 April, 2014. Fieldwork mainly focussed on the limited number of natural or artificial exposures of potentially fossiliferous Beaufort Group bedrocks within the study area as well as on thick deposits of Pleistocene alluvium in stream valleys. Few of the informative rock exposures were situated in the upland plateau and hilltop sites where the wind turbines will be situated since the bedrocks here are usually mantled by soil and vegetation.

2. GEOLOGICAL OUTLINE OF THE STUDY AREA

The Nojoli Wind Farm study area is situated to the east of the Great Fish River near Cookhouse, Eastern Cape (Figs. 1-2). Most of the proposed infrastructure will be developed in rolling hilly terrain above a low, west to south-facing escarpment that is dissected by small intermittent-flowing streams (Figs. 5 to 8). The grassy uplands here, known as the Patryshoogte, lie at elevations of *c*. 800 – 900 m amsl while the low-lying areas in the west and southeast lie at *c*. 670-770 m and *c*. 700-800 m amsl respectively. The study area lies in the south-eastern portion of the Main Karoo Basin, underlain by bedrocks of the Lower Beaufort Group (Karoo Supergroup) (Figs. 3 & 4). However, exposure of the sedimentary bedrocks in this region is generally very poor, and mainly restricted to stream beds, erosion gullies and occasional patches on hill slopes, together with a few road cuttings, dams and quarries. Elsewhere the bedrocks are generally mantled with thick superficial deposits (soils, colluvium, alluvium) and grassy vegetation on the higher-lying plateau (Bedford Dry Grassland), with more woody Fish River Thicket vegetation on the escarpment slopes, especially along stream valleys. A thin, impersistent veneer of downwasted or colluvial, angular sandstone gravels cover large areas of Lower Beaufort Group outcrop area, including many of the hillcrest areas where vegetation is sparse (Fig. 36) and many of the wind turbines will be sited.

