Palaeontological specialist assessment: combined desktop and field-based study

PROPOSED WOLF WIND ENERGY FACILITY NEAR JANSENVILLE, EASTERN CAPE

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EXECUTIVE SUMMARY

Wolf Wind Farm (Pty) Ltd, owned by juwi Renewable Energies (Pty) Ltd (juwi), is proposing to construct a wind energy facility (WEF) of 80 MW generation capacity, together with associated infrastructure, on a site in the Klein-Winterhoekberge near Steytlerville, Eastern Cape. The proposed Wolf WEF will comprise 27 wind turbines and will be connected to the national grid *via* a proposed new 132 kV overhead transmission line to the existing Wolwefontein Substation, some 11 km south of the wind farm itself.

- **Impact on palaeontology**

Excavations into bedrocks as well as superficial sediments (alluvium, scree, soils *etc.*) during the construction phase of the Wolf WEF may disturb, damage, destroy or seal-in scientifically valuable and legally-protected fossil material preserved at or beneath the land surface. These notably include excavations for turbine foundations, new internal access roads, underground cables, the new on-site substation and associated building infrastructure. A combined desktop and field-based palaeontological heritage assessment of the Wolf WEF project has accordingly been undertaken in accordance with Section 38 of the National Heritage Resources Act (1999).

Fieldwork for this project was carried out by the author and an assistant over two days during the period 27-30 June 2014. Field work concentrated on representative exposures of the various important rock units within and on the margins of the study area (*e.g.* rocky outcrops, road cuttings, borrow pits, erosion gullies). The sensitivity of fossil-bearing rocks to the proposed WEF development depends on levels (1) near-surface exposure, (2) low tectonic deformation (*e.g.* folding, cleavage) and (3) bedrock weathering.

- **Geological and palaeontological context**

The proposed Wolf Wind Energy Facility near Steytlerville is located towards the northern edge of the Cape Fold Belt and the southern margin of the Main Karoo Basin. It includes outcrop areas of the upper part of the Cape Supergroup and the lower part of the Karoo Supergroup. The southernmost sector of the associated 132 kV transmission line corridor, including the Wolwefontein Substation, is underlain by Uitenhage Group sediments within the northern margin of the Algoa Basin.

The study area is underlain by fifteen or so geological units (formations of sedimentary rocks) of Late Devonian to Recent age, most of which have yielded fossils elsewhere in the Cape region of the RSA. The bedrock formations are assigned to the Witteberg, Dwyka and Ecca Groups of Middle to Late Palaeozoic age as well as the Uitenhage Group of Mesozoic

age (See geological map Fig. A). These bedrocks are mantled by a wide range of much younger superficial sediments (calcrete, alluvium, colluvium, surface gravels, soils *etc.*), mostly of Late Caenozoic age. Many of the bedrock units have very narrow outcrop areas and are not indicated separately on 1: 250 000 scale geological maps while, with few exceptions, the geologically recent superficial sediments are not mapped at all.

The study area for the wind farm along the crest of the Klein-Winterhoekberge is underlain by quartzitic sediments of the Late Devonian Witpoort Formation (Witteberg Group). These shallow marine quartzites are largely unfossiliferous but occasional lagoonal mudrock horizons recorded from within the Witpoort Formation elsewhere in the Eastern Cape have yielded outstanding fossil assemblages of fish, plants and even very early tetrapods (air-breathing limbed vertebrates). The study area of the 132 kV transmission line to the south of the Klein-Winterhoekberge traverses a wide spectrum of potentially fossiliferous sedimentary formations within the Witteberg, Dwyka, Ecca and Uitenhage Groups. These range in age from Early Carboniferous to Late Jurassic. In particular, the Early Carboniferous Waaipooort Formation, the Early Permian Prince Albert Formation and the Middle Permian Whitehill Formation have yielded important assemblages of fossil fish, aquatic reptiles, terrestrial plants and invertebrates in the Cape region. Mass mortality event beds packed with fossil fish are recorded from exposures of the Waaipoort Formation near Darlington Dam (Lake Mentz), just 15 km NE of the study area, for example.

The present broad-based field assessment of the study region determined that the potentially fossiliferous rock units within the study area are:

- for the most part very poorly exposed, due to pervasive cover by superficial sediments (colluvium / scree, soil, alluvium, calcretes, surface gravels) and vegetation;
- often highly deformed due to intense folding and faulting (including thrust faults) within this sector of the Cape Fold Belt, with the frequent development of a pervasive tectonic cleavage within mudrock units that are most likely to have once contained fossils (cleavage often destroys fossils and also makes them more difficult to observe and collect);
- often highly weathered, ferruginised and permeated by secondary calcrete near surface.

With the exception of low-diversity trace fossil assemblages within the upper Witteberg Group to the east of the study area (Kweekvlei Formation), no significant fossil occurrences were recorded during the two-day field study.

- **Palaeontology impact assessment**

The destruction, damage or disturbance of fossils preserved at the ground surface or below ground during construction represents a *negative* impact that is confined to the development footprint (*site specific*). Such impacts are limited to the *construction period*, can usually be mitigated but cannot be fully rectified (*i.e. irreversible*). Most of the sedimentary formations represented within the study area contain fossils of some sort, so impact on fossil heritage are *probable*. However, because of the generally sparse occurrence of well-preserved fossils within the majority of the bedrock formations concerned here (notably those underlying the proposed wind turbine sites) as well as within the overlying superficial sediments (soil, alluvium, colluvium *etc.*), the magnitude of these impacts is rated as *very low*.

Due to (1) the general scarcity of fossil remains, (2) the high levels of bedrock weathering and tectonic deformation as well as (3) the extensive superficial sediment cover observed within and close to the Wolf WEF study area, the overall impact significance of the construction phase of the proposed wind energy project is assessed as VERY LOW in terms of fossil heritage resources (Table 1). This applies to the wind turbines and associated infrastructure on the Klein-Winterhoekberge as well as to the 132 kV transmission line connection to the existing Wolwefontein Substation. There is no preference on palaeontological heritage grounds for any of the transmission line route options under consideration.

Following construction, no significant further impacts on fossil heritage are anticipated during the operational and decommissioning phases of the WEF.

In the absence of comprehensive data on other alternative energy or comparable developments in the Steytlerville – Jansenville region of the Eastern Cape, it is impossible to realistically assess cumulative impacts on fossil heritage resources. The impact significance of a proposed WEF underlain by similar geology in the Kommadagga – Riebeeck East area, some 100 km to the east of the Wolf WEF, was rated by the author as low (Almond 2013).

- **Mitigation measures**

Given the low palaeontological sensitivity of the broader Wolf WEF study area, as determined from fieldwork, as well as the inferred very low impact significance of the project for fossil heritage conservation, no specialist palaeontological mitigation is recommended here, pending the discovery of substantial new fossil remains during construction.

During the construction phase all substantial bedrock excavations should be monitored for fossil material by the responsible ECO. Should substantial 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 safeguard these, preferably *in situ*, and 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 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).

The palaeontologist concerned with mitigation work will need a valid fossil collection permit from ECPHRA 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).

No mitigation is required during the operational and decommissioning phases of the development.

These mitigation recommendations should be incorporated into the Environmental Management Plan (EMP) for the Wolf WEF.

- **Palaeontology conclusion**

Although potentially fossiliferous bedrocks of the Cape and Karoo Supergroups are mapped within the Wolf WEF study area, in practice significant impacts are not expected here during the construction or later phases of the development. This is because the bedrocks are generally (1) tectonically deformed (folding / faulting / cleavage), (2) weathered near-surface, and (3) widely mantled in thick superficial deposits of low palaeontological sensitivity (colluvium, alluvium, soil *etc.*). No areas or sites of exceptional fossil heritage sensitivity or significance have been identified within the study area. The palaeontological sensitivity of the Wolf WEF development area, including the wind farm itself as well as the associated transmission line and other infrastructure, is rated as low (unrestricted). The impact significance of the proposed WEF is assessed as VERY LOW, and this applies equally to the various transmission line options under consideration (Table 1).

No specialist palaeontological mitigation is recommended for this project, pending the discovery of significant new fossil material during construction. Should substantial fossil remains such as vertebrate bones and teeth, plant-rich fossil lenses or dense fossil burrow assemblages be exposed during development, the responsible Environmental Control Officer should safeguard these, preferably *in situ*, and alert ECPHRA (*i.e.* The Eastern Cape Provincial Heritage Resources Authority) 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).

Table 1: Assessment of impacts of the proposed Wolf WEF on fossil heritage resources during the construction phase of the development (*N.B.* Significant impacts are not anticipated during the operational and decommissioning phases).

			WITHOUT MITIGATION						
Phase	**Project aspect**	**Impact description**	**Extent**	**Magnitude**	**Duration**	**Probability**	**Confidence**	**Reversibility**	**Significance**
Construction	**Wind turbines and associated infrastructure, Klein-Winterhoek ridge**	**Disturbance, damage or destruction of fossils at surface or beneath the ground**	**Site specific**	**Very low**	**Construction period**	**Probable**	**Unsure**	**Irreversible**	**VERY LOW**
Construction	**132 kV transmission line corridor (all alternatives)**	**Disturbance, damage or destruction of fossils at surface or beneath the ground**	**Site specific**	**Very low**	**Construction period**	**Probable**	**Unsure**	**Irreversible**	**VERY LOW**

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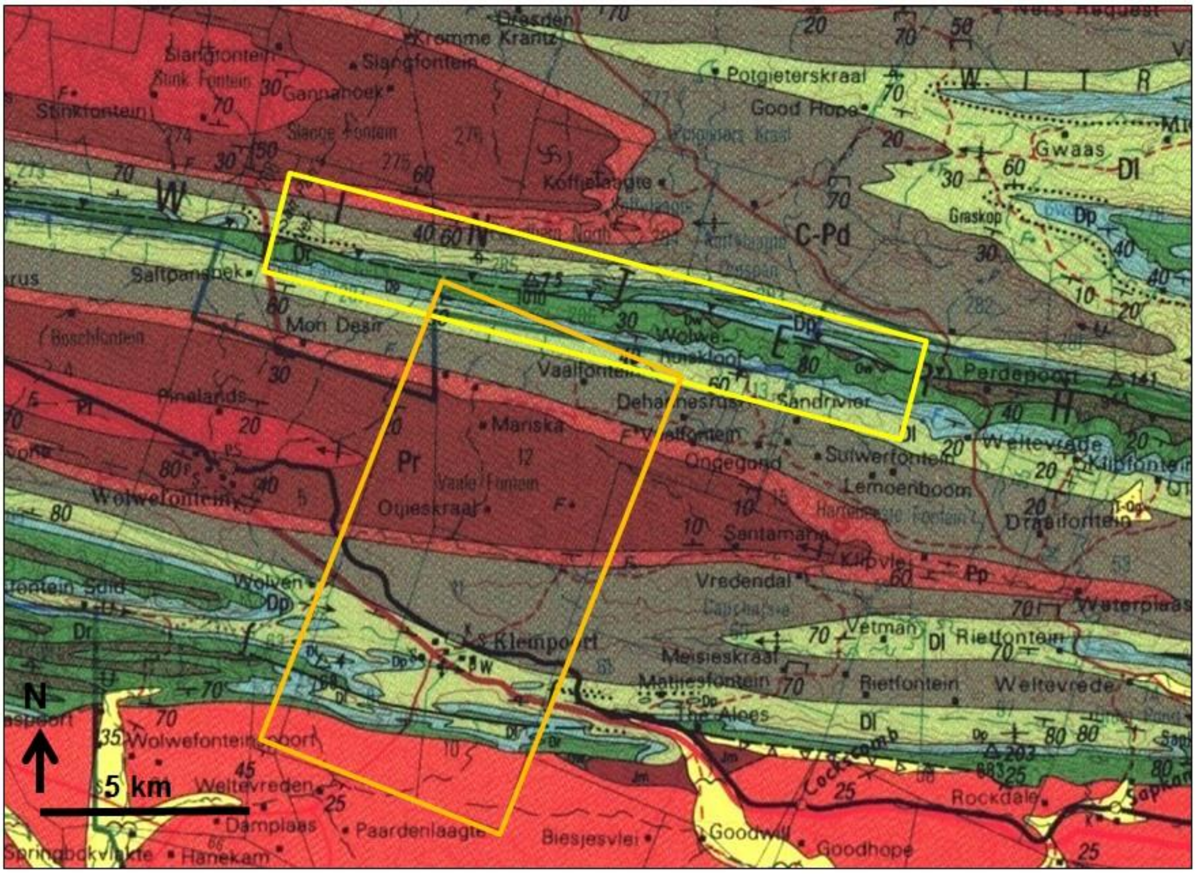

Fig. A. Extract from 1: 250 000 geological map 3324 Port Elizabeth (Council for Geoscience, Pretoria) showing the approximate location (yellow rectangle) of the proposed Wolf WEF study area along the summit of the Klein Winterhoek Mountains between the R75 tar road to Jansenville and the Perdepoort gorge. The study area for the 132 kV transmission line connection to Wolwefontein Substation is roughly indicated by the orange rectangle.

