Palaeontological specialist assessment: combined field-based and desktop study

PROPOSED DIEPRIVIER - MELKHOUT 132 kV TRANSMISSION LINE PROJECT, HUMANSDORP MAGISTERIAL DISTRICT, EASTERN CAPE.

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EXECUTIVE SUMMARY

Eskom are proposing to construct approximately 26 km of overhead 132 kV powerline from the Dieprivier Substation through to the Melkhout Substation near Humansdorp in the Humansdorp District Municipality, Eastern Cape. The project also entails decommissioning of redundant infrastructure, the construction of a new substation at Dieprivier, as well as the construction of new, or maintenance of existing, minor roads.

The proposed development footprint to the west and north of Humansdorp is underlain by Palaeozoic bedrocks of the Table Mountain Group and Bokkeveld Group (Cape Supergroup). Three of the formations involved – the Late Ordovician Cederberg Formation as well as the Early Devonian Baviaanskloof and Gydo Formations – are known elsewhere within the Cape Fold Belt for their important records of marine and terrestrial fossils. However in the Humansdorp region the bedrocks have generally suffered high levels of tectonic deformation and chemical weathering, seriously compromising their fossil heritage. No fossil remains were observed during a one-day palaeontological field assessment, either within the Palaeozoic bedrocks or in the overlying Late Caenozoic superficial sediments (colluvium, alluvium, pedocretes, soil *etc*).

On the basis of the current field assessment as well as the paucity of previous fossil records from the Humansdorp region it is concluded that the palaeontological sensitivity of the Palaeozoic bedrocks here is low due to high levels of tectonic deformation (*e.g.* folding, cleavage) and chemical weathering. This applies especially to the more mudrock-rich stratigraphic units (*e.g.* Cederberg and Gydo Formations) that may originally have been highly fossiliferous. The various Late Caenozoic superficial deposits mantling the bedrocks in the study region (*e.g.* alluvium, colluvium, soils, pedocretes) are also of low palaeontological sensitivity.

Given the resulting low to very low impact significance of the proposed transmission line – including the associated substation and road developments - as far as palaeontological heritage is concerned, no further specialist studies or mitigation are considered necessary for this project.

It is recommended that:

- The Environmental Control Officer (ECO) responsible for the transmission line development should be at least aware of the possibility – albeit low - of important fossils (*e.g.* shells, plant remains, trace fossils, mammalian bones and teeth) being present or unearthed on site and should regularly monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;

- In the case of any significant fossil finds (*e.g.* vertebrate teeth, bones) made during construction, these should be safeguarded - preferably *in situ* - and reported by the ECO as soon as possible to the relevant heritage management authority (ECPHRA. Contact details: Mr Sello Mokhanya, 74 Alexander Road, King Williams Town 5600; smokhanya@ecphra.org.za) so that appropriate mitigation (*i.e.* recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer's expense; and

- These recommendations should be incorporated into the Environmental Management Plan (EMP) for the 132 kV transmission line project.

The palaeontologist concerned with mitigation work will need a valid palaeontological collection permit from SAHRA (Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za). All work would have to conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording fossil collection and curation, final report) should adhere to the minimum standards for Phase 2 palaeontological studies developed by SAHRA (2013).

1. INTRODUCTION

Eskom are proposing the following infrastructure developments as part (Project 1) of their planned network strengthening and upgrade in the Patensie, Humansdorp and Kareedouw areas, Humansdorp and Hankey District Municipalities, Eastern Cape (Arcus GIBB (Pty) Ltd Background Information Document, April 2012):

- Construction of approximately 26 km of overhead 132 kV powerline from the existing Melkhout Substation through to the Dieprivier Substation.

- Construction of a new Dieprivier Substation.

- Decommissioning of redundant infrastructure once new infrastructure has been commissioned.

- Construction of new or maintenance of existing minor roads.