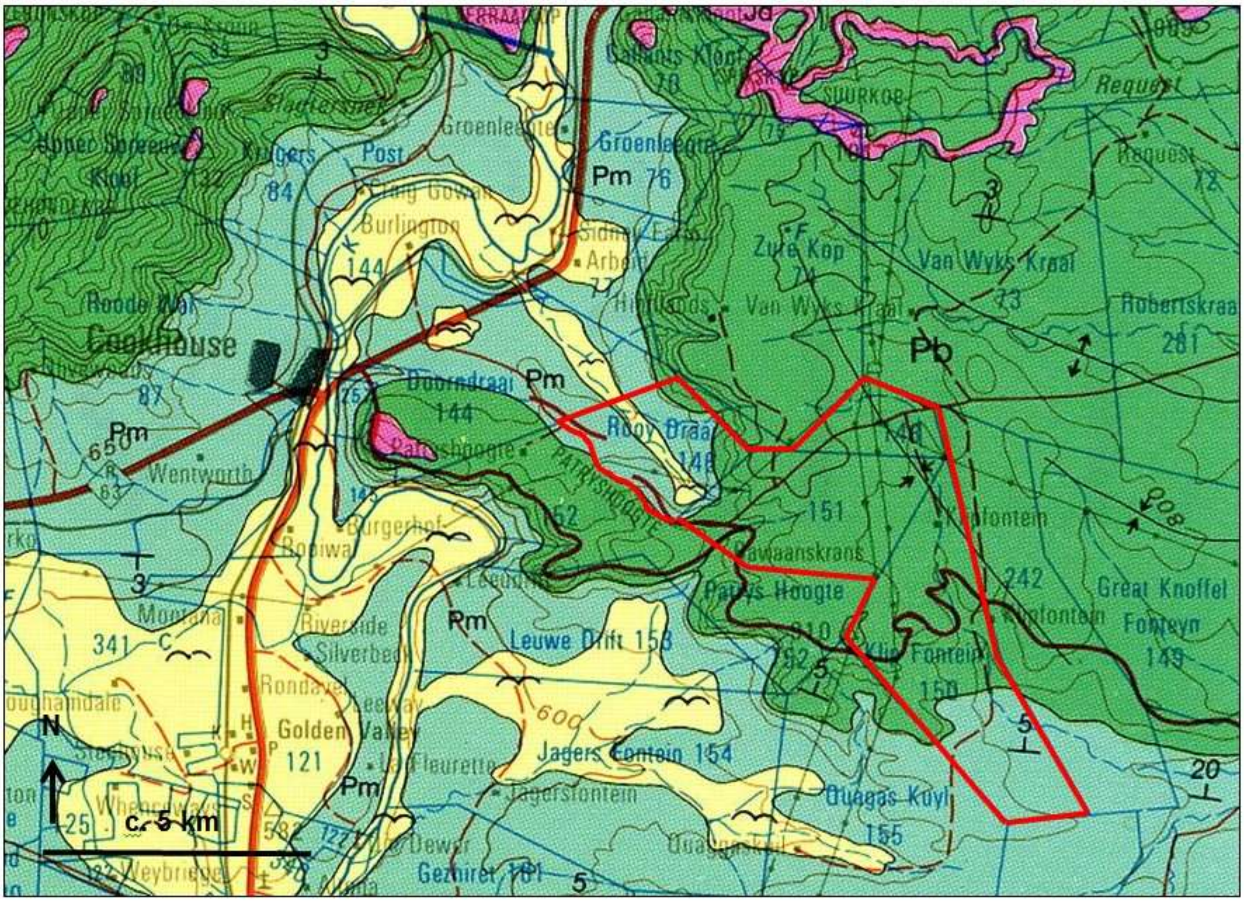


Fig. 3. Extract from the 1: 250 000 scale geological map 3224 Graaff-Reinet (Council for Geoscience, Pretoria) showing the location of the Nojoli Wind Farm study area *c*. 8 to 16 km south and southeast of Cookhouse, Eastern Cape (red polygon). The main rock units represented within the wind energy project area include:

LOWER BEAUFORT GROUP (ADELAIDE SUBGROUP)
Middleton Formation (Pm, blue-green)
Balfour Formation (Pb, dark green)

KAROO DOLERITE SUITE (Jd, pink)

LATE CAENOZOIC SUPERFICIAL DEPOSITS
Alluvium (pale yellow with "flying bird" symbol)