The main geological units represented within the broader WEF study region are:

1. WITTEBERG GROUP (Late Devonian – Early Carboniferous)

Weltevrede Subgroup (Dw, grey)
Witpoort Formation including the Perdepoort Member (Dp, pale blue) and underlying Rooirand Member (Dr, dark green)
Lake Mentz Subgroup and Kommadagga Subgroup (Cl / Dl, pale green)
***N.B.* In this area the various formations of the Lake Mentz and Kommadagga Subgroups are not mapped individually at 1: 250 000 scale.**

2. DWYKA GROUP (Late Carboniferous – Early Permian)

Elandsfontein Formation (C-Pd, dark grey)

3. ECCA GROUP (Early to Middle Permian)

Prince Albert, Whitehill and Collingham Formations (Pp, buff)
Ripon Formation (Pr, dark brown)

4. UITENHAGE GROUP

Enon Formation (Je, red)

5. CAENOZOIC SUPERFICIAL SEDIMENTS

Quaternary to Recent Alluvium (yellow with single "flying bird" symbol)

***N.B.* Large areas of older bedrocks are mantled by a range of other superficial deposits, such as colluvium (slope deposits, *e.g.* scree), downwasted gravels and soils that may reach thicknesses of several meters but are generally not mapped at 1: 250 000 scale.**

Given the low effective palaeontological sensitivity of all these rock units, due to tectonic deformation, weathering and poor surface exposure, the entire study area for the Wolf WEF is considered *unrestricted*.

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PROPOSED WOLF WIND ENERGY FACILITY NEAR STEYTLERVILLE, UITENHAGE & JANSENVILLE MAGISTERIAL DISTRICTS, EASTERN CAPE

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August 2014

1. INTRODUCTION & BRIEF

1.1. Project outline

The company Wolf Wind Farm (Pty) Ltd, owned by juwi Renewable Energies (Pty) Ltd (juwi), is proposing to construct a wind energy facility (WEF) of 80 MW generation capacity, together with associated infrastructure, on a site in the Klein-Winterhoekberge. The study site of *c*. 6902 ha area is located near the village of Wolwefontein in hilly to mountainous terrain some 50 km ENE of Steytlerville and 40 km SE of Jansenville, Jansenville and Uitenhage District Municipalities, Eastern Cape (Figs. 1 to 3). The proposed Wolf WEF will comprise 27 wind turbines and will be connected to the national grid *via* a proposed new 132 kV overhead transmission line to the existing Wolwefontein Substation, some 11 km south of the wind farm itself.

In addition to the 27 wind turbines, the WEF will comprise the following main infrastructural components:

- 132 kV overhead transmission line, with associated access track, linking the WEF to the existing Wolwefontein Substation (see Fig. 3). Three route options for the line are under consideration. The pylons will each have a 1 m^2 impact area.
- Cabling between project components, with cable trenches excavated along access roads.
- Onsite substation (60 m x 80 m footprint), with an associated stockpiling and laydown area (60 m x 200 m).
- Concrete foundations (26 m diameter, 3 m deep) to support the wind turbines
- Hard stands to support cranes at each turbine position.
- Additional service and access roads (main access road, turbine access roads), with stormwater infrastructure and gates as required, road sidings for most turbine locations. Existing farm roads will be rehabilitated.
- Laydown area with a temporary maintenance and storage building, guard cabin, offices, contractors camp – probably located along the mountain ridgeline. The construction yard and contractors camp will be rehabilitated after construction.
- Batching plant at the foot of the ridge, close to the main access road (to be rehabilitated after construction).

1.2. Brief for this palaeontological heritage study

Aurecon South Africa (Pty) Ltd (Aurecon) has been appointed to undertake the required environmental process in terms of the National Environmental Management Act (No. 107 of

1998), as amended, on behalf of Wolf Wind Farm (Pty) Ltd. The present palaeontological heritage assessment has been commissioned by Aurecon in accordance with Section 38 of the National Heritage Resources Act (1999) (Contact details: Mr Dirk Pretorius, Aurecon. Tel: +27 44 805 5458; Fax: +27 44 805 5454. Cell: +27 72 100 2712. E-mail: Dirk.Pretorius@aurecongroup.com. Address: Suite 201, 2nd Floor, Bloemhof Building, 65 York St, George, South Africa). The heritage assessment component of the EIA is being co-ordinated by ACO Associates (Contact: Mr Tim Hart, ACO Associates. Postal address: 8 Jacobs Ladder, St James, 7945. Physical address: Unit D17, Prime Park, 21 Mocke Road, Diep River, 7800. E-mail: tim.hart@aco-associates.com. Phone: 021-7064104 / 073 1418618).

The Wolf WEF project area is underlain by potentially fossiliferous sediments of the Cape and Karoo Supergroups of Palaeozoic age, the Uitenhage Group of Mesozoic age, as well as much younger (mainly Pleistocene – Holocene) superficial deposits that may also contain scientifically important fossil remains (Sections 2 and 3). Fossil heritage preserved within these rocks is protected by law (National Heritage Resources Act of 1999). A combined desktop and field-based palaeontological heritage assessment for the Wolf WEF as part of a comprehensive heritage assessment has accordingly been commissioned with the following brief, as defined by Aurecon:

Undertake a desktop 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 paleontological significant geological units in the proposed development areas.
- Undertaking field work, if necessary, to verify results of desktop investigation.
- Document (GPS coordinates and map) all sites, objects and structures identified on the candidate sites.
- Submit the relevant application form, as required by SAHRA and Eastern Cape Provincial Heritage.
- Compile a report which would include:

  (1)Identification of paleontological significant sites within the proposed development areas.
  (2) Assess the sensitivity and significance of paleontological resource of the site.
  (3) Evaluation of the potential impacts of construction, operation and maintenance of the proposed developments on paleontological 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 paleontological 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 paleontological 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”.
  (8) Provide a spatial file (.shp or .kmz) categorising all areas of the site into as one of Three categories (1) No Go (Red), (2) Conditional (Yellow) (subject to the implementation of strict mitigation measures) and (3) unrestricted or Go (Green) (areas suitable for proposed development with general mitigations).

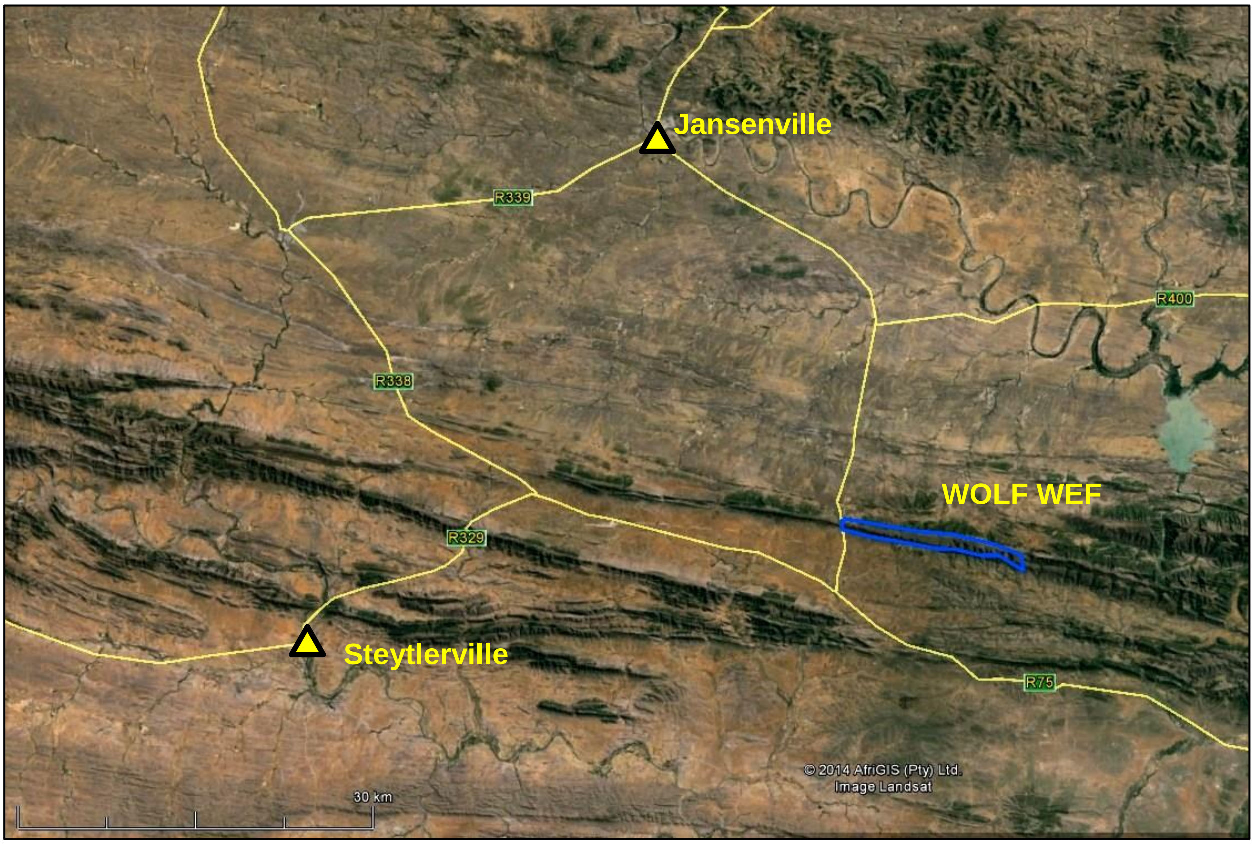

Fig. 1. Satellite image showing the location (blue polygon) of the proposed Wolf WEF in the Klein-Winterhoek Mountains to the northeast of Steytlerville, Eastern Cape

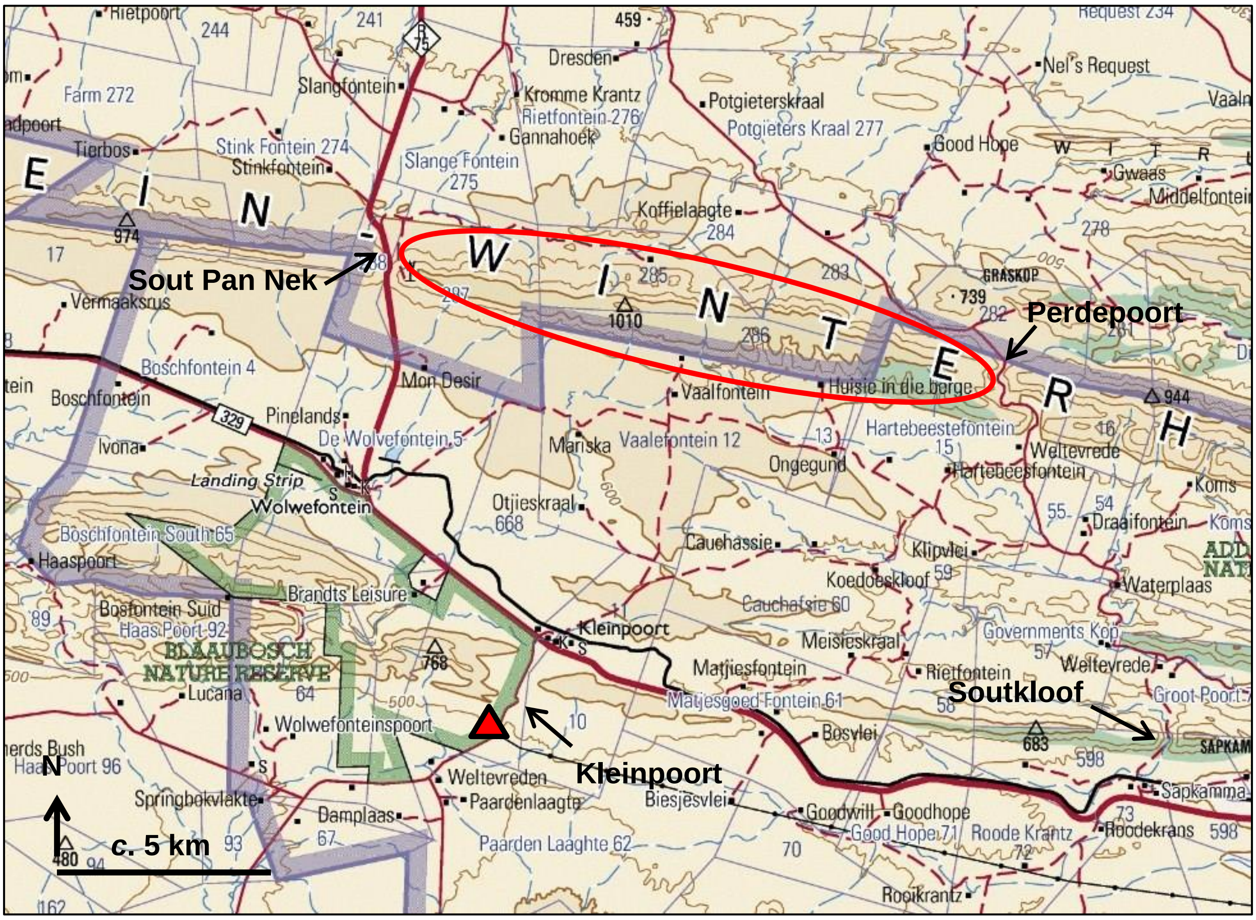

Fig. 2. Extract from 1: 250 000 topographical map 3324 Port Elizabeth (Courtesy of the Chief Directorate: National Geo-Spatial Information, Mowbray) showing the approximate location (red ellipse) of the proposed Wolf WEF along the summit of the Klein-Winterhoek Mountains east of the R75 tar road to Jansenville and to the northeast of Wolwefontein. The Wolwefontein Substation to the southwest of Kleinpoort is indicated by the red triangle. Narrow gorges or passes where informative geological sections can be seen are indicated at Sout Pan Nek, Perdepoort and Soutkloof and Kleinpoort.