Arcus Gibb Engineering and Science have been commissioned to conduct an Environmental Impact Assessment of the proposed 132 kV transmission line developments between Kareedouw and Patensie, Eastern Cape. A Phase 1 Heritage Impact Assessment Report for the entire Kareedouw – Patensie 132 kV transmission line study area by eThembeni Cultural Heritage (Van Schalkwyk & Wahl, May 2012) included the following remarks and recommendations regarding palaeontological heritage resources, largely based on desktop input by present author:

> The proposed electrical infrastructure between Kareedouw and Patensie is underlain by potentially fossiliferous bedrocks of Palaeozoic, Mesozoic and Caenozoic age, while the fossil

potential of the Kareedouw – Dieprivier sector is likely low due to tectonism. Geological formations in the Dieprivier – Melkhout sector might contain well-preserved plant material. Early Cretaceous Kirkwood Formation beds near Patensie may contain important fossils of dinosaurs and other terrestrial vertebrates as well as petrified wood, while older alluvial sediments of the Gamtoos drainage system are also potentially fossil-bearing. The potential impact on palaeontological remains is low to medium.

A heritage practitioner should complete a 'walk-through' of the final selected power line route and all other activity areas (access roads, construction camps, materials' storage areas, etc.) prior to the start of any construction activities and assess direct impacts on discrete resources such as traditional burial places, and archaeological and palaeontological sites.

Since likely impacts on fossil heritage along the proposed new 132 kV transmission line are mainly associated with excavations for the pylon footings, as well as the construction of new substations, it is recommended that a Phase 1 palaeontological field assessment of the final transmission line route be undertaken once the pylon positions have been finalized and *before* construction commences. The resulting report should make recommendations regarding any necessary mitigation during the construction phase of the transmission line and associated infrastructure (*e.g.* recording, sampling of fossil assemblages, field monitoring of selected pylon positions).

The present palaeontological heritage assessment report dealing with Project 1 (Melkhout to Dieprivier) of the 132 kV development has accordingly been commissioned on behalf of Eskom and Arcus GIBB (Pty) Ltd by eThembeni Cultural Heritage (Contact details: Box 20057 Ashburton 3213, Pietermaritzburg, South Africa. Tel: 033 – 326 1136. Fax: 086 – 672 8557. E-mail: thembeni@iafrica.com).

It contributes to the Environmental Impact Assessment for the proposed transmission line development and it will also inform the Environmental Management Plan for the project.

1.1. Legislative context for palaeontological assessment studies

The report has been commissioned on behalf of Eskom and Arcus GIBB Engineering and Science by eThembeni Cultural Heritage (Contact details: Box 20057 Ashburton 3213, Pietermaritzburg, South Africa. Tel: 033 – 326 1136. Fax: 086 – 672 8557. E-mail: thembeni@iafrica.com). It contributes to the Environmental Impact Assessment for the proposed transmission line development, governed by the National Environmental Management Act (NEMA, Act 107 of 1998, amended in 2008), and it will also inform the Environmental Management Plan for the project. The present palaeontological heritage report also falls under Section 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999).

The proposed transmission line developments are located in areas that are underlain by potentially fossiliferous sedimentary rocks of Palaeozoic and Late Tertiary or Quaternary age (Sections 2 and 3). The construction phase of the transmission line and associated infrastructure may entail substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock. In addition, considerable areas of bedrock may be sealed-in or sterilized by lay-down areas as well as new gravel roads. All these developments may adversely affect fossil heritage resources at or beneath the surface of the ground within the development footprint by destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good. Once constructed, the operational and decommissioning phases of the transmission line are unlikely to involve further adverse impacts on palaeontological heritage, however.

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 developed by SAHRA (2013).

1.2. Scope and brief for the desktop study

This palaeontological specialist report provides a combined desktop and field-based assessment of the observed or inferred palaeontological heritage along the proposed Melkhout – Dieprivier 132 kV transmission line corridor (Fig. 1), with recommendations for further specialist palaeontological studies and / or mitigation where this is considered necessary.

The deliverables and scope of work for this study, as defined by eThembeni Cultural Heritage, are as follows:

- One PIA report for the Transmission Line Project.
- Assessment of heritage resource significance in term of standards and criteria acknowledged and accepted by the South African Heritage Resources Agency (SAHRA). These criteria should be clearly stipulated in an appendix to each report.
- Assessment of the potential development impact on heritage resources in terms of the criteria included in Appendix B.
- *Précis* of the qualifications and experience of the person preparing the reports, demonstrating her/his ability to undertake the principal services.
- Statement of independence of the person preparing the reports, demonstrating her/his ability to undertake the principal services in an objective, unbiased manner.