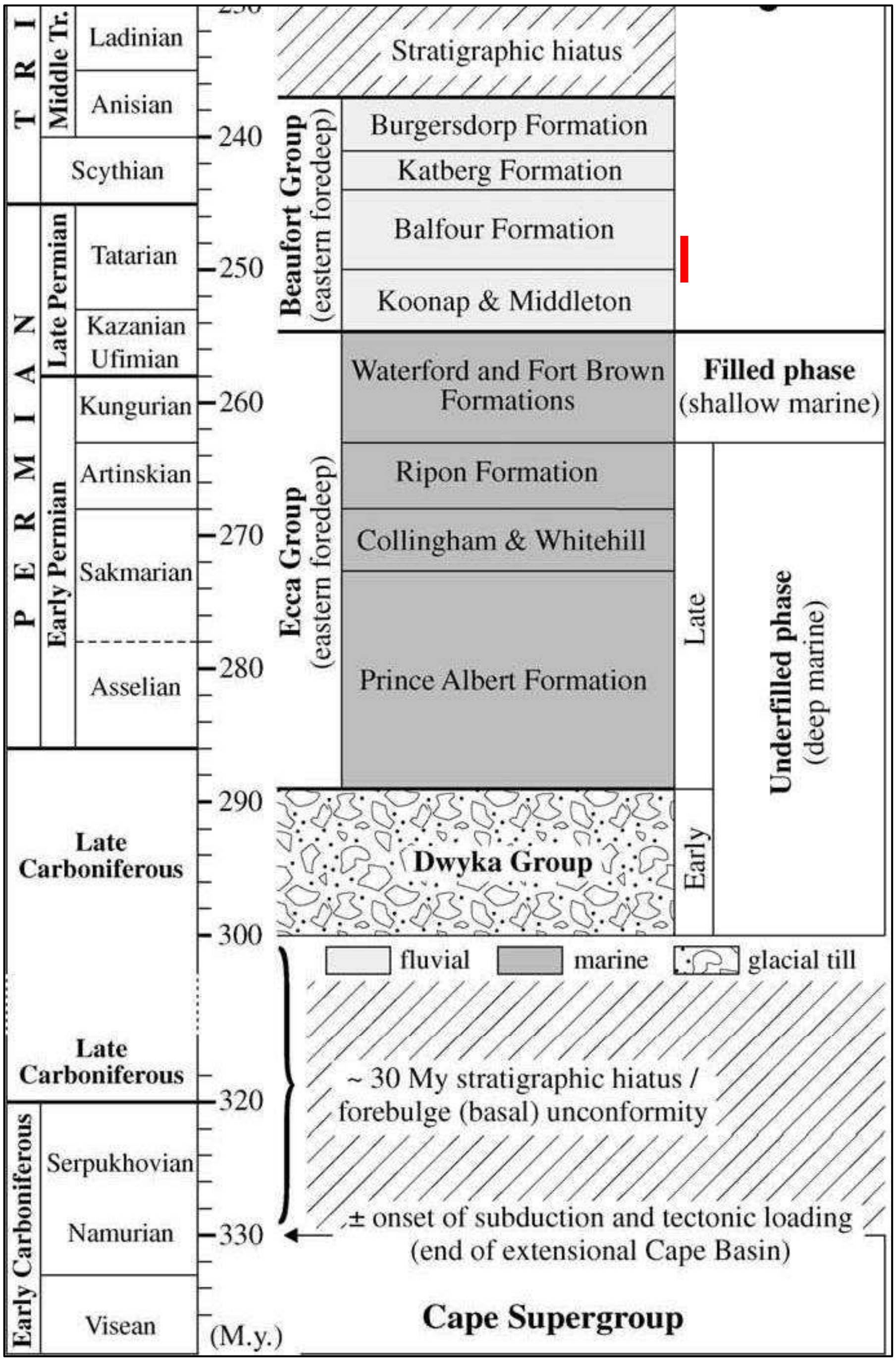


Fig. 4. Stratigraphic subdivision of the Carboniferous and Permian portions of the Karoo Supergroup in the Main Karoo Basin (From Catuneanu *et al.* 2005). The Late Permian Middleton and Balfour Formations within the Lower Beaufort Group (Adelaide Subgroup) that are represented within the Nojoli Wind Farm project area are emphasized by the thick red bar.

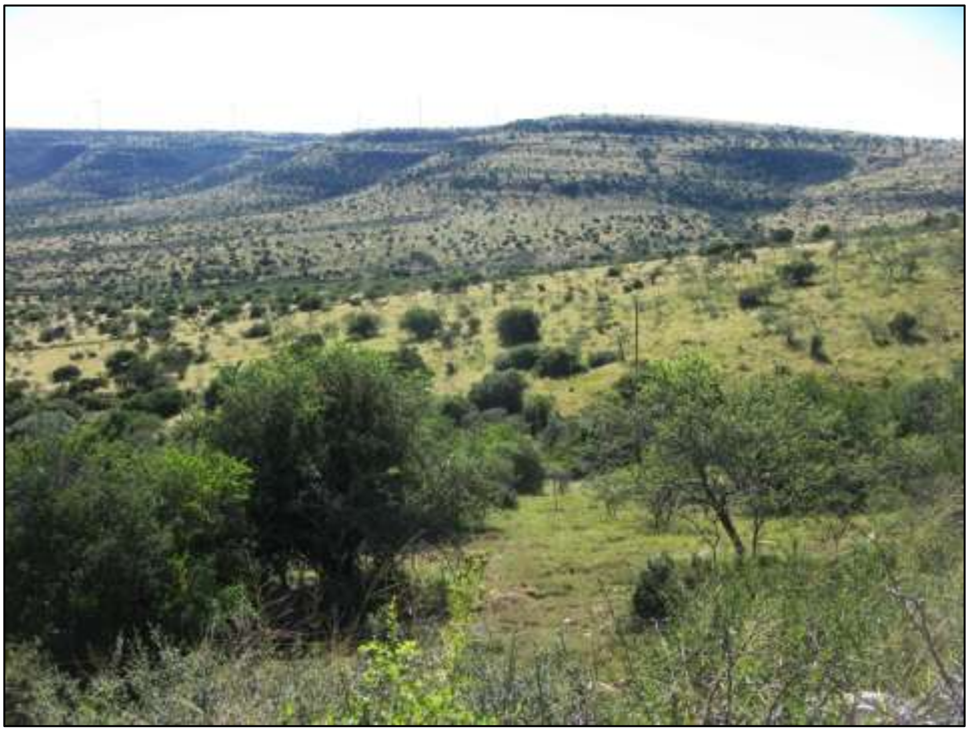


Fig. 5. View north-westwards towards the low, west-facing escarpment on Rooy Draai 146 (note wind turbines on the skyline). The escarpment is built of the sandstone-rich Oudeberg Member at the base of the Balfour Formation while the Middleto Formation underlies the valley floor.

Fig. 6. Close-up of the Oudeberg Member escarpment on Bavians Krantz 151 showing limited stream bank exposure of overbank mudrocks of the underlying Middleton Formation in the foreground (Loc. 249).

Fig. 7. View southwards across Farm 148 showing the general lack of exposure of Lower Beaufort Group bedrocks in the Patryshoogte plateau area.

Fig. 8. View south-westwards across the south-eastern portion of Klipfonteyn 150 showing lack of bedrock exposure (here the Middleton Formation) in the lower-lying areas due to soil and alluvial cover as well as grassy vegetation.