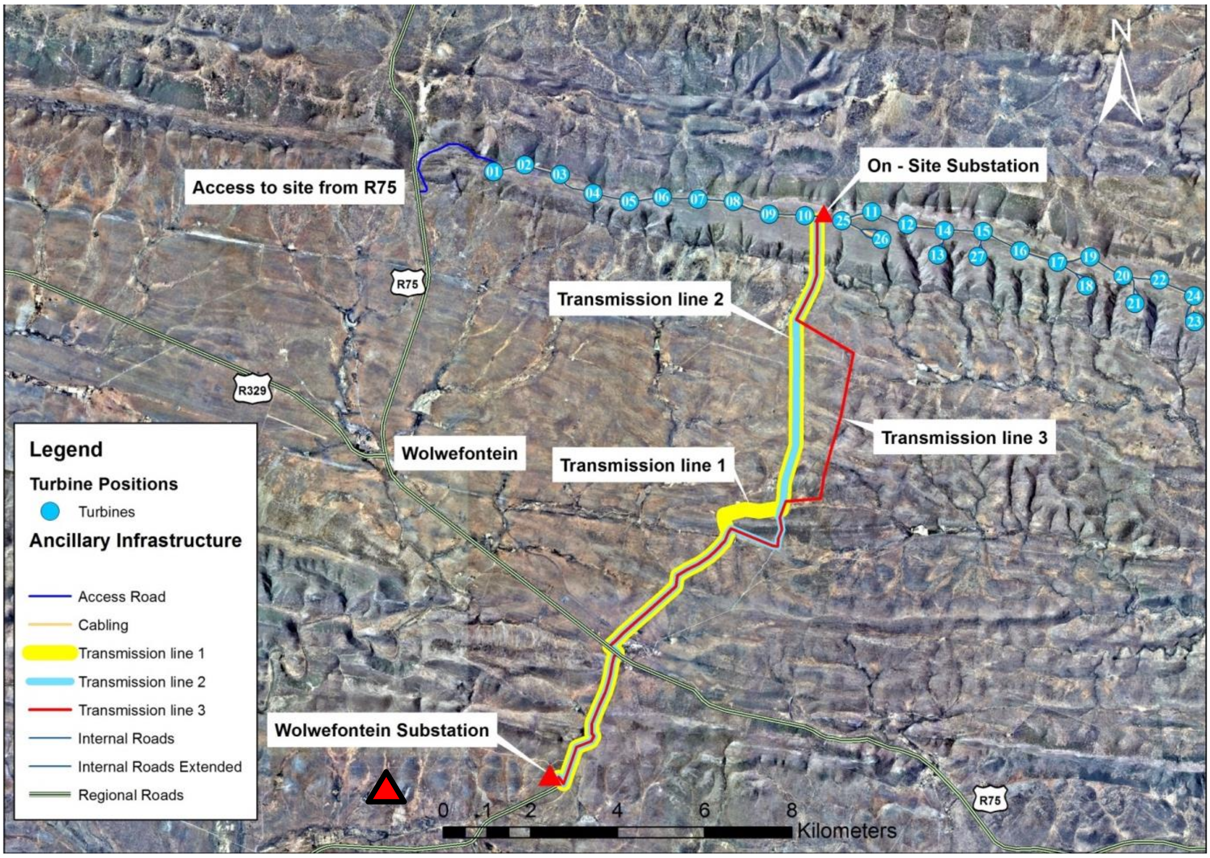

Fig. 3. Aerial photograph of the Wolf WEF study area, Eastern Cape. The wind farm along the crest of the Klein Winterhoek Mountains is outlined in blue. The red lines show alternative 132 kV transmission line connections to the existing Wolwefontein Substation (red triangle).

1.3. Legislative context for palaeontological assessment studies

The Wolf WEF near Steytlerville is located in an area that is underlain by potentially fossil-rich sedimentary rocks of Late Palaeozoic and younger, Mesozoic, 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 on-site 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, 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 operational and decommissioning phases of the wind farm development are 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).

1.4. 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.

1.5. 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 Steytlerville – Jansenville 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.

1.6. Information sources

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

1. A brief project outline kindly supplied by Aurecon South Africa (Pty) Ltd;
2. A review of the relevant scientific literature, including published geological maps and accompanying sheet explanations (*e.g.* Toerien & Hill 1989) as well as several previous fossil heritage assessments in the Port Elizabeth sheet area (*e.g.* Almond 2013, 2014);
3. 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 27-30 June, 2014. Fieldwork mainly focussed on the limited number of natural or artificial exposures of potentially fossiliferous bedrocks within or close to the study area as well as on thick deposits of Pleistocene and younger 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 geology of the Wolf WEF study area to the northeast of Steytlerville is outlined on the 1:250 000 geology sheet 3324 Port Elizabeth (Council for Geoscience, Pretoria) with an accompanying short sheet explanation by Toerien and Hill (1989) (Fig. 4). The study area is embedded within the southern limb of the Permo-Triassic Cape Fold Belt, here constructed from Palaeozoic (Permo-Carboniferous) bedrocks of the Cape and Karoo Supergroups, and also overlaps with the northern edge of the Mesozoic Algoa Basin, underlain by sediments of the Uitenhage Group.

Throughout most of the Wolf WEF and associated transmission line study area the Palaeozoic and Mesozoic bedrocks are mantled by a range of much younger superficial sediments of probable Late Tertiary / Quaternary to Recent age such as colluvium (slope deposits such as scree), alluvium, soils and downwasted surface gravels. These sediments are not mapped at 1: 250 000 scale for the most part (none are shown within the study area in Fig. 4) but they may be several meters thick and some (*e.g.* older alluvial deposits exposed by gulley or *donga* erosion) may contain important fossil heritage.

In the following section of the report, a very brief account is given of the most important sedimentary rock units represented within (1) the main Wolf WEF study area along the Klein-Winterhoekberge, where the wind turbines will be located, as well as (2) the 132 kV transmission line study area between the Wolf WEF and the Wolwefontein Substation, with illustrations of representative rock exposures examined for fossil heritage during the course of fieldwork. Further data on almost all of these rocks units is available in the palaeontological assessment report for a large wind farm project in the Kommadagga – Riebeeck East area some 100 km further to the east (Almond 2013).

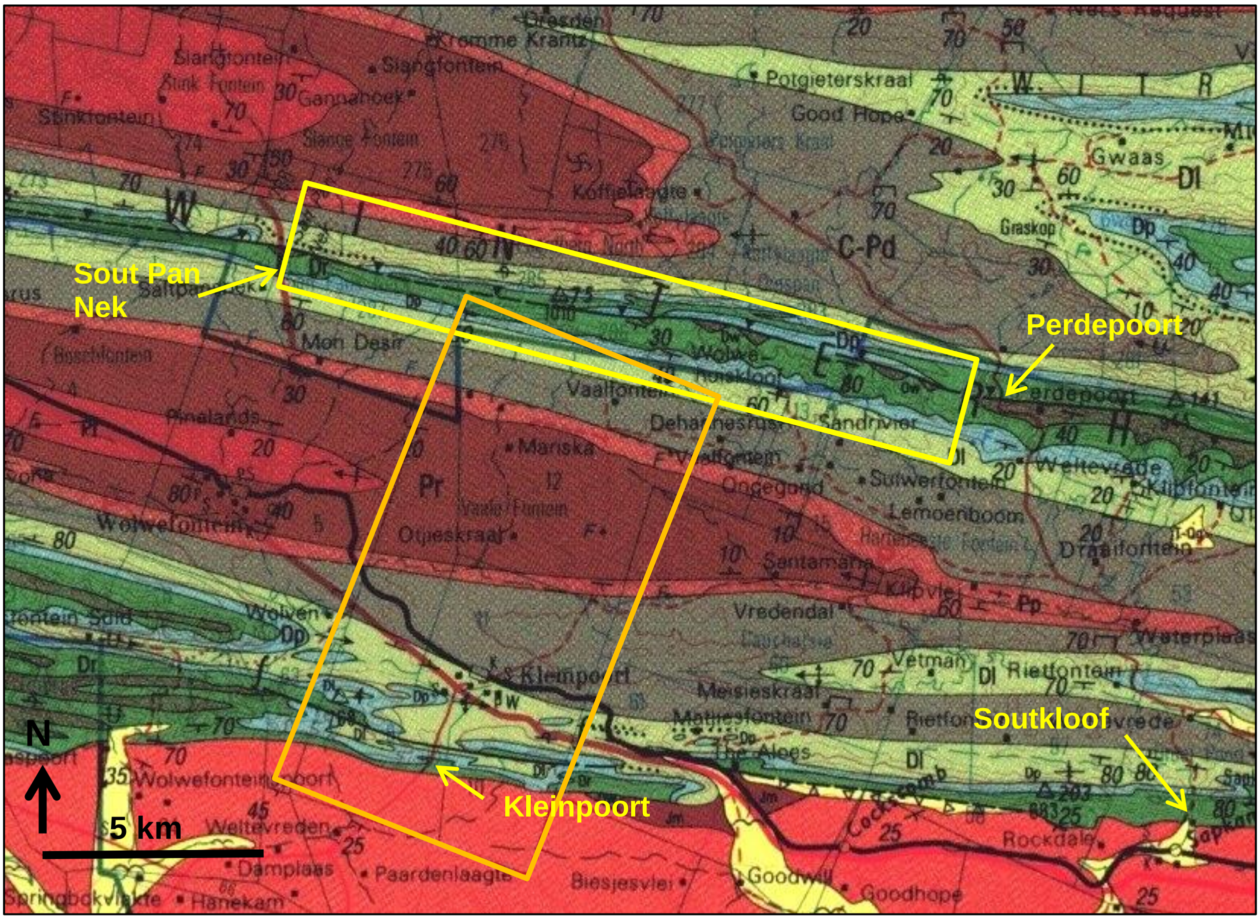

Fig. 4. Extract from 1: 250 000 geological map 3324 Port Elizabeth (Council for Geoscience, Pretoria) showing the approximate location (yellow rectangle) of the proposed Wolf WEF study area along the summit of the Klein Winterhoek Mountains between the R75 tar road to Jansenville and the Perdepoort gorge. The study area for the 132 kV transmission line connection to Wolwefontein Substation is roughly indicated by the orange rectangle (See satellite image in Fig. 3 for a more accurate map).

The main geological units represented within the broader WEF study region comprise the following:

1. WITTEBERG GROUP (Late Devonian – Early Carboniferous)

Weltevrede Subgroup (Dw, grey)
Witpoort Formation including the Perdepoort Member (Dp, pale blue) and underlying Rooirand Member (Dr, dark green)
Lake Mentz Subgroup and Kommadagga Subgroup (Cl / Dl, pale green)
***N.B.* In this area the various formations of the Lake Mentz and Kommadagga Subgroups are not mapped individually at 1: 250 000 scale.**

2. DWYKA GROUP (Late Carboniferous – Early Permian)

Elandsfontein Formation (C-Pd, dark grey)

3. ECCA GROUP (Early to Middle Permian)

Prince Albert, Whitehill and Collingham Formations (Pp, buff)

Ripon Formation (Pr, dark brown)

4. UITENHAGE GROUP

Enon Formation (Je, red)

5. CAENOZOIC SUPERFICIAL SEDIMENTS

Quaternary to Recent Alluvium (yellow with single “flying bird” symbol)

***N.B.* Large areas of older bedrocks are mantled by a range of other superficial deposits, such as colluvium (slope deposits, *e.g.* scree), downwasted gravels and soils that may reach thicknesses of several meters but are generally not mapped at 1: 250 000 scale.**

2.1. Geology of the main Wolf WEF study area (Klein-Winterhoekberge)

The proposed WEF itself (yellow rectangle in Fig. 2) is to be developed along the summit plateau of the rugged Klein-Winterhoek Mountains, a narrow WNW-ESE trending ridge of quartzitic rocks of the **Witpoort Formation** (Witteberg Group) that lies at an elevation of *c*. 960-990 m amsl. This relatively flat plane represents an elevated pediment surface of Tertiary (or perhaps older) date incised across tough-weathering, steeply-dipping beds of the Witpoort succession. The basic structure of the Klein Winterhoek Mountains as a narrow, north-vergent anticline has been complicated by thrusting along the anticlinal axial plane; the thrust plane is marked on the geological map (Fig. 4) as a black line with small triangular ticks. Levels of bedrock deformation - especially as far as potentially fossiliferous mudrock units are concerned - are therefore expected to be high

The latest Devonian (Famennian) Witpoort Formation is a thick (*c*. 400 – 850 m) succession of clean-washed, shallow marine quartzites and subordinate siltstones that builds the main Klein-Winterhoek range within the Wolf WEF study area as well as the Grootrivierberge range south of Kleinpoort settlement and several subparallel, subordinate anticlines in the broader region. Cyclical deposition of small-scale, coarsening-upwards parasequences together with sedimentary structures indicative of shallow shelf storm deposition are well seen within the lower part of the Witpoort succession, the often reddish-brown weathering **Rooirand Member** (**Dr**) (Cotter 2000) (Figs. 5, 6 & 9). The uppermost Witpoort Formation comprises the pale-weathering, highly quartzitic **Perdepoort Member** (*Witstreep*) characterized by amalgamated, tabular-bedded quartzites with horizontal to low-angle cross lamination (Figs. 5 & 13). This unit may in part represent a beach facies that was deposited during a period of low sea levels associated with expansion of the Late Devonian ice sheets on Gondwana. Sandy diamictites (debris flows and / or possible tillites) and subglacial deformation features occur intermittently within the **Skitterykloof Member** at or close to the Witpoort / Kweekvlei contact in the western portion of the Cape Fold Belt (Almond *et al.* 2002) but have yet to be identified in the Eastern Cape outcrop area.