1.3. Approach to the palaeontological heritage Assessment study

A preliminary desktop study on fossil heritage within the broader study area was undertaken prior to field work. This study involved a review of relevant palaeontological and geological literature, including geological maps as well as previous palaeontological heritage assessments carried out in the region (*e.g.* Almond 2009, 2010a, 2010b, 2010c, 2011a, 2011b, 2012). Potentially informative rock exposures within the study region were identified before fieldwork commenced using aerial photographs and / or satellite images.

The field-based palaeontological heritage assessment of the proposed power line route focused on the identification of those sections of the route that are underlain by potentially fossiliferous bedrocks and that may therefore require mitigation before or during the construction phase of the development. GPS data for all numbered localities mentioned in the text are given in the Appendix.

Palaeontological field assessment does not centre primarily on the examination of proposed pylon positions. Bedrock is often not well exposed at all these positions, while other components of the development footprint (including new access roads, construction camps, laydown areas) have not usually been finalised at the time of the field survey. Potential impacts of the power line development on fossil heritage must be *inferred* from a broader assessment of the palaeontological sensitivity of the rock units represented within and beneath the study area. This is primarily achieved through a careful field examination of representative exposures of all the rock units to determine the diversity, density and distribution of fossil remains within them. These exposures may be natural or artificial and include, for example, rocky outcrops in stream or river banks, cliffs, quarries, dams, dongas, open building excavations or road and railway cuttings. For the present project road cuttings along the R62 Kareedouw to Humansdorp tar road as well as minor roads to the south and north of the N2 trunk road as well as several borrow pits in the Humansdorp region proved the most informative sources of geological and palaeontological data. Unconsolidated or consolidated superficial deposits, such as alluvium, scree, calcrete or wind-blown sands, may occasionally contain fossils and were also included in the field assessment study where they are well-represented in the study area.

The present palaeontological field assessment report provides an illustrated, fully-referenced review of the (a) actual or known as well as (b) inferred palaeontological heritage within all rock units represented in the study area based on the initial desktop study as well as new data from fieldwork and any subsequent palaeontological analysis (*e.g.* lab identification of fossil material).

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 were then determined. The impacts are assessed in Section 4 of this report. Adverse palaeontological impacts normally occur during the construction rather than the operational or decommissioning phase.

1.4. Assumptions & limitations

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

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

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

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

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

5. Absence of a comprehensive computerized database of fossil collections in major RSA institutions which can be consulted for impact studies.

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 case of the Melkhout – Dieprivier study area a major limitation for fossil heritage studies is the low level of exposure of potentially fossiliferous bedrocks, as well as the paucity of previous specialist palaeontological studies in this part of the Eastern Cape. However, representative exposures of all the relevant major bedrock and superficial rock units were examined along of close to the proposed transmission line corridor and confidence levels for this assessment are correspondingly high.

1.5. Information sources

This combined desktop and field-based study was based on the following information sources:

1. A short Background Information Document produced by Arcus Gibb Engineering and Science (April, 2012);

2. A Phase 1 Heritage Impact Assessment Report by for the Patensie to Kareedouw transmission line projects by Len van Schalkwyk and Elizabeth Wahl (May 2012);

3. A review of the relevant scientific literature, including published geological maps and accompanying sheet explanations, as well as several desktop and field-based palaeontological assessment studies in the broader Humansdorp study region by the author (*e.g.* Almond 2009, 2010a, 2010b, 2010c, 2011a, 2011b, 2012).

3. A one-day field survey of potentially fossiliferous rock exposures along the preferred transmission line corridor by the author (8 April 2013).

4. The author's previous field experience with the formations concerned and their palaeontological heritage (See also review of Eastern Cape fossil heritage by Almond *et al.* 2008).