As shown on the relevant 1: 250 000 geological map, Sheet 3224 Graaff-Reinet published by the Council for Geoscience (Fig. 3), the study area is largely underlain by Late Permian continental sediments of the **Lower Beaufort Group** (Adelaide Subgroup, Karoo Supergroup). In particular the Karoo sediments belong to the **Middleton Formation** (**Pm**) and the overlying **Balfour Formation** (**Pb**) (Hill 1993, Cole *et al*. 2004, Johnson *et al*., 2006) (Fig. 4). Structural dips of the Beaufort Group sediments in the study region are generally shallow (3 to 5°), with small-scale ENE-WSW fold axes mapped to the south and east of Cookhouse, so low levels of tectonic deformation and cleavage development are expected. However, steeply-dipping Beaufort Group beds are encountered in several stream and donga exposures, perhaps related to local dolerite intrusion and / or faulting (Figs. 10 & 16). Fault zones are suggested by concentrations of quartz veins, brecciation and oblique surfaces showing well-developed quartz mineral lineation (*e.g.* Klipfonteyn 150, Loc. 235).

Lower Beaufort Group sedimentation patterns in the Cookhouse region may reflect wetter, more humid conditions on the floodplain compared to those obtaining in the western portion of the Main Karoo Basin (Almond 2013c). This is suggested by the comparative paucity of well-developed palaeosols marked by calcrete nodules (*cf* Catuneanu & Bowker 2001) as well as the rarity of prominent mudcracked horizons, of basal channel breccio-conglomerates with reworked mudflakes and calcrete glaebules, and of gypsum pseudomorphs. Local soft sediment deformation of channel sandstones (*e.g.* loading, ball-and-pillow formation) and pyrite pseudomorphs within calcrete nodules and sandstones suggest swampy conditions and high water tables. This is supported by abundant evidence for ponds and playa lakes on the floodplain (small scale wave-ripples, algal matted surfaces, invertebrate trace fossils and other evidence for emergence discussed above). Plant life, as usual in the Lower Beaufort Group, is poorly represented, and then mainly by water-loving reedy plants such as the sphenophyte ferns (horsetails) and petrified woods. Intermittent anoxia and reducing conditions within near-surface sediments (reflected by pyrite formation) may nevertheless have favoured the preservation of plant remains over bones and teeth (*cf* Tordiffe *et al.* 1985, Oghenekome 2012). The rarity of terrestrial vertebrate remains may also be a reflection of more challenging palaeoenvironmental conditions in this region as well as the lack of profound drought events to concentrate skeletal remains at the land surface (*cf* Smith 1993b). Note that, due to the oblique NW-SE orientation of the Main Karoo Basin in Late Permian times, the Lower Beaufort beds in the Eastern Cape were deposited at higher, cooler palaeolatitudes to those of the Western and Northern Cape.

To the north and south of the Nojoli study area the Lower Beaufort Group is extensively intruded by major intrusive sills of the **Karoo Dolerite Suite** (**Jd**) of Early Jurassic age (*c*. 183 Ma) (Fig. 3). Dolerite intrusions are not mapped within the Nojoli study area itself but they are clearly present subsurface and are exposed in at least one road cutting (Fig. 25).

3.1. Middleton Formation

This formation forms the middle portion of the Adelaide Subgroup east of 24°E, including the Graaff-Reinet sheet area (Hill 1993, Johnson *et al*., 2006). The fluvial Middleton succession comprises greenish-grey to reddish overbank mudrocks with subordinate resistant-weathering, fine-grained channel sandstones deposited by large meandering river systems. Because of the dominance of recessive-weathering mudrocks, the Middleton Formation erodes readily to form low-lying *vlaktes* at the base of the Escarpment near Cookhouse and extensive exposures of fresh (unweathered) bedrock are rare.

The sedimentology of the meandering fluvial Middleton Formation succession has been outlined by Hill (1993) as well as Catuneanu and Bowker (2001) and is described for the Cookhouse - Middleton area by Almond (2010b, 2013b, 2013c). The Lower Beaufort succession here is dominated by blue-grey to greenish-grey, hackly-weathering mudrocks. These are mainly silty but also muddy, variously massive (unbedded) to well-bedded, often showing clearly developed fining-upwards and thinning-upward cycles within the succession. Olive-grey, maroon to purple-brown and mottled maroon / grey mudrocks occur less frequently but are not uncommon. Arid climate palaeosol horizons characterised by abundant rusty to cream-coloured calcrete are variously rare to fairly common within different parts of the overbank mudrock succession and are an important focus for palaeontological fieldwork since vertebrate fossils are often concentrated at these levels. Rare stellate pseudomorphs after gypsum ("desert roses") also point towards at least seasonally arid Late Permian palaeoclimates in the eastern Main Karoo Basin during some Late Permian time intervals.