All of the proposed wind turbine positions in the Wolf WEF study area are located on a WNW-ESE trending anticlinal ridge of the Witpoort Formation, the Klein Winterhoek Mountains (Fig. 3). However, the crests of the quartzite ridges here have been planed off by fluvial erosion to form high-lying pediment surfaces at around 960 to 990 m amsl. Topographic relief and levels of bedrock exposure on these pediment surfaces are correspondingly very low, with high levels of cover by downwasted surface gravels (principally angular clasts of local quartzite), gravelly soils and shrubby vegetation (Figs. 10 to 12). Locally, low ridges of resistant-weathering, tabular-bedded Witpoort quartzites are visible, often showing steep dips, locally ferruginised and brecciated. These last features may well be related to local thrust faulting. Exposure of any intervening mudrock facies – such as potentially fossiliferous lagoonal deposits, as recorded near Grahamstown (*e.g.* Hiller & Taylor 1992, Gess 2002) - is negligible to zero on these pediment surfaces; no Witpoort mudrock exposures were encountered here during the present field assessment.

Turbine positions along the ridge of the Klein Winterhoek Mountains overlie the lower portion of the Witpoort Formation (Rooirand Member) which is overthrust to the north over the stratigraphically younger Perdepoort Member along the northern edge of the ridge (Fig. 4). The extensive thrusted contact within the Klein Winterhoek Witteberg succession can be clearly seen in views down the summit ridge towards the west as well as in Perdepoort gorge (Fig. 8). Good sections through the Witpoort Formation succession, with several successive parasequences within the reddish-brown hued Rooirand Member capped by cleaner-washed, pale quartzites of the Perdepoort Member, are seen along Perdepoort gorge, just east along strike from the Wolf WEF study area (Figs. 5 & 6). Witpoort quartzites are also well exposed in narrow anticlinal ridges at Soutkloof, *c*. 16.5 km east of Kleinpoort (Fig. 9), near Rietfontein homestead just to the northwest where a good section through a northwards-overfolded anticline can be seen, and in Kleinpoort gorge near Kleinpoort settlement(Fig. 16). The southern flanks of the Klein-Winterhoek ridge are built of south-dipping Perdepoort quartzites that have been incised by numerous stream gullies as a consequence of Late Tertiary continental uplift. Due to dense vegetation and overlying colluvial deposits, these beds are only poorly exposed outside steep-sided stream gullies (Fig. 13). The lower portion of the Witteberg succession (**Weltevrede Formation**) is best seen as small heterolithic inliers of thin-bedded quartzites, sandstones and micaceous siltstones in Perdepoort gorge (Fig. 7). The outcrop area of these older beds within the Wolf WEF study area is small and they are unlikely to be directly impacted by the proposed development, so this rock unit is not considered further here.

Good sections through poorly-sorted, rubbly colluvial deposits mantling the lower slopes of the Klein Winterhoek Mountains are seen in Salt Pan Nek along the R75 (Loc. 418) (Fig. 14). The angular quartzitic clasts here, ranging up to boulder size, are embedded within a highly calcretised, creamy-coloured, finer-grained matrix. Much of this material may have been emplaced as debris flows. Perdepoort Member bedrocks underlying the scree deposits along the Klein-Winterhoekberge mountain front may be deeply weathered in some areas (Fig. 15).

Fig. 5. Several successive quartzite / sandstone packages (parasequences) of the brown-weathering Rooirand Member overlain by paler Perdepoort Member quartzites (Witpoort Formation), Perdepoort gorge.

Fig. 6. Closer view of tabular-bedded, upward-thickening Rooirand Member quartzites in Perdepoort gorge.

Fig. 7. Thin-bedded, brown-weathring, micaceous siltstones and sandstones of the Weltevrede Formation underlying the Witpoort Formation in Perdepoort gorge (Loc. 428).

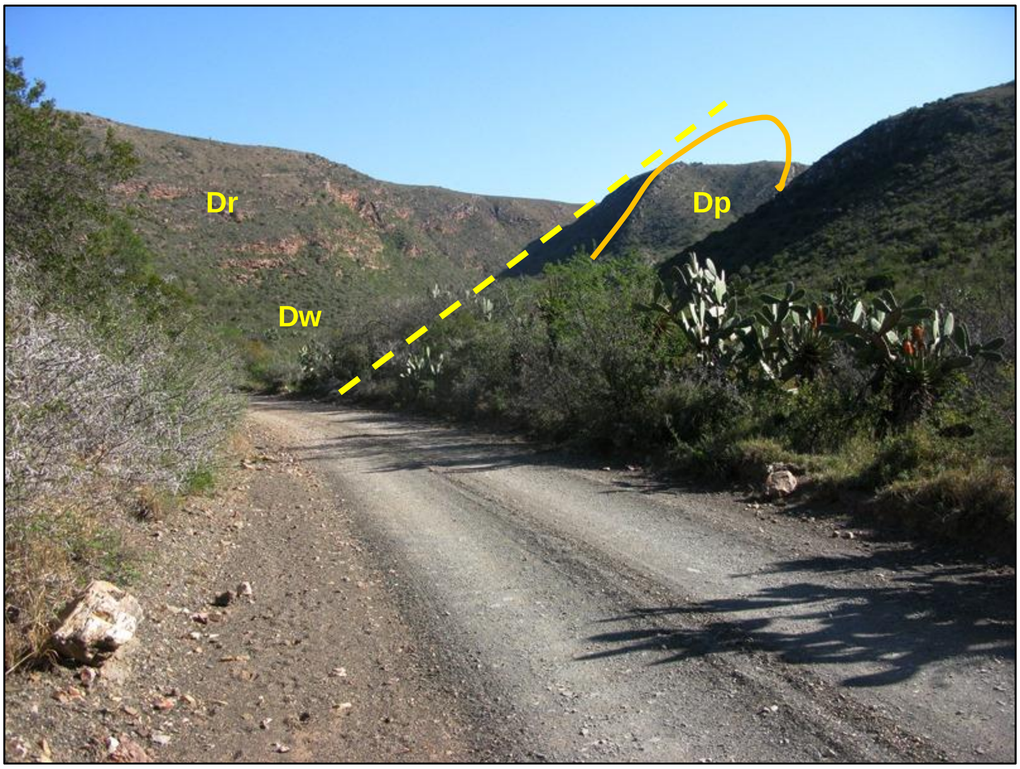

Fig. 8. View westwards along the axis of the Klein-Winterhoek range from Perdepoort. In the distance the Weltevrede Formation (Dw) and Rooirand Member (Dr) are thrust northwards over a tight, north-verging anticline of the Perdepoort Member (Dp). The dashed line marks the approximate location of a major thrust plane. Note the

subhorizontal pediment surface truncating the Klein-Winterhoek range here (Loc. 428).

Fig. 9. Steeply-dipping, upward-shallowing packages (parasequences) of tabular-bedded quartzites of the Rooirand Member, Witpoort Formation, exposed in Soutkloof, *c*. 16.5 km east of Kleinpoort.

Fig. 10. Low exposure of WNW-ESE striking, steeply south-dipping Witpoort quartzites (Rooirand Member) on the summit plateau, Salt Pans Neck 287 (Loc. 419).

Fig. 11. Float block of highly brecciated and ferruginised Witpoort quartzite reflecting intense local fault-related tectonism along the Klein-Winterhoek range, Salt Pans Neck 287 (Hammer = 30 cm).

Fig. 12. Generally poor bedrock exposure on the Klein-Winterhoekberge summit plateau, with Witpoort Formation bedrocks largely obscured by vegetation and downwasted quartzitic gravels, Salt Pans Neck 287.

Fig. 13. Northern flanks of the Klein-Winterhoek ridge (Salt Pans Neck 287) showing dense vegetation cover, limited exposure of Perdepoort Member quartzites in incised stream gullies, as well as poorly-sorted, gravelly colluvial deposits mantling the footslopes (foreground). These last overlie upper Witteberg Group bedrocks.

Fig. 14. Crudely-bedded, rubbly colluvial deposits in Sout Pan Nek along the R75 just west of the Wolf WEF study area. The angular quartzite clasts are embedded in a highly calcretised finer-grained matrix (Loc. 418).

Fig. 15. Pale, weathered, steeply-dipping Witpoort quartzites on the northern flank of the Klein-Winterhoek range mantled by thick gravelly colluvial deposits and soil (Hammer = 30 cm).

Fig. 16. Roadside exposures of Witpoort Formation quartzites in Kleinpoort gorge, *c.* 1 km north of Wolwefontein Substation.

2.2. Geology of the 132 kV transmission line study area

The study area for the proposed 132 kV transmission line connection to the existing Wolwefontein Substation (orange rectangle in Fig. 4) transects low lying (*c*. 600-700 m amsl), highly dissected hilly terrain lying between the Klein-Winterhoek and Grootrivier mountain ranges. This region is underlain by a megasyncline within bedrocks of the upper **Witteberg Group** (**Lake Mentz** and **Kommadagga Subgroups**, with numerous constituent formations), **Dwyka Group** (Elandsvlei Formation) and **Ecca Group** (Prince Albert, Whitehill, Collingham and Ripon Formations). The eastern extremity of the Grootrivier mountain range, around Kleinpoort gorge, has a comparable stratigraphy and structure to the Klein-Winterhoek range to the north, and is also thrust-faulted.

Immediately to the south of Kleinpoort gorge the folded Cape Supergroup bedrocks are unconformably overlain by much younger, broadly south-dipping continental red-bed sediments of the **Enon Formation** (Uitenhage Group) of Late Jurassic age (Je, red in Fig. 4). This major geological boundary represents the northern edge of the Algoa Basin which developed in relation to the final break-up of Gondwana (McLachlan & Anderson 1976, Shone 2006).

- **Upper Witteberg Group**

Above the Witpoort Formation the upper Witteberg Group succession comprises seven, mostly thin, sedimentary formations of Early Carboniferous age that are grouped within the Lake Mentz and Kommadagga Subgroups. The former subgroup was deposited across the entire length of the Cape Basin whereas the latter subgroup is only recorded from the Eastern Cape, perhaps in part due to more pronounced pre-Dwyka erosion further to the west. Since detailed mapping of these thin, poorly-exposed formations is rather difficult, all the Early Carboniferous formations are grouped together as a single composite stratigraphic unit on the 1: 250 000 geological maps (Dl, pale green in Fig. 4).

The **Kweekvlei Formation** at the base of the Lake Mentz Subgroup consists essentially of an upward-coarsening, shoaling succession of dark grey micaceous mudrocks with an increasing proportion of thin-bedded sandstones towards the top. It reaches a thickness of some 200 m in the eastern Witteberg Group outcrop area. Dominant sedimentary structures include horizontal, lenticular, flaser and wavy lamination, with storm-generated hummocky cross-stratification occurring within thicker, well-sorted sandstones in the uppermost part of the succession. The Kweekvlei Formation represents a laterally extensive, non-marine sedimentary package recording a major post-glacial flooding event following the latest Devonian Gondwana glaciation (Almond *et al.* 2002).

The recessive-weathering Kweekvlei Formation is very poorly exposed within the Wolf WEF transmission line study area where it is usually mantled with Witpoort quartzite colluvium as well as other superficial deposits. The only good exposure examined during this study was found in a small borrow pit just north of Soutkloof, *c*. 16 km east of Kleinpoort (Groot Poort 74). The siltstones are fissile, grey- to brownish-weathering with intervals of thin-bedded sandstones or wackes (Fig. 17). The succession is overturned towards the north and further evidence for tectonic disturbance is seen in the form of quartz veining as well as disrupted sandstone beds towards the top of the succession. Weathered and secondarily calcretised mudrocks exposed in a large borrow pit at the northern end of Kleinpoort gorge, just southwest of the Kleinpoort settlement, probably also belong to the Kweekvlei Formation (Fig. 18).

The Early Carboniferous (Tournaisian / Visean) **Floriskraal Formation** (**Df**) consists of several sandstone-dominated shoaling cycles that tend to form prominent, laterally persistent, yellowish-brown ridges sandwiched between the recessive weathering Kweekvlei and Waaipoort Formations. Tabular cross-bedding as well as tempestite-related sedimentary features (*e.g.* hummocky and swaley cross-stratification, interference ripples, flaggy sandstones with primary current lineation, wave ripple lamination of micaceous siltstones) and frequent winnowed pebbly horizons suggest deposition in an extensive but shallow, storm-influenced lake or lagoon (Broquet 1992). Sandstones here are often texturally and compositionally less mature than those of the lower Witteberg formations. Poorly-sorted gritty and feldspathic facies are common, and wackes may grade into diamictite-like rocks (Gresse & Theron 1992). Occasional pebbles of exotic (extra-basinal) lithologies such as granites hint at a possible reworking of glacial debris in the provenance area (Loock 1967).

Floriskraal Formation beds exposed just north of Soutkloof (Groot Poort 74) are highly brecciated and quartz veined, reflecting high levels of tectonic deformation of the Witteberg succession in this region (Figs. 19 & 20).