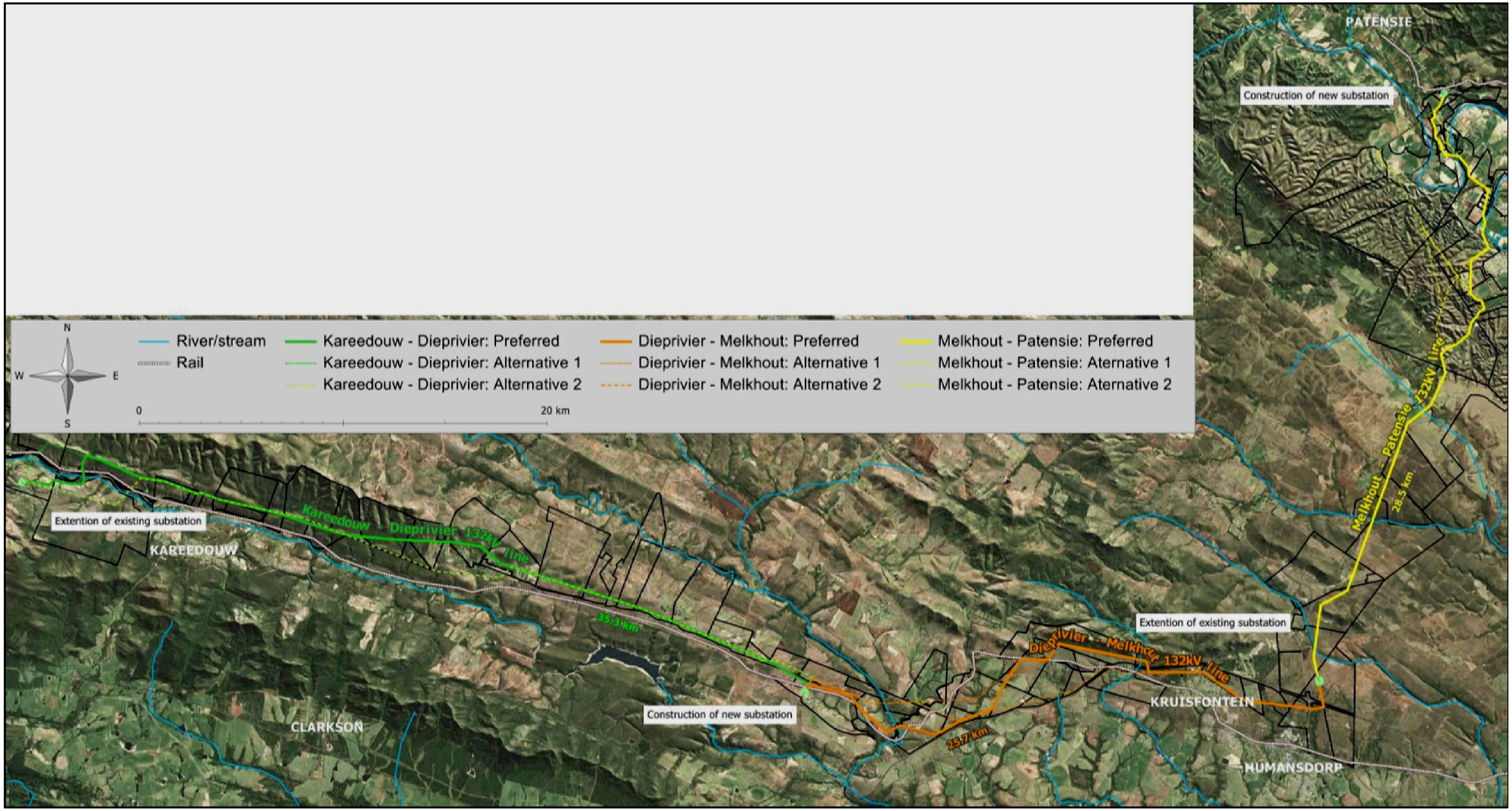

Fig. 1. Map showing proposed Eskom 132 kV transmission line developments between Kareedouw and Patensie in the Eastern Cape (from the Background Information Document produced by Arcus Gibb Engineering and Science, dated April 2012). This report assesses palaeontological heritage resources along the central sector (*c*. 26 km) between Melkhout Substation to the north of Humansdorp and the proposed new Dieprivier Substations to the west (orange line).