Middleton Formation sandstones include thin crevasse-splay bodies with a tabular geometry as well as thicker, tabular to lenticular channel sandstones, variously single- to multi-storey, massive or with internal cross-bedding. The channel sandstones are generally fine- to medium-grained, buff coloured, with conformable to erosive bases. However, well-developed basal channel breccio-conglomerates with reworked mudflakes and calcrete nodules are not generally seen. Contacts between finer-grained sandstones and overbank mudrocks are often obscure (especially where the rocks are baked) and may be loaded, suggesting soupy, waterlogged floodplain conditions (Fig. 11). Large megaripples, undulose channel bar surfaces and prograding point bar sands are seen locally. These surfaces are often associated with features such as small-scale wave ripples, algal mat textured surfaces, adhesion warts, narrow horizontal burrows (possibly mat-grazers), fine mudcracks, possible thin sandstone dykes, and even rare tetrapod tracks. Similar spectra of sedimentary structures have been described by Stear (1978) and Smith (1993a) in association with emergent sandy palaeosurfaces in channels and around playa lakes or ponds on the Lower Beaufort floodplains of the western Great Karoo.

According to the 1: 250 000 geological map (Fig. 3) the Middleton Formation underlies the lower-lying, low relief areas of the Nojoli Wind Farm study area in the south-eastern portion of Klipfonteyn 150 as well as much of Rooy Draai 146. Wind turbine positions are proposed for the former but not the latter area. The great majority of the Middleton Formation outcrop area is mantled with thick silty alluvium, soils and downwasted gravels, mainly of sandstone with occasional petrified wood fragments. Extensive bedrock exposures are very rare (Fig. 8).

Good stream bank and hill slope exposures of uppermost Middleton Formation mudrocks (massive, grey-green to thinly-bedded) and thin interbedded lenticular sandstones were examined on Bavians Krantz 151 and Rooy Draai 146 at Locs. 249 – 253 (Figs. 6, 9 to 12). Crumbly, thin-bedded, grey-green siltstones with sparse small, pale grey-weathering calcrete nodules and occasional interbedded thin, lenticular channel sandstones are seen at Loc. 249. Cubical pyrite pseudomorphs are present in some sandstone float blocks. In streambed exposures at Loc. 253 the Beaufort Group beds vary from steeply-dipping to gently inclined. Some of the fine-grained sandstone interbeds show loading features suggesting rapid sand deposition over water-logged muddy sediment.

Fig. 9. Hillslope exposure of interbedded sandstones and mudrocks of the upper Middleton Formation on Rooy Draai 146 (Loc. 252)(Hammer = 30 cm).

Fig. 10. Steeply-dipping interbedded sandstones and mudrocks of the Middleton Formation exposed in a stream gulley on Bavians Krantz 151 (Loc. 253).

Fig. 11. Brown-weathering, fine-grained sandstones of the Middleton Formation showing loading into the underlying dark grey mudrocks, Bavians Krantz 151 (Loc. 253) (Hammer = 30 cm).

Fig. 12. Thin-bedded to laminated, dark grey overbank mudrocks with isolated small sandstone lenticle, Middleton Formation, Bavians Krantz 151 (Loc. 249) (Hammer = 30 cm).

3.2. Balfour Formation

The fluvial Balfour Formation comprises recessive weathering, grey to greenish-grey overbank mudrocks with subordinate resistant-weathering, grey, fine-grained channel sandstones deposited by large meandering river systems in the Late Permian to Earliest Triassic Period (Hill 1993). The formation reaches a maximum thickness of over 2000 m in the Fort Beaufort area but is only 650 m near Graaff-Reinet (Johnson 1976, Visser & Dukas 1979). Thin wave-rippled sandstones were laid down in transient playa lakes on the flood plain. Reddish mudrocks are comparatively rare, but increase in abundance towards the top of the Adelaide Subgroup succession near the upper contact with the Katberg Formation. The base of the Balfour succession is defined by a sandstone-rich zone, some 50-100 m thick, known as the **Oudeberg Member**. The Oudeberg sandstones and interbedded mudrocks crop out along the edge of the low escarpment to the east of Cookhouse and underlie the greater part of the Nojoli study area. It is likely that at least the lowermost portion of the overlying mudrock-dominated **Daggaboersnek Member** underlies some of the interior portions of the study area, away from the escarpment edge, but this is difficult to confirm given the low levels of bedrock exposure here (The smooth-topped *koppie* at 859 m amsl some 2 km south of Klipfontein homestead may be capped by Daggaboersnek Member mudrocks but no surface exposures were seen here). Dark grey mudrocks with thin, tabular sandstones and wave ripples (formed in shallow lakes) within this member are well-exposed at higher elevations in Daggaboersnek itself along the main road between Cookhouse and Cradock (Hill 1993).