The upper part of the Lake Mentz Subgroup is formed by the thick (*c*. 460 m), recessive-weathering **Waaipoort Formation** (**Cw**) of Early Carboniferous (Tournaisian / Visean) age. The Waaipoort succession typically contains a wide range of sedimentary facies (rock types), including dark micaceous siltstones and fine sandstones, many of which feature prominent, pervasive wavy cross-lamination. The environmental setting of this formation – perhaps lacustrine or lagoonal – remains equivocal (Evans 1997, 1999, 2005). Good exposures of the Waaipoort sediments are generally scarce, due to its recessive-weathering nature and extensive drift cover, although there are several informative road, railway cutting and stream sections in the present study region. Mudrock facies may show high levels of deep chemical weathering, with secondary kaolinitisation and mineral veining.

Waaipoort Formation exposures examined during fieldwork within and close to the Wolf WEF transmission line study area include several road cuttings through steeply-dipping to subvertical, grey-green to brown-weathering wackes and greyish silstones along the R75 to the east of Kleinpoort (Fig. 21) as well as highly deformed, folded and faulted heterolithic beds in the vicinity of Rietfontein homestead that also show evidence for soft-sediment deformation such as load casts (Governments Kop 57) (Fig. 22). In all cases, the Witteberg bedrocks are mantled with thick rubbly colluvium (up to 3 m locally) and in the latter locality the outcrop is pervasively cleaved.

Fig. 17. Steeply-dipping, thin-bedded siltstones and wackes of the Kweekvlei Formation just north of Soutkloof (Groot Poort 74) (Loc. 426a) (Hammer = 30 cm).

Fig. 18. Large borrow pit at the northern end of Kleinpoort gorge, probably excavated into laminated mudrocks of the Kweekvlei Formation, here highly weathered and calcretised near-surface. Farm Blaauwbosch Kuil 669 (Loc. 433).

Fig. 19. Ridge of highly tectonised, brecciated and quartz-veined Floriskraal Formation sandstones exposed just northwest of Soutkloof (Groot Poort 74) (Loc. 426b).

Fig. 20. Detail of highly tectonised Floriskraal sandstones, Groot Poort 74 (scale is 15 cm long).

Fig. 21. Steeply-dipping wackes of the Waaipoort Formation exposed along the R75 to the southeast of Kleinpoort (Farm Klein Poort 11). Note thick mantle of colluval rubble, calcretised below (cream) and ferruginised above (orange) (Loc. 423).

Fig. 22. Steeply-dipping, faulted and cleaved succession of interbedded wackes and siltstones of the Waaipoort Formation, road cutting near Rietfontein homestead (Loc. 426c).

The **Kommadagga Subgroup** of the Eastern Cape is a thin (430 m to 250 m), glacially-influenced succession of shallow marine siliclastic sediments of Early Carboniferous age that forms the uppermost part of the Witteberg Group in the Eastern Cape (Willowmore – Grahamstown region) (Loock 1967, Johnson 1976, Swart 1982, Toerien & Hill 1989, Johnson & Le Roux 1994). It is paraconformably or uncomformably overlain by the Dwyka Group. The four constituent formations of the Kommadagga Subgroup vary in thickness along strike and may be absent in some areas, in part due to pre-Dwyka erosion. The lenticular, sparsely pebbly, massive, dark grey, sandy diamictites of the basal **Miller Formation** (10-95 m thick) may be of debris flow rather than direct glacial melt-out origin. The pebbles are mainly of quartz and black chert. This unit interfingers with pale, sparsely to highly pebbly, laminated quartzites or siliceous sandstones of the **Swartwaterspoort Formation** (*c*. 6-10 m or less) that are characterised by chaotic bedding, including convoluted intraformational folds. This deformation has been variously linked to slumping or subglacial deformation. The horizontally-laminated pebbly sands may have been originally deposited in a beach setting with reworking of poorly-sorted glacial outwash or tillite. Thinly-laminated offshore mudrocks of the overlying **Soutkloof Formation** (45-165 m) include rhythmitites towards the base; these are possibly glacially-related seasonal varves. They form the lower portion of a major shallowing-upwards cycle that grades up into the fine- to medium-grained, well-sorted, grey, feldspathic to lithofeldspathic sandstones of the **Dirkskraal Formation** (175 m or less). A shallow shoreface or even beach setting for this last unit has been proposed (Johnson & Le Roux 1994). The Kommadagga Subgroup in its type area near Kommadagga and Saltaire Stations, some 22 km to the west of Riebeek East, is approximately 260 m thick (Toerien & Hill 1989).

Apart from the prominent-weathering Swartwaterspoort quartzites, the Kommadagga Subgroup rock units are very poorly exposed in the study area and are often highly deformed (Fig. 23).

Fig. 23. Steeply-dipping, deformed outcrop of the Kommadagga Subgroup on Matjesgoed Fontein 11, *c*. 3 km ESE of Kleinpoort, younging towards the north (left). The prominent-weathering pale ridge is the Swartwaterspoort Formation.

- **Dwyka Group**

The Late Carboniferous to Early Permian sediments of the **Elandsvlei Formation** (**Dwyka Group, C-Pd**), the oldest sediments of the Main Karoo Basin, were deposited as glacial tillites and interglacial mudrocks in a shallow epicontinental sea on the margins of Gondwana. The geology of the Dwyka Group has been summarized by Visser (2003), Visser *et al.* (1990) and Johnson *et al.* (2006), among others.

The generally massive, well-consolidated Dwyka tillites are more erosion-resistant than most of the uppermost Witteberg and lower Ecca rocks that lie stratigraphically below and above. They therefore tend to build topographic highs in the Eastern Cape study region. Thinner-bedded, mudrock-rich interglacial intervals are generally poorly exposed.

Dwyka tilllites displaying the typical tombstone weathering style are well seen close to the road about one kilometre to the north of Rietfontein homestead (Governments Kop 57) (Fig. 24) but otherwise are poorly exposed within the study region.

Fig. 24. Dwyka Group tillites exposed on hillslopes *c*. 1 km north of Rietfontein homestead, Governments Kop 57 (Loc. 427a). Note typical tombstone weathering.

- **Ecca Group**

The glacio-marine rocks of the Dwyka Group are overlain by dark basinal, submarine fan and deltaic mudrocks and fine-grained wackes of the Early to Middle Permian Ecca Group. Useful overviews of the geology of the Ecca Group are given by Johnson *et al.* (2006) and Johnson (2009). The fossil record of the Ecca Group in the Western Cape has recently been reviewed by Almond (2008a, b). These marine to brackish water or lacustrine sediments crop out in the central, undulating hilly portion of the broad valley between the Klein Wingterhoek and Groot Winterhoek ranges (Fig. 4).

The Dwyka Group is conformably overlain by post-glacial basinal mudrocks of the **Prince Albert Formation** (**Pp** in part), the lowermost subunit of the Ecca Group. This thin-bedded to laminated mudrock-dominated succession of Early Permian (Asselian / Artinskian) age was previously known as "Upper Dwyka Shales". Key geological accounts of this formation are given by Visser (1992) and Cole (2005). The Prince Albert succession consists mainly of thin-, tabular-bedded mudrocks of blue-grey, olive-grey to reddish-brown colour with occasional thin (dm) buff sandstones and even thinner (few cm), soft-weathering layers of yellowish water-lain tuff (*i.e.* volcanic ash layers). Extensive diagenetic modification of these sediments has led to the formation of thin cherty beds, pearly- blue phosphatic nodules, rusty iron carbonate nodules, as well as beds and elongate ellipitical concretions impregnated with iron and manganese minerals. These last occur within prominent-weathering, metallic-looking beds, some of which display well-developed snuffbox weathering and concentric *Liesegang* rings. As a result of their rich iron and manganese ore content, surface gravels derived from the Prince Albert Formation often develop a metallic "desert varnish".

Yellowish- and brown-weathering shales and thin-bedded sandstones of the Prince Albert Formation are exposed in road cuttings just north of Waterplaas homestead (Farm Koms 53) *en route* to Perdepoort gorge (Fig. 25). The thin beds are highly jointed, steeply-dipping and laminated. There are also good exposures of khaki to grey-green, highly-cleaved mudrocks with phosphatic and siliceous diagenetic concretions exposed in borrow pits on farm Hartebeesfontein 15 (Fig. 26). The Prince Albert Formation is intensely folded at both these localities, with a well-developed axial-planar cleavage, as often observed within the Cape Fold Belt.

The **Whitehill Formation** (Pp in part) is a thin (*c*. 30m) succession of well-laminated, carbon-rich mudrocks of Early Permian (Artinskian) age that forms part of the lower Ecca Group. These sediments were laid down about 278 Ma in an extensive shallow, brackish to freshwater basin – the Ecca Sea – that stretched across southwestern Gondwana, from southern Africa into South America (McLachlan & Anderson 1971, Oelofsen 1981, 1987, Visser 1992, 1994, Cole & Basson 1991, MacRae 1999, McCarthy & Rubidge 2005, Johnson *et al*. 2006). Fresh Whitehill mudrocks are black and pyritic due to their high content of fine-grained organic carbon, probably derived from persistent or seasonal phytoplankton blooms that promoted anoxic conditions on the Ecca Sea bed. Near-surface weathering of the pyrite leads to the formation of gypsum, lending a pale grey colour to the Whitehill outcrop (hence informally known as the "*Witband*"). Large (meter-scale) diagenetic nodules and lenses of tough, greyish dolomite are common and often display a stromatolite-like fine-scale banding.

Limited exposures of white-weathering Whitehill Formation mudrocks, together with large dolomite concretions, are seen in a borrow pit on Vaalfontein 12, just south of the homestead (Loc. 432) (Figs. 27 & 28).

The tabular-bedded **Collingham Formation** (**Pp** in part) is characterized by the regular "striped" alternation of thin-bedded, well-jointed siliceous mudrocks and soft-weathering pale yellow tuffs (*i.e.* volcanic ash layers) (Viljoen 1992, 1994). These tuffs have been radiometrically dated to 270 Ma or Middle Permian. Basinal mudrocks and tuffs deposited by suspension settling in the lower part of the Collingham give way higher up to thicker, tabular-bedded turbidite units deposited by sediment gravity flows. The Collingham Formation is more resistant to erosion than the adjacent Lower Ecca sediments and often forms a subdued ridge in the landscape. No good exposures of the Collingham Formation were seen during the present field study.

The **Ripon Formation** (**Pr**) crops out along the southeastern margin of the Main Karoo Basin from Prince Albert eastwards. This is a thick, non-marine submarine fan succession comprising tabular-bedded greywackes, rhythmitites and dark mudrocks deposited by turbidity current and suspension settling processes (Johnson 1976, Kingsley 1977, Kingsley 1981, Johnson & Kingsley 1993, Catuneanu *et al.* 2005, Johnson *et al.* 2006). The Ripon succession thickens across the Port Elizabeth sheet area from 600 m in the west to 900 m in the east (Toerien & Hill 1989).

The Ripon Formation builds the core of a major syncline within the 132 kV transmission line study area. It forms gently hilly terrain but bedock exposure away from stream beds and occasional road cuttings is generally poor (Fig. 29). Stream bank exposures on Hartebeesfontein 15 show dark grey, apparently massive mudrocks overlain by well-bedded brownish wackes (Fig. 30). Both the mudrocks and wackes show a pervasive penetrative cleavage (Fig. 31).

Fig. 25. Steeply-dippping, thin-bedded shales and sandstones of the Prince Albert Formation north of Waterplaas, Farm Koms 53 (Loc. 427b) (Hammer = 30 cm).

Fig. 26. Gently-dipping, well-bedded mudrocks of the Prince Albert Formation transected by a pervasive subvertical tectonic cleavage, borrow pit on Hartebeestefontein 15 (Loc. 429) (Hammer = 30 cm).

Fig. 27. Borrow pit exposure of white-weathering mudrocks of the Whitehill Formation, Vaalfontein 12 (Loc. 432) (Hammer = 30 cm).

Fig. 28. Boulder-sized diagenetic concretion of grey dolomite embedded within the Whitehill Formation, borrow pit on Vaalfontein 12 (Loc. 432) (Hammer = 30 cm). Such concretions are sometimes associated with well-preserved crustacean fossils in the W. Cape.

Fig. 29. Hilly terrain with little bedrock exposure underlain by the Ripon Formation, looking southwestwards towards Koedoeskloof on farm Cauchafsie 60.

Fig. 30. Stream bank exposure of dark mudrocks and brownish wackes of the Ripon Formation, Hartebeesfontein 15 (Loc. 430).

Fig. 31. Close-up of well-bedded silty mudrocks of the Ripon Formation on Hartebeesfontein 15 showing well-developed, steeply-inclined tectonic cleavage.

- **Enon Formation**

The southernmost sector of the Wolf WEF transmission line study area, south of Kleinpoort, lies within the northern margin of the extensive Algoa Basin of the Eastern Cape. This basin is infilled with a 3.5 km thick succession of alluvial fan, fluvial and estuarine to marine shelf sediments of Late Jurassic to Early Cretaceous age (*c*. 150-125 Ma) that are referred to the **Uitenhage Group** (McLachlan & Anderson 1976, Shone 2006). The continental sediments of the Uitenhage Group were laid down in a spectrum of depositional settings on or close to the margins of the newly developing African continent during the Late Jurassic to Early Cretaceous Period (Du Toit 1954, McLachlan & McMillan 1976, Tankard *et al.* 1982, Dingle *et al.* 1983, Shone 2006). They include coarse breccio-conglomerates deposited in piedmont fans ("fanglomerates") and highly energetic braided rivers, pebbly conglomerates and sandstones in meandering river channels, overbank mudrocks (mainly silty alluvium) with occasional lacustrine mudrocks too. Thin to 4 m-thick volcanic tuffs or tuffites (volcanic ash mixed with siliciclastic sediment) have also been recorded from the Uitenhage Group succession.