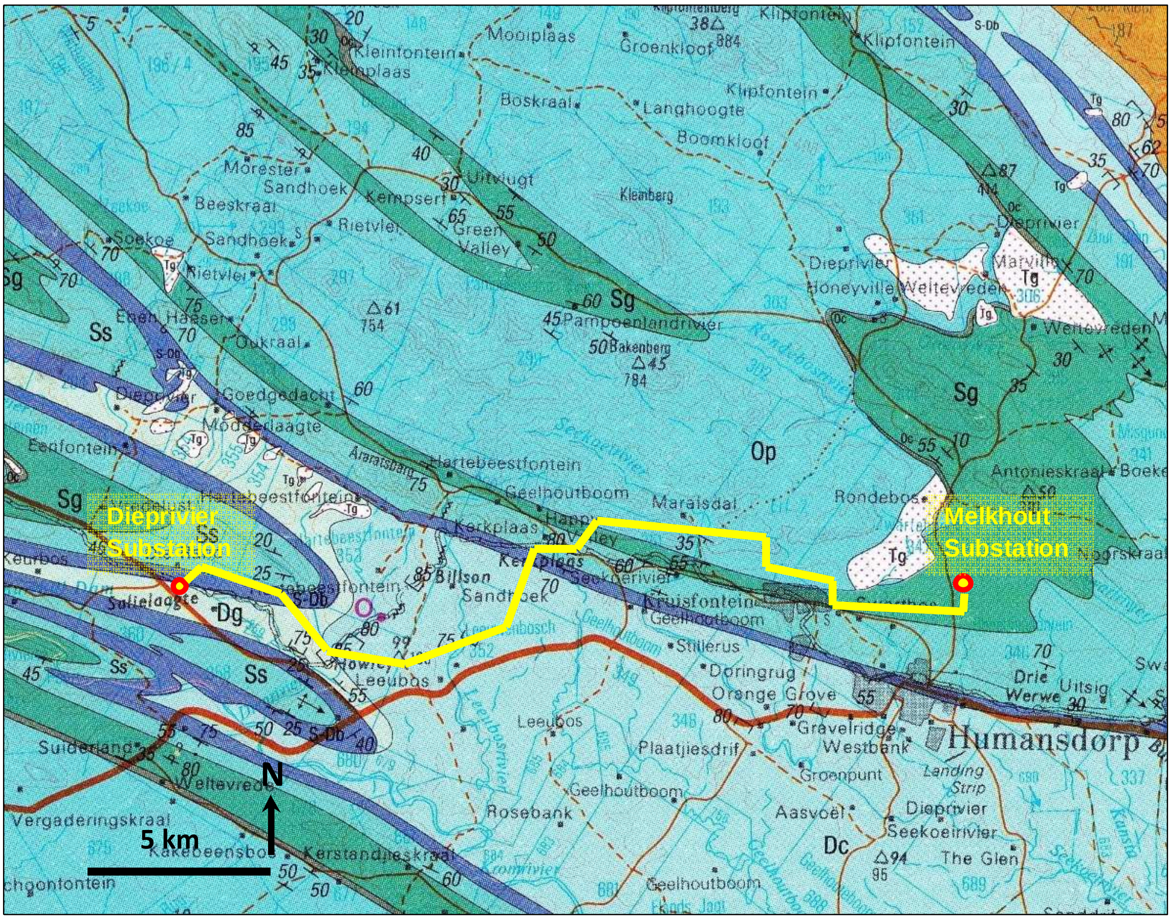

Fig. 2. Extract from 1: 250 000 geology sheet 3324 Port Elizabeth (Council for Geoscience, Pretoria) showing the *approximate* route of the proposed Dieprivier - Melkhout 132 kV transmission line to the northwest of Humansdorp (yellow line). Please note that the outcrop areas of the various formations shown are also approximate at this scale and can only be accurately determined through fieldwork and where superficial sediment cover is low. The N2 trunk road is not indicated on this map.