Key recent reviews of the Balfour Formation fluvial succession have been given by Visser and Dukas (1979), Catuneanu and Elango (2001), Katemaunzanga (2009) and Oghenekome (2012). Catuneanu and Elango (2001) identified six upward-fining depositional sequences within the Balfour succession that are separated by subaerial unconformities and lasted on average about 0.7 Ma (million years). The sequences were generated by tectonic processes within the Cape Fold Belt. Fluvial deposition by sandy braided rivers in the early part of each sequence was followed by more mixed channel sandstones and overbank mudrocks laid down by meandering rivers higher in the sequence. Sedimentological data, such as the rarity of palaeosols (fossil soils, desiccation cracks, red beds), suggest that palaeoclimates during this period were predominantly temperate to humid and water tables were generally high.

The stratigraphy and sedimentology of the five stratigraphic members recognised within the Balfour Formation in the Eastern Cape are discussed by Oghenekome (2012) and mapped for the Bedford – Adelaide area just north-east of the Nojoli Wind Farm. This mapping supports the assignation of the bedrocks within the Nojoli study area to the Oudeberg Member, a thick sandstone-dominated package at the base of the Balfour Formation succession. This is Sequence 'A' of Catuneanu and Elango (2001), described as *c*. 400 m thick and composed of braided fluvial sandstones towards the base passing up to sand-bed and fine-grained meandering river deposits towards the top.

The large Afrimat Cookhouse hardrock quarry located *c*. 800 m south of Klipfontein homestead (Loc. 239) is excavated into stacked channel sandstones of the Oudeberg Member (The quarry itself not accessible for safety reasons). Sand, gravel and aggregate is manufactured from Beaufort Group sandstones and wackes here. The steep quarry cut faces expose a thick package of greyish amalgamated channel sandstones with local, gently-dipping erosional bases marked by intraformational channel breccias (Fig. 13). Examples of tabular or trough cross-bedding are developed locally.

At Loc. 229 on Klipfonteyn 150 tough, pale grey, feldspathic, medium-bedded, well-jointed sandstones appear to have been baked by an underlying dolerite intrusion, as suggested by secondary mineralised nodules within the beds. Small scale wave ripples on sandstone bed tops were probably generated in shallow ponds within the channel. Extensive bedding plane exposures of well-jointed (baked, mottled, silicified) Balfour sandstones, locally cross-bedded and ripple cross-laminated or flaggy-bedded with primary current lineation, are seen in a stream bed adjacent to the Bavaianskrans homestead (Loc. 242) (Fig. 14). Pervasive mottling of sandstone facies at several localities is suggestive of thermal metamorphism (Fig. 15).

Intervals of dark-grey, hackly-weathering, massive to well-bedded overbank mudrocks and thin, buff crevasse-splay sandstones of the lower Balfour Formation are locally exposed along shallow streams, at the base of erosional dongas, and on poorly-vegetated hill slopes (*e.g.* extensive exposures at Locs. 230, 233 on Klipfonteyn 150) (Figs. 18 to 23). Horizons of small, pale to dark grey calcrete nodules representing palaeosols are fairly common.

Balfour Formation mudrock facies are also well seen in several artificial excavations within the study area, such as the roadside quarry on Farm 148, *c*. 800 m southeast of the Poseidon Substation (Loc. 227), the small quarry 330 m NNE of Klipfontein homestead (Loc. 228) (Fig. 17), and a small roadside quarry along the Patryshoogte road (Farm Bavians Krantz 151, Loc. 240). Here dark grey-green, hackly-weathering, massive or thin- to medium-bedded overbank siltstones contain subordinate thin (10-40 cm), lenticular, buff to greenish-grey sandstone beds that are probably of crevasse splay origin. Pedogenic calcrete horizons of sphaeroidal to irregular nodule horizons are present, but comparatively uncommon. Some of the small (<10 cm) nodules are dark grey to blackish inside (Fig. 24), very dense and give off a distinctive sulphurous odour when struck, suggesting a pyrite-rich composition. Others have rusty-brown interiors, perhaps as a result of local dolerite intrusion. Both concretion types are generally fossil-poor in the study area. Cubical, rusty-brown goethite pseudomorphs after pyrite are also occasionally seen within the sandstones, suggesting anoxic conditions during early diagenesis. Other calcrete nodules are pale grey and calcitic. These can be distinguished from paler, creamy, less-dense Quaternary calcrete nodules developed in near-surface weathered mudrocks (saprolite) of the Beaufort Group bedrock beneath younger soil cover (Figs. 18 & 20). Mud-cracked horizons within the Balfour succession are thin and rare (*e.g.* quarry Loc. 228) while no gypsum pseudomorphs were seen. The occasional thin (*c*. 1-1.5 m) lenticular channel sandstones are massive or structured by current ripple cross-lamination or climbing ripple cross-lamination, especially towards the top. The sandstones often prominently mottled, probably due to thermal metamorphism during Early Jurassic dolerite intrusion (Fig. 15).