The Uitenhage Group sediments in the present study area are mapped on the 1: 250 000 Port Elizabeth sheet as belonging to the **Enon Formation** (**J-Ke**), here unconformably overlying the Late Devonian sediments of the Witteberg Group that build the Grootrivierberge mountain ridges to the north. The Enon Formation is characterized by coarse, immature piedmont fanconglomerates or breccio-conglomerates of Late Jurassic to Early Cretaceous age. Successions with intermittent cross-bedded sandstone interbeds and well-developed pebble imbrication were deposited within high-energy braided river systems that grade or interdigitate southwards as well as upwards into meandering fluvial sediments ("wood beds" and "variegated marls") of the Kirkwood Formation, as well seen in the Kirkwood area itself. Larger clasts within the typically reddish-brown Enon conglomerates consist primarily of poorly-sorted Cape Supergroup quartzites, are often well-rounded and secondarily stained with iron oxides, and may be cracked as a result of overburden pressure. The Enon Formation within the Algoa Basin reaches thicknesses of some 300-500 m in its type area which lies close to the Enon Mission Station (Winter 1973, Hill 1975, McLachlan & McMillan 1976, Dingle *et al.* 1983). According to these last authors (ibid., p. 112 and their fig. 77), in its type area the Enon Formation comprises a thin basal breccio-conglomerate (*c*. 20 m) followed by *c*. 170 m of volcanic rocks (tuffs and basalts) and then *c*. 300 m of conglomerates and sandstones. However, the Middle to Late Jurassic volcanics along the northern margins of the Algoa Basin are now considered to constitute a stratigraphically separate **Suurberg Group** of pre-Enon age (Hill 1975, Toerien & Hill 1989). These Jurassic volcanic rocks are shown in red (Js) and purple (Jm) on the Port Elizabeth geological map, for example just southeast of Kleinpoort, but they do not crop out in the present study area and are not considered further here.

Excellent exposures of the Enon conglomerates are seen in typical gully-dissected hilly terrain on farm Roode Krantz 72 on the south side of the R75, some 15.5 km ESE of Kleinpoort (Fig. 32). In contrast, these beds are very poorly exposed in the subdued terrain south of the Grootrivierberge, between Kleinpoort gorge and the Wolwefontein Substation. It is noted that future re-assessment of the ruditic red beds mapped as Enon on the 1: 250 000 Port Elizabeth sheet may reassign some of them to the somewhat younger (Early Cretaceous) Buffelskloof Formation.

Fig. 32. Excellent hillslope exposures of south-dipping, orange-hued Enon Formation conglomerates, with thin pale sandstone interbeds, Roode Krantz 72 (Loc. 425).

- **Superficial deposits**

Bedrocks beneath the low-lying terrain between the Klein-Winterhoek and Grootrivier Mountains are largely mantled with thick superficial deposits including silty to gravelly alluvium associated with numerous small stream courses, poorly-sorted colluvial deposits (especially close to the mountain fronts) as well as soils and downwasted surface gravels. Good exposures through these deposits are seen in extensive networks of erosional gullies or *dongas*, such as those examined for fossils on Salt Pans Neck 287 and Hartebeestefontein 15 (Figs. 13 to 17). At the latter locality, most of the succession overlying the Dwyka bedrock comprises several (3-4) meters of yellowish-brown weathering older alluvium with dispersed gravels and gravel layers - mainly angular to rounded quartzite, vein quartz, chert and ferricrete, the first sometimes flaked. These older deposits show increasing calcretisation towards the top. They are sharply overlain by a thin orange-brown subsoil with very sparse, often ferruginised gravels (occasionally flaked) and then by darker brown modern soils with dispersed gravel clasts. Given the abundance of flaked Middle Stone Age artefacts within at least the upper part of the succession, these deposits are probably Pleistocene age or younger.

Fig. 33. View southwards from the plateau of the Klein-Winterhoekberge showing low relief terrain to the south bounded by the Grootrivierberge (Arrow indicates Kleinpoort). Note extensive donga erosion of thick superficial deposits associated with drainage courses here. Groot-Winterhoek mountains in the background.

Fig. 34. Extensive erosion donga exposure of Pleistocene and younger alluvium, Hartebeestefontein 15 (Loc. 431).

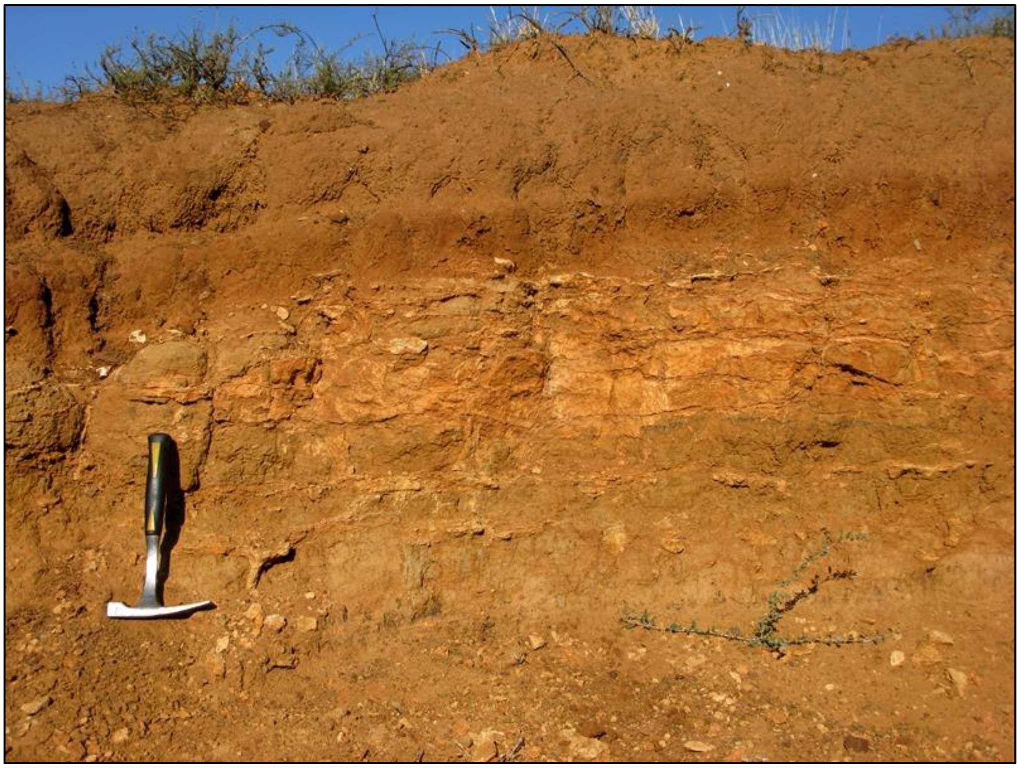

Fig. 35. Detail of thick, older calcretised silty alluvium shown in the previous figure, capped by orange-brown subsoil and brownish modern soil (Hammer = 30 cm).

Fig. 36. Oligomict downwasted surface gravels overlying the older alluvium outcrop area, Hartebeestefontein 15 (Hammer = 30 cm). Many of the paler quartzite clasts are anthropogenically flaked.

Fig. 37. Poorly-sorted silty alluvium and downwasted colluvial gravels exposed by gulley erosion in the southern foothills of the Klein-Winterhoek range, Salt Pans Neck 287 (Hammer = 30 cm).

3. PALAEONTOLOGICAL HERITAGE

A brief review of the fossil assemblages recorded from the various geological formations that are represented within the Wolf WEF study area near Steytlerville is given here, based largely on data compiled a previous report for the Kommadagga region some 100 km to the east (Almond 2013). Most of these sedimentary rock units are only sparsely fossiliferous. The palaeontological sensitivity of several potentially fossiliferous mudrock units has been seriously compromised in the Wolf WEF study region as a result of high levels of tectonic deformation (*e.g.* folding, cleavage formation, brecciation and quartz veining) as well as deep chemical weathering since the fragmentation of Gondwana some 120 million years ago. The outcrop areas of the mudrock-rich sedimentary successions that are most likely to yield fossil remains (*e.g.* the Waaipoort and Whitehill Formations) are narrow and ill-defined; most are not separately mapped at 1: 250 000 scale. Furthermore, the less resistant-weathering sedimentary rocks are largely mantled in a substantial veneer of superficial deposits such as soil, alluvium, colluvium and downwasted rock rubble. These surface deposits may shield many (but not all) of the fossiliferous bedrocks from significant disturbance during development except, of course, where deep excavations are involved (*e.g.* for wind turbine foundations).

3.1. Fossils in the Witteberg Group

Few fossils have been recorded so far from the bulk of the **Witpoort Formation** outcrop area, especially from the more prominent-weathering quartzitic facies which are the only rocks exposed at surface in many upland areas. Fossils recorded in the generally less deformed Western Cape outcrop area include a few vascular plants within sandstone facies of both the Rooirand and Perdepoort Members (*e.g.* the lycopod *Haplostigma*) and undescribed Fammenian palynomorphs (Plumstead 1967, Almond *et al*. 2002). Highly impoverished trace fossil assemblages include vertical burrows (*Skolithos*, *Monocraterion*), horizontal burrows with a differentiated mantle and central core (possibly *Nereites*), and *Spirophyton*, which is not recorded higher than the Rooirand Member. In contrast, an extraordinarily rich high latitude biota of Late Devonian fish, arthropods, vascular plants, algae and trace fossils has been described from dark lagoonal mudrocks within the upper Witpoort near Grahamstown in the Eastern Cape Province, with exciting new taxa such as fossil lampreys and early tetrapodomorphs still emerging (*e.g.* Anderson & Anderson 1985, Rayner 1988, Hiller & Taylor 1992, Anderson *et al.* 1994, Gess & Hiller 1995, Anderson *et al*. 1995, 1999, Long *et al.* 1997, Gess 2001, 2002, Gess *et al*. 2006, Gess 2012 and work in progress). The fish fauna consists of armoured placoderms, sharks, several acanthodians, palaeoniscoids, crossopterygians (including coelacanths, osteolepiforms and lungfish) and an early lamprey. The arthropods include ostracods, scorpions and a cyrtoctenid (comb-footed) eurypterid. Lenticles of dark laminated siltstones with fragmentary kaolinitized plant remains that are reminiscent of the Grahamstown fossils have also been found in the Western Cape (J. Almond & F. Evans, pers. obs.). It is likely that comparable lenses of lagoonal mudrocks occur sporadically throughout the Witpoort Formation outcrop area but are only very rarely exposed due to their recessive-weathering character.

No fossil remains were recorded from the Witpoort Formation in the Wolf WEF study area during the present field assessment. Potentially fossiliferous mudrock intervals are not exposed at surface on the planed-off anticlinal crests of Witpoort rocks where the proposed wind turbines are to be situated. Siltstone-rich successions occur within the lower parts of upward-coarsening shoaling cycles (parasequences), as seen in various poorts to the east of the WEF study area (*e.g.* Perdepoort, Soutkloof), and are likely to contain low diversity shallow marine trace fossil assemblages, but no examples were observed.

The fossil record of the **Kweekvlei Formation** has been briefly reviewed by Almond (2008b). Dark, post-glacial mudrocks of the Kweekvlei Formation in the southern Cederberg and elsewhere contain sparse to abundant low diversity trace fossil assemblages, notably *Teichichnus* and horizontal back-filled burrows, especially in the upper, silty to sandy parts of the upward shoaling succession (Almond 1998, 2008b). Transported fragments of vascular plants, preserved in some cases within nodules, are also found in the upper Kweekvlei (Anderson & Anderson 1985, Evans 2005, J.C. Loock pers. comm., J. Almond pers. obs.). Simply branched, leafless woody stems, some of them with fine striations, have been provisionally assigned to the problematic genus *Praeramunculus*. This is possibly a propteridophyte (McLoughlin & Long 1994) or a progymnosperm (Gess & Hiller 1995). Lycopods are referred to the genus *Archaeosigillaria*. Fish fossils referred to the Kweekvlei by Anderson and Anderson (1985) are misassigned, although fish remains may indeed be present here. Restricted salinities, low temperatures at high palaeolatitudes and perhaps also bottom anoxia may be implicated in the paucity of body and trace fossils within this post-glacial mudrock unit (*cf* Broquet 1992, Almond 1998b). Attempts to isolate organic-walled microfossils from black mudrock facies towards the base of the Kweekvlei Formation have so far proved unsuccessful.

Apart from low diversity trace fossil assemblages of some palaeontological interest on Groot Poort 74 (Figs. 18 and 19), no fossil remains were recorded within **Kweekvlei mudrocks** during the present field assessment. Exposure levels are generally very low and the palaeontological sensitivity of these sediments has been widely compromised by cleavage formation and near-surface weathering (Fig. 18).