The main geological units represented within the study include the following formations (Palaeontologically more sensitive marine units indicated in red):

TABLE MOUNTAIN GROUP (Ordovician to Early Devonian)
Peninsula Formation (Op, middle blue)
Cederberg Formation (Oc, grey)
Goudini Formation (Sg, green)
Skurweberg Formation (Ss, pale blue)
Baviaanskloof Formation (S-Db, dark blue)

BOKKEVELD GROUP (Early Devonian)
Gydo Formation (Dg, v. pale blue)

SUPERFICIAL DEPOSITS (Late Caenozoic)
Grahamstown Formation (Tg, white with red stipple) – ancient alluvial gravels, pedocretes (e.g. ferricrete)

2. GEOLOGICAL OUTLINE OF THE STUDY AREA

The proposed new 132 kV transmission line runs eastwards from Dieprivier Substation, just north of the R62 tar road and some 16 km west of Humansdorp, Eastern Cape (Fig. 1). It traverses dissected, hilly terrain north of the N2 trunk road before crossing the latter and skirting Humansdorp along its northern edge (*N.B.* The N2 is *not* shown on the geological map Fig. 2). The line then heads eastwards across the R330 tar road to Patensie, ending at the existing Melkhout Substation, situated *c*. 0.75 km north of the N2 and some 2 km north of the edge of Humansdorp.

The geology of the Dieprivier - Melkhout study area near Humansdorp is shown on the 1: 250 000 geology sheet 3324 Port Elizabeth published by the Council for Geoscience, Pretoria (Toerien & Hill 1989) (Fig. 2). Additional relevant data is provided by the more recent 1: 50 000 geological sheet explanation for the Port Elizabeth – Uitenhage area to the east (Le Roux 2000) as well as the older sheet explanation by Haughton *et al.* (1937) covering the coastal belt near the Gamtoos Valley.

The western end of the proposed transmission line as well as the eastern sector running northwest and north of Humansdorp mainly overlie more resistant-weathering arenitic rocks of the Table Mountain Group. The hill slopes here are incised by numerous transverse streams. Bedrock exposure on the lower slopes, and especially in the central sector of the transmission line which overlies the recessive-weathering, mudrock-dominated Lower Bokkeveld Group, is usually poor due to pervasive cover by superficial sediments (colluvium, alluvium, soil) as well as by fynbos vegetation (Figs. 4 & 5). The terrain is generally less rugged than seen in the more arid, western ranges of the Cape Fold Mountains because the resistance of the bedrocks here has been compromised by deep chemical weathering while the lower slopes have been planed off by erosion to form elevated, gently-sloping pediment surfaces of probable Late Tertiary (Neogene) age, reflecting ancient land surfaces (Partridge 1998, Partridge & Maud 1987, 2000).

The entire study area is underlain at depth by Early to Middle Palaeozoic sedimentary rocks of the **Cape Supergroup**. These comprise rocks of the sandstone-dominated **Table Mountain Group** of Ordovician to Early Devonian age and the immediately overlying, mudrock-dominated lowermost **Bokkeveld Group** of Early Devonian age. The stratigraphic relationships of the Cape Supergroup sedimentary formations concerned are shown below in Fig. 3. They include:

- predominantly fluvial sandstones and quartzites of the **Peninsula** (Op), **Goudini** (Sg) and **Skurweberg (**Ss**) Formations**, of Ordovician to Silurian age;
- post-glacial mudrocks of the **Cederberg Formation** (Oc) of late Ordovician age (Note that the glacial diamictites of the underlying **Pakhuis Formation** are not mapped separately in this area.);
- earliest Devonian wackes (= impure sandstones) and mudrocks of the **Baviaanskloof Formation** (S-Db), interpreted to be inshore coastal marine to paralic (near-shore) fluvial deposits;
- shallow marine mudrocks and subordinate sandstones of the **Lower Bokkeveld Group** / **Ceres Subgroup** (Dc) of Early Devonian age.

Most of these rocks have a poor fossil record but those three marine units emphasized with an asterisk in Fig. 3 are potentially highly fossiliferous, as outlined in Section 3. At least two of these three potentially sensitive rock units crop out at various points along the proposed transmission line route (Fig. 2). Note that a separate Cederberg Formation is *not* mapped between the Peninsula and Goudini Formation outcrop areas along the transmission line route, but is shown just north of Melkhout Substation; its present within the study area remains equivocal. The Cape Supergroup rocks in the study area lie within the south-eastern sector of the Cape Fold Belt of Permo-Triassic age (Newton *et al.* 2006). Levels of tectonic deformation here are high as a result of intense NNE-directed crustal compression, with steep bedding plane dips within tight folds along subparallel WNW-ESE