Fig. 13. Amalgamated grey, tabular sandstones of the Oudeberg Member, Balfour Formation exposed in the cut face of the Afrimat aggregate quarry on Klipfonteyn 150 (Loc. 239). Note gently-dipping erosional surfaces.

Fig. 14. Balfour Formation channel sandstone palaeosurface with underlying cross-bedding, close to the Bavaainskrans homestead (Loc. 242) (Hammer = 30 cm).

Fig. 15. Lenticular channel sandstone of the Balfour Formation showing ripple cross-lamination and pervasive mottling, roadside quarry on Farm 148 (Loc. 227) (Hammer = 30 cm).

Fig. 16. Steeply-dipping, cross-bedded and mottled sandstones of the Balfour Formation exposed in a deep stream gulley, Klipfonteyn 150 (Loc. 235).

Fig. 17. Quarry exposure of thick, massive to bedded, dark grey overbank mudrocks of the Balfour Formation near Klipfontein homestead (Loc. 228) (Hammer = 30 cm).

Fig. 18. Small, pale grey-weathering, sphaeroidal calcrete nodules marking a Late Permian palaeosol, Balfour Formation overbank mudrocks on Klipfonteyn 150 (Loc. 232) (Hammer = 30 cm).

Fig. 19. Stream bank exposure of dark grey overbank mudrocks of the Balfour Formation, mantled by Late Caenozoic alluvial gravels, Klipfonteyn 150 (Loc. 232).

Fig. 20. Balfour Formation mudrocks overlain by sandstone gravels, thick silty alluvium and soils exposed in a stream bank section, Klipfonteyn 150 (Loc. 232) (Hammer = 30 cm). The irregular, pale cream calcrete nodules here are probably Quaternary in age.

Fig. 21. Extensive hillslope exposure of Balfour Formation mudrocks on Klipfonteyn 150 (Loc. 233).

Fig. 22. Extensive stream bank and hillslope exposure of Balfour Formation mudrocks and thin crevasse splay sandstones, Klipfonteyn 150 (Loc. 230).

Fig. 23. Small hillcrest exposure of Balfour Formation mudrocks partially mantled by sandstone colluvial gravels, Klipfonteyn 150 (Close to Loc. 230).

Fig. 24. Dark grey, pyritic calcrete nodules from the Balfour Formation overbank mudrocks, Farm 148 (Loc. 227) (Scale in cm).

Fig. 25. Small road cutting exposure of dark grey dolerite and adjacent deformed country rocks of the Balfour Formation, Bavians Kranz 151 (Loc. 241) (Hammer = 30 cm).

3.3 Karoo Dolerite Suite

Dolerite intrusions are not mapped within the Nojoli WEF study area but are present both to the north and south of the study area (Fig. 3). Areas tinted reddish-brown on satellite images may feature subsurface dolerite intrusions (Fig. 2). An example of massive, dark grey intrusive dolerite is exposed in a low road cutting along the Patryshoogte road (Loc. 241) (Fig. 25). The sedimentary country rocks are baked and disturbed while doleritic colluvium is recorded in the area (Loc. 240) (Fig. 35). Many of the Balfour sandstone display prominent mottling as well as secondary mineralisation that is probably the consequence of thermal metamorphism.

3.3. Caenozoic drift

Surface exposure of fresh Beaufort Group rocks within the development footprint is generally very poor, as also evident from satellite images, apart from stream beds, dongas and steeper hill slopes. The hill slopes are typically mantled with a thin to thick layer of **colluvium** or slope deposits (*e.g.* sandstone scree and downwasted gravels) and soil. Thicker accumulations of sandy, gravelly and bouldery **alluvium** of Late Caenozoic age (< 5 Ma) are found in stream and river beds where they may be deeply dissected by donga erosion, as well seen on Klipfonteyn 150 (See satellite image, Fig. 53). These colluvial and alluvial deposits may be extensively calcretised (*i.e.* cemented with soil limestone or calcrete) especially, but not exclusively, in the neighbourhood of dolerite intrusions.

Good vertical exposures through the thick colluvial, alluvial and soil cover are seen along stream banks and, particularly, in areas of erosional gullying *donga* formation (*e.g.* Locs. 232, 235-236, 243-248) (Figs. 26 to 33). Semi-consolidated gravels of angular to subrounded sandstone clasts often directly overlie the Beaufort Group bedrock while lenses of less well-consolidated sandstone gravels occur at intervals within the silty alluvium succession. These gravels contain crudely flaked clasts of MSA as well as probable ESA affinities (but often indeterminate), indicating a Pleistocene or younger age.

The buff to pale brown older silty alluvium often contains dense calcrete glaebules, some of which are elongate and may be fragments of rhizoliths (calcretised root casts) (Fig. 47). These deposits are overlain by much darker brown modern soils. The alluvium may be 3 to 5 meters or more thick, especially along larger stream valleys. A horizon of dense, small, pale cream calcrete nodules of probable Quaternary age is locally developed at the base of soils or alluvium overlying Beaufort Group bedrocks and often extends into the uppermost weathered zone of the bedrock or saprolite (*e.g.* Locs. 227, 232) (Fig. 20).

Excellent exposures through older and younger alluvial deposits as well as modern soils are seen overlying steeply-dipping Beaufort Group mottled sandstones and dark grey mudrocks in the banks of a prominent west-east trending erosional donga system on Klipfonteyn 150, some 3.7 km south of the Klipfontein homestead (Loc. 235-237, 243-248) (Figs. 27 to 33). Up to a meter or so of calcretised gravels are locally present directly overlying the Beaufort Group bedrocks. The lower, paler, buff-coloured silty alluvium typically contains dense assemblages of small calcrete glaebules, as well as possible calcretised rhizolith fragments. It is overlain by several meters of buff to orange-brown, massive to crudely-bedded, semi-consolidated, incipiently calcretised older alluvium with thin gravel lenticles. The older alluvium contains dispersed flaked tools (including rare ESA bifaces of sandstone and hornfels) and occasional petrified wood fragments. Downwasted onto its upper surface are found concentrations of angular sandstone gravels, downwasted flaked tools (ESA / MSA), angular pieces of silicified wood, reworked calcrete flakes, rare chert clasts (probably tuffaceous) and fossil teeth (Section 4). The enclosed stone artefacts and the fossil horse tooth found support a probable Pleistocene age for these orange-brown older alluvial deposits. The surface gravels are in turn overlain by darker brown modern soils and vegetation.

Colluvial (slope) gravels within the Balfour Formation outcrop area consist mainly of angular sandstone clasts (sometimes anthropogenically flaked) with a minor component of greenish-grey chert (possibly tuffaceous), vein quartz and petrified wood. At Loc. 240 along the Patryshoogte road (Bavians Krantz 151) the colluvium is well-consolidated and semi-calcretised with ferruginous *terra rossa* and well-rounded clasts (corestones) of dolerite derived from a local intrusion (*cf* Loc. 241) (Fig. 35). At Locs. 250-252 (Bavians Krantz 151 & Rooy Draai 146) the gravels overlie steps in the lower escarpment slopes formed by prominent-weathering sandstones of the uppermost Middleton Formation (Fig. 34). However, the sandstone and associated fossil wood clasts are probably derived from the base of the overlying Oudeberg Member (Balfour Formation), though this remains to be confirmed.

Fig. 26. Thick silty alluvium and basal, poorly-sorted colluvial breccia overlying Middleton Formation bedrocks on Bavians Krantz 151 (Loc. 253).

Fig. 27. Thick silty alluvium with angular basal and internal gravels, capped by darker soils, Klipfonteyn 150 (Loc. 232) (Hammer = 30 cm).

Fig. 28. Gulley exposure of Balfour Formation mudrocks overlain by semi-consolidated, agular basal alluvial gravels, calcretised silty alluvium and brown modern soils, Klipfonteyn 150 (Loc. 232) (Hammer = 30 cm).

Fig. 29. Balfour Formation channel sandstones overlain by calcretised silty alluvium and orange-brown younger alluvium and soils, Klipfonteyn 150 (Close to Loc. 245).

Fig. 30. Semi-consolidated, partially calcretised Quaternary alluvium dissected by gulley erosion, Klipfonteyn 150 (Close to Loc. 148).

Fig. 31. Extensive donga erosion of thick, semi-consolidated older alluvial deposits on Klipfonteyn 150 (Loc. 148).

Fig. 32. Well-calcretised basal alluvial gravels (*c*. 1 m thick) overlying Balfour Formation sandstones, Klipfonteyn 150 (Loc. 235).

Fig. 33. Thick, well-consolidated and stratified, orange-brown Pleistocene alluvium with basal gravels overlying dark grey Balfour Formation mudrocks, stream banks, Klipfontein 150 (Loc. 235).

Fig. 34. Thin colluvial gravels of sandstone clasts overlying Middelton Formation bedrocks on Bavians Krantz 151 (Loc. 250). These gravels contain downwasted fragments of petrified wood.

Fig. 35. Well-consolidated colluvial deposits overlying Balfour Formation bedrocks on Bavians Krantz 151 (Hammer = 30 cm) (Loc. 240). Note reddish-brown, ferruginous sandy to clayey matrix and floating dolerite corestones.