The sparse body fossil record of the **Floriskraal Formation** includes reworked vascular plant debris, sometimes current-orientated, on the tops of flaggy sandstones. Occasional large lycopod fragments may belong to the peculiar genus *Longicicatrix* (*cf* Anderson & Anderson 1985). There are unconfirmed records of acanthodian fish (so-called spiny sharks) within "phosphatic limestone" nodules near Touwsrivier (Evans 1997, 2005). Dense, monospecific assemblages of horizontal burrows (*Palaeophycus*) are characteristic of the Floriskraal Formation and poorly-preserved wash-out traces, possibly including members of the *Scolicia* Group, are also widely seen (Almond 2008b). The low diversity of ichnogenera recorded from this formation as well as the absence of *Spirophyton* support a non-marine setting for the Floriskraal Formation. The Floriskraal sandstones examined during the present field study were too tectonised to yield useful traces or other fossils (Fig. 20).

The **Waaipoort Formation** contains the only substantial fossil biota of Carboniferous age from South Africa. The depositional environment is variously interpreted as an extensive brackish lagoon or a freshwater, perhaps glacially-influenced, lake situated at high, subpolar palaeolatitudes (Broquet 1992, Evans 1999, 2005). A moderately diverse, non-marine fish / plant biota of Tournaisian (Early Carboniferous) age is preserved within diagenetic "phosphatic limestone" nodules. The Waaipoort fish fauna includes a range of palaeoniscoids (primitive actinopterygians or ray-finned bony fish), chondrichthyans (ctenacanthiform sharks, possible chimaeroids), two or more acanthodians, and perhaps also rare sarcopterygians (lobe-finned bony fish) (Theron 1962, Marais 1963, Jubb 1965, Loock 1967, Gardiner 1969, 1973, Jubb & Gardiner 1975, Oelofsen 1981, Evans 1997, 1998, 1999, 2005). Many of the palaeoniscoids and as well as some sharks and acanthodians are well-articulated to quite intact, suggesting that bottom anoxia may have excluded scavengers, at least intermittently. Impressive mass mortality "fish beds" in the Eastern Cape – for example from the Darlington Dam / Lake Mentz area less than 15 km NE of the proposed Wolf WEF - have been variously attributed to episodic overturn of the restricted Waaipoort water body, phytoplankton blooms, or the sudden influx of cold glacial meltwaters (Evans 1998, 1999). The only invertebrates recorded in the Waaipoort Formation are rare thin-shelled bivalves (probably non-marine unionids) and a giant sweep-feeding cyrtoctenid eurypterid (Waterston *et al*. 1985). Vascular plant remains, comprising the lycopod *Archaeosigillaria*, branched axes of the problematic *Praeramunculus* and additional unnamed forms, are locally abundant but notably low in diversity (Plumstead 1967, Loock 1967, Anderson & Anderson 1985, Evans 1999). They are often preserved as dense clumps of transported debris, with or without disarticulated fish remains (*e.g.* scales, bony dermal plates), within phosphatic carbonate diagenetic nodules. Reproductive organs of charophytes or stoneworts, an advanced group of fresh / brackish water algae, are reported from the Prince Albert area. A range of Tournaisian miospores has been isolated from Waaipoort nodules, where they have been partially protected from diagenetic alteration (Streel and Theron 1999). Waaipoort ichnoassemblages are restricted and bioturbation indices are generally low, favouring a non-marine environmental interpretation.

No fossil remains were observed from the Waaipoort Formation during the present field assessment. The bedrocks here tend to be highly deformed (folded, faulted) and potentially fossiliferous mudrocks are often cleaved (Fig. 22). It is noted, however, that one of the richest fossil fish localities recorded in the Waaipoort Formation is close to Lake Mentz / Darlington Dam, within 15 km to the NE of the proposed Wolf WEF.

Little is known about the fossil record of the **Kommadagga Subgroup** of Early Carboniferous age which lies at the top of the Witteberg Group succession in the Eastern Cape (Loock 1967, Rossouw 1970, Johnson 1976, Swart 1982, Loock & Visser 1985, Johnson & Le Roux 1994, Theron 1994, Thamm & Johnson 2006). Impoverished contemporary biotas may have been ecologically restricted by high, near-polar palaeolatitudes and intermittent Gondwana glaciation. The dark diamictites of the Miller Formation have yielded palynomorph assemblages and rare vascular plant fragments (Stapleton 1977a). Fragmentary, poorly-preserved plant material, including lycopods, as well as trace fossils are recorded from the Dirkskraal Formation in the Kommadagga type area (*cf* Almond 2013).

The Kommadagga Subgroup succession in the Wolf WEF study area is very poorly exposed, apart from the unfossiliferous Swartwaterspoort quartzites. No fossil remains were recorded from these Early Carboniferous rocks during the present field study.

3.2. Fossils in the Dwyka Group

The Dwyka Group in the southern portion of the Main Karoo Basin has a generally poor fossil record (McLachlan & Anderson 1973, Anderson & McLachlan 1976, Visser *et al*., 1990, Von Brunn & Visser 1999, Visser 2003, Almond 2008a, 2008b). This is hardly surprising given the glacial climates that prevailed during much of the Late Carboniferous to Early Permian Periods in southern Africa. However, most Dwyka sediments were deposited during periods of glacial retreat associated with climatic amelioration. Sparse, low diversity fossil biotas within interglacial or postglacial mudrocks mainly consist of arthropod trackways (*e.g. Umfolozia* - probably made by small crustaceans) and fish swimming trails associated with dropstone laminites. Sporadic vascular plant remains mainly comprise drifted wood and leaves of the *Glossopteris* Flora. Palynomorphs are also likely to be present within finer-grained mudrock facies. Glacial diamictites (tillites or "boulder mudstones") are normally unfossiliferous but do occasionally contain fragmentary transported plant material as well as palynomorphs in the fine-grained matrix. Occasional pale grey limestone glacial erratics from tillites along the southern margins of the Great Karoo (Elandsvlei Formation) contain Cambrian eodiscid trilobites as well as archaeocyathid sponges that have been sourced in Antarctica. Such derived fossils provide important data for reconstructing the movement of Gondwana ice sheets (Cooper & Oosthuizen 1974).

No fossil remains were recorded from the Dwyka Group within the Wolf WEF study area. The poorly-exposed Dwyka tillites examined here are unlikely to contain fossil remains.

3.3. Fossils in the Ecca Group

The fossil biota of the post-glacial mudrocks of the **Prince Albert Formation** is usefully summarized by Cole (2005). Typical trace fossil assemblages of the non-marine *Mermia* Ichnofacies commonly are dominated by delicate arthropod trackways (especially *Umfolozia*), scratch burrows or furrows (*Isopodichnus*), arthropod resting traces (*Gluckstadtella*) and undulose fish fin trails (*Undichna*) (*e.g.* Anderson 1974, 1976, 1981). More complex arthropod traces, some of them possible generated by small eurypterids, are also known. Diagenetic nodules containing the remains of palaeoniscoids (primitive bony fish), sharks, spiral bromalites (coprolites *etc.*) and wood have been found in the Ceres Karoo and rare shark remains (*Dwykaselachus*) occur near Prince Albert on the southern margin of the Great Karoo (Oelofsen 1986). Microfossil remains in this formation include sponge spicules, foraminiferal and radiolarian protozoans, acritarchs and miospores.

The Prince Albert mudrocks examined around the Wolf WEF study area (Fig. 28) are highly cleaved with little or no bedding plane exposure. No fossils were recorded within this stratigraphic unit during the present field study.

The **Whitehill Formation** is one of the most fossiliferous stratigraphic units within the Ecca Group (Almond 2008a, 2008b and refs. therein). In brief, the main groups of Early Permian fossils found within the Whitehill Formation include:

- small aquatic mesosaurid reptiles (the earliest known sea-going reptiles)

- rare cephalochordates (ancient relatives of the living lancets)
- a variety of palaeoniscoid fish (primitive bony fish)
- highly abundant small eocarid crustaceans (bottom-living, shrimp-like forms)
- insects (mainly preserved as isolated wings, but some intact specimens also found)
- a low diversity of trace fossils (*e.g.* king crab trackways, possible shark coprolites / faeces)
- palynomorphs (organic-walled spores and pollens)
- petrified wood (mainly of primitive gymnosperms) and other sparse vascular plant remains (*Glossopteris* leaves, lycopods *etc.*).

The stratigraphic distribution of the most prominent fossil groups – mesosaurid reptiles, palaeoniscoid fishes and notocarid crustaceans – within the Whitehill Formation has been documented by several authors, including Oelofsen (1987), Visser (1992) and Evans (2005).

Whitehill Formation exposures in borrow pits within the Wolf WEF study area generally comprise highly weathered, secondarily mineralised pale grey mudrocks (Fig. 27). Greyish-weathering dolomitic nodules are associated with well-preserved crustacean remains at some localities in the Western Cape (*cf* Fig. 28) but fossils were recorded within these sediments during the present field assessment.

The palaeontology of the **Collingham Formation** has been reviewed by Viljoen (1992, 1994) and Almond (2008a). Transported, water-logged plant debris and tool marks generated by logs are often associated with thicker turbidite beds, especially within the upper part of the Collingham Formation. Substantial blocks of silicified wood are known from the Laingsburg area. The heterolithic character of this succession favours trace fossil preservation, with very high levels of bioturbation recorded locally. The abundance of fossil burrows indicates that oxygenation of bottom waters and the sea bed had improved substantially since Whitehill times. Abundant, moderately diverse trace fossil assemblages recorded from the Collingham Formation include horizontal, 2 cm-wide epichnial grooves with obscurely segmented levees ("*Scolicia*", possibly generated by gastropods), narrow, bilobate arthropod furrows ("*Isopodichnus*"), reticulate horizontal burrows (perhaps washed out *Megagrapton*-like systems), densely packed horizontal burrows with a rope-like surface texture covering selected bedding planes (*cf Palaeophycus*), narrow branching burrows, rare arthropod trackways (*Umfolozia*) and fish swimming trails (*Undichna*) (Anderson 1974). The trackway of a giant sweep-feeding eurypterid has been identified from the upper Collingham Formation near Laingsburg, and fragmentary body fossils of similar animals are known from coeval sediments in South America (Almond 2002). At over two metres long, these bottom-feeding arthropod predators are the largest animal so far known from the Ecca Sea.

No good exposures of the Collingham Formation were seen during the present field assessment of the Wolf WEF study area.

The fossil record within the **Ripon Formation** is rather sparse and hitherto has not received much attention from palaeontologists. Fragmentary, compressed plant remains (*e.g.* stems, leaves) of the Permian *Glossopteris* Flora, mostly unidentified, occur sporadically throughout the Ripon succession, especially within the lowermost part. They include flattened silicified logs ("*Dadoxylon*") with well-developed seasonal growth rings (Johnson & Kingsley 1993, their fig. 8). Fossil plant and wood material from the Ripon Formation was not included in the key reviews by Anderson and Anderson (1985) and Bamford (1999, 2004), however. A range of, mostly unidentified, offshore trace fossils are mentioned in the literature (Anderson 1974, Kingsley 1977, Kingsley 1981, Johnson and Kingsley 1993, Johnson *et al.* 2006). They include sporadic to locally abundant arthropod tracks, trails as well as horizontal and (possible) vertical burrows. *Umfolozia* and *Maculichna* arthropod trackways, probable *Quadrispinichna* resting traces ("small vertebrate footprint"), sinuous *Undichna* fish swimming trails and narrow meandering burrows are recorded from Ripon submarine fan facies in the Grahamstown area (Ecca Pass and Great Fish River; Mountain 1946, Haughton 1928, Anderson 1974, 1976, 1981, Kingsley 1981, Almond 2011). It is likely that a wide spectrum of non-marine *Mermia* ichnofacies ichnofossils, as well as various organic-walled microfossils, are represented within this formation, similar to those seen in contemporary turbidite fans in the better-sampled southwestern part of the Ecca Basin (Almond 2008a, b).

No fossils were recorded from the Ripon Formation during the present field assessment.

3.4. Fossils within the Enon Formation

The palaeontological heritage of the coarse-grained facies (conglomerates, breccias) within the Uitenhage Group, including the Enon Formation *sensu stricto*, is currently unclear because of the uncertain stratigraphic position of many records with respect to currently accepted lithostratigraphy. Key references to the earlier literature are given by Du Toit (1956), McLachlan and McMillan (1976), Tankard *et al.* (1982) and Dingle *et al.* (1983). In general, the proximal Uitenhage "red bed" sediments deposited in alluvial fans and energetic braided river systems such as the Enon Formation are fossil-poor. In the eastern Gamtoos Basin lignites, pollens and a range of plant compression fossils are recorded from the Uitenhage Group beds in the scientific literature, but these appear to stem from the Kirkwood Formation rather than the Enon Formation proper (These two units were not distinguished by Haughton *et al*., 1937; the reference by Le Roux, 2000, and Toerien and Hill, 1989, to fossil wood from the Enon is therefore probably erroneous; *cf* also McLachlan & McMillan 1976, Dingle *et al.* 1983). Silicified wood has been recorded, however, from conglomerates of the Enon Formation near Worcester and Nuy in the Western Cape (Sönghe 1934, McLachlan & McMillan 1976, Gresse & Theron 1992). Charred wood fragments are also reported as common within the Enon of the Algoa Basin (Rogers & Du Toit 1909, Haughton & Rogers 1924, McLachlan and McMillan 1976) while unidentifiable carbonized miospores from borehole cores in the same basin are mentioned by Scott (1976a, b). No fossil localities are noted within the Enon Formation in its type area near Enon Mission Station in the key palaeontological review of the Uitenhage Group by McLachlan and McMillan (1976).

No fossil remains were recorded from the Enon Formation during the present field assessment.

3.5. Fossils within Caenozoic superficial deposits

Neogene to Recent alluvial deposits may also contain fossil remains of various types. In coarser sediments (*e.g.* conglomerates) these tend to be robust, highly disarticulated and abraded (*e.g*. rolled bones, teeth of vertebrates) but well-preserved skeletal remains of plants and invertebrate animals as well various trace fossils may be found within fine-grained alluvium. Late Caenozoic fossil biotas from superficial deposits in the broader Karoo region, for example, include non-marine molluscs (freshwater bivalves, gastropods, crustaceans), ostrich egg shells, trace fossils (*e.g.* calcretised termitaria, coprolites, rhizoliths), and plant remains such as wood, carbonized roots, peats or palynomorphs (pollens) in organic-rich alluvial horizons. Human artefacts such as stone tools that can be assigned to a specific interval of the archaeological time scale (*e.g.* Middle Stone Age) can be of value for constraining the age of Pleistocene to Recent drift deposits like alluvial terraces. Ancient alluvial "High Level Gravels" tend to be coarse and to have suffered extensive reworking (*e.g.* winnowing and erosional downwasting), so they are generally unlikely to contain useful fossils.

No fossil remains were recorded from the Late Caenozoic superficial deposits during the present field assessment of the Wolf WEF study area

Fig. 38. Horizontal invertebrate burrow with a granular or pelleted exterior, Kweekvlei Formation just north of Soutkloof (Groot Poort 74) (Loc. 426a) (Scale in cm and mm).

Fig. 39. Variety of invertebrate burrows within the Kweekvlei Formation just north of Soutkloof (Groot Poort 74) (Loc. 426a) including possible *Palaeophycus striatus* (wrinkled wall) and T*eichichnus* (towards top).

4. ASSESSMENT OF IMPACTS ON FOSSIL HERITAGE

The construction phase of the proposed wind energy facility development will entail substantial excavations into the superficial sediment cover (soils, surface gravels *etc.*) and in most cases also into the underlying bedrock. These notably include excavations for the wind turbine and transmission line pylon foundations, underground cables, new internal access roads and foundations for associated infrastructure such as on-site substations and the workshop / administration building. In addition, sizeable areas of potentially fossiliferous bedrock may be sealed-in or sterilized by infrastructure such as hard standing areas for each wind turbine, lay down areas and access roads. All these developments may adversely affect potential fossil heritage exposed at the 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, the operational and decommissioning phases of the wind energy facility will not involve further adverse impacts on palaeontological heritage, however.

Desktop analysis of the fossil records of the various rock units underlying the Wolf WEF study area combined with field assessment of numerous representative rock exposures within and close to this area indicate that the majority of these units are of low to very low palaeontological sensitivity (Section 3). Elsewhere in the Eastern Cape diverse, scientifically important fossil assemblages are recorded within the Witpoort and Waaipoort Formations (both Witteberg Group) as well as the Prince Albert and Whitehill Formations of the Ecca Group (Almond *et al.* 2008). Of these, only the Late Devonian Witpoort Formation – largely comprising resistant-weathering quartzites - will underlie the proposed wind turbine positions along the crest of the Klein-Winterhoek mountain range. There is no field evidence for the presence within the study area of black lagoonal mudrocks within the Witpoort Formation, such as have proved richly fossiliferous in the Grahamstown area (fish, tetrapodomorphs, arthropods, algae, vascular plants, trace fossils *etc.*). It should be noted that comparable fossil-rich mudrock lenses occurrences might be present hidden at depth beneath the cover of superficial sediments, however.

The Early Carboniferous Waaipoort Formation rocks are locally highly fossiliferous (fossil fish, plants *etc.*), for example near Darlington Dam in the Eastern Cape, some 15 km to the northeast of the Wolf WEF project area. However, the readily eroded Waaipoort sediments are very poorly exposed within the study area due to extensive superficial sediment cover and in most cases would only be directly affected by deeper (> *c*. 2m) excavations. For the same reason the distribution of the Waaipoort Formation is poorly defined on existing geological maps of the broader study region (Fig. 4).

The Prince Albert and Whitehill Formations only crop out in the central parts of the transmission line study area. Both have very narrow outcrop areas, are poorly exposed and are unlikely to be significantly impacted by the proposed WEF development. Furthermore, field assessment suggests that they are poorly fossiliferous in this region due to deep chemical weathering, tectonic deformation and cleavage development.

The Late Caenozoic superficial sediments (soils, alluvium, colluvium *etc.*) overlying the Palaeozoic and Mesozoic bedrocks in the Wolf WEF study area are of low to very low palaeontological sensitivity. Construction of the wind turbines, overhead power lines and associated infrastructure is therefore unlikely to entail significant impacts on local fossil heritage resources.

The inferred impact of the proposed wind farm development on local fossil heritage is analysed in Table 1 below. This assessment applies only to the construction phase of the

WEF development since further impacts on fossil heritage during the operational and decommissioning phases of the WEF are not anticipated. The Wolf WEF (wind turbines and associated infrastructure) and the 132 kV overhead transmission line are assessed separately.

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 confined to the development footprint (*site specific*). Such impacts are limited to the *construction period*, can usually be mitigated but cannot be fully rectified (*i.e. irreversible*). Most of the sedimentary formations represented within the study area contain fossils of some sort, so impact on fossil heritage are *probable*. However, because of the generally sparse occurrence of well-preserved fossils within the majority of the bedrock formations concerned here (notably those underlying the proposed wind turbine sites) as well as within the overlying superficial sediments (soil, alluvium, colluvium *etc.*), the magnitude of these impacts is conservatively rated as *very low*. Because of the generally low levels of bedrock exposure within the study area, confidence levels for this palaeontological heritage assessment are only moderate (*unsure*) following the two-day field assessment of representative rock exposures.

No areas or sites of exceptional fossil heritage sensitivity or significance are identified within the study area. Due to (1) the general scarcity of fossil remains, (2) the high levels of bedrock weathering and tectonic deformation as well as (3) the extensive superficial sediment cover observed within and close to the Wolf WEF study area, the overall impact significance of the construction phase of the proposed wind energy project is assessed as VERY LOW. This applies to the wind turbines and associated infrastructure on the Klein-Winterhoekberge as well as to the 132 kV transmission line connection to the existing Wolwefontein Substation. No significant further impacts on fossil heritage are anticipated during the operational and decommissioning phases of the WEF. There are no fatal flaws in the Wolf WEF development proposal as far as fossil heritage is concerned.

In the absence of comprehensive data on further alternative energy or other developments in the Steytlerville – Jansenville region of the Eastern Cape, it is impossible to realistically assess cumulative impacts on fossil heritage resources. The impact significance of a proposed WEF underlain by similar geology in the Kommadagga – Riebeeck East area, some 100 km to the east of the Wolf WEF, was rated by the author as low (Almond 2013).

Table 1: Assessment of impacts of the proposed Wolf WEF on fossil heritage resources during the construction phase of the development (*N.B.* Significant impacts are not anticipated during the operational and decommissioning phases).

			WITHOUT MITIGATION						
Phase	**Project aspect**	**Impact description**	**Extent**	**Magnitude**	**Duration**	**Probability**	**Confidence**	**Reversibility**	**Significance**
Construction	**Wind turbines and associated infrastructure, Klein-Winterhoek ridge**	**Disturbance, damage or destruction of fossils at surface or beneath the ground**	**Site specific**	**Very low**	**Construction period**	**Probable**	**Unsure**	**Irreversible**	**VERY LOW**
Construction	**132 kV transmission line corridor (all alternatives)**	**Disturbance, damage or destruction of fossils at surface or beneath the ground**	**Site specific**	**Very low**	**Construction period**	**Probable**	**Unsure**	**Irreversible**	**VERY LOW**

			WITH MITIGATION						
Phase	**Project aspect**	**Impact description**	**Extent**	**Magnitude**	**Duration**	**Probability**	**Confidence**	**Reversibility**	**Significance**
Construction	**Wind turbines and associated infrastructure, Klein-Winterhoek ridge**	**Disturbance, damage or destruction of fossils at surface or beneath the ground**	**Site specific**	**Very low**	**Construction period**	**Probable**	**Unsure**	**Irreversible**	**VERY LOW**
Construction	**132 kV transmission line corridor (all alternatives)**	**Disturbance, damage or destruction of fossils at surface or beneath the ground**	**Site specific**	**Very low**	**Construction period**	**Probable**	**Unsure**	**Irreversible**	**VERY LOW**

5. MITIGATION & RECOMMENDATIONS FOR THE HERITAGE RESOURCES MANAGEMENT PLAN

Given the low palaeontological sensitivity of the broader Wolf WEF study area, as determined from field work, as well as the inferred very low impact significance of the project for fossil heritage conservation (Section 4), no specialist mitigation is recommended here, pending the discovery of substantial new fossil remains during construction.

During the construction phase all substantial bedrock excavations should be monitored for fossil remains by the responsible Environmental Control Officer (ECO). In particular, the ECO should be alerted to the (slight) possibility that fossil-rich lenses or horizons of dark, organic-rich lagoonal mudrocks may be exposed during excavations into the Witpoort Formation along the Klein-Winterhoek ridge. Other possibilities include dark grey phosphatic carbonate nodules containing fossil plants and / or fish in the Waaipoort Formation (Dl in part on map Fig. 4) as well as well-preserved fish and reptile remains within the Whitehill Formation (Pp in part in Fig. 4).

Should substantial 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 safeguard these, preferably *in situ*, and 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 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).

The palaeontologist concerned with mitigation work will need a valid fossil collection permit from ECPHRA 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).

These mitigation recommendations should be incorporated into the Environmental Management Plan (EMP) for the Wolf WEF. The operational and decommissioning phases of the development are unlikely to have significant impacts on palaeontological heritage and no further recommendations are made in this regard.

It should be noted that should fossils be discovered before or during construction and reported by the responsible ECO to the responsible heritage management authority (ECPHRA) for professional recording and collection, as recommended here, the overall impact significance of the project would remain very 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.

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QUALIFICATIONS & EXPERIENCE OF THE AUTHOR

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

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

Declaration of Independence
I, John E. Almond, declare that I am an independent consultant and have no business, financial, personal or other interest in the proposed wind farm development project, application or appeal in respect of which I was appointed other than fair remuneration for work performed in connection with the activity, application or appeal. There are no circumstances that compromise the objectivity of my performing such work.

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APPENDIX: GPS LOCALITY DATA FOR NUMBERED SITES MENTIONED IN TEXT

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

N.B. Given the sensitivity and conservation importance of fossil sites in the RSA, this data is *not* for public release.

Locality number	South	East	Comments
418	33º 14’ 43.16”	24º 50’ 13.49”	Calcretised colluvial rubble, Salt Pan Nek, west side of R75
419	33º 14’ 57.5”	24º 52’ 03.6”	Low exposures on Witpoort quartzites on summit plateau, Salt Pans Neck 287
420	33º 15’ 01.9”	24º 52’ 22.6”	Secondarily ferruginised Witpoort quartzites, thin mudflake breccio-conglomerates, Salt Pans Neck 287
421	33º 15’ 08.9”	24º 52’ 39.9”	Witpoort quartzites showing conchoidal fracture, Salt Pans Neck 287
422	33º 15’ 16.1”	24º 51’ 00.4”	Poorly sorted alluvial and colluvial deposits in southern foothills of Klein-Winterhoekberge, Salt Pans Neck 287
423	33º 20’ 16.4”	24º 53’ 45.6”	Road cuttings through Waaipoort Formation along R75, Klein Poort 11.
424	33º 20’ 25.4”	24º 54’ 04.6”	Road cuttings through Waaipoort Formation along R75, Klein Poort 11.
425	33º 22’ 25.6”	25º 02’ 04.4”	Hillslope exposures of Enon Formation south of the R75, Roode Krantz 72
426a	33º 20’ 53.32”	25º 03’ 17.82”	Borrow pit exposing Kweekvlei shales and thin sandstones just north of Soutkloof (Grootpoort 74). Abundant low-diversity trace fossils, microbial mat textures.
426b	33º 20’ 53.90”	25º 03’ 12.59”	Tectonized ridge of Floriskraal sandstones just north of Soutkloof (Grootpoort 74)
426c	33º 19’ 53.10”	25º 02’ 21.8”	Folded & faulted Waaipoort Formation roadcutting near Rietfontein homestead, Governments Kop 57
427a	33º 19’ 23.76”	25º 02’ 07.29”	Dwyka tillite hillslope exposures, Governments Kop 57
427b	33º 18’ 55.8”	25º 02’ 24.4”	Road cuttings through the Prince Albert Formation north of Waterplaas, Farm Koms 53.

428	33º 16’ 34.6”	25º 00’ 49.7”	View point of Witpoort stratigraphy as well as Klein-Winterhoek thrust and Weltevrede Formation in Perdepoort gorge.
429	33º 18’ 00.9”	24º 59’ 19.4”	Borrow pit exposurEs of well-cleaved Prince Albert Formation mudrocks, Hartebeestefontein 15.
430	33º 18’ 17.3”	25º 58’ 52.4”	Stream bank exposure of Ripon Formation mudrocks and wackes, Hartebeestefontein 15.
431	33º 17’ 24.8”	24º 58’ 08.0”	Donga exposures of sandy and gravelly superficial deposits, Hartebeestefontein 15
432	33º 16’ 50.8”	24º 54’ 54.8”	Borrow pit into the Whitehill Formation, Vaalfontein 12
433	33º 19’ 59.84”	24º 52’ 42.21”	Large borrow pit into the Kweekvlei Formation, Farm Blaauwbosch Kuil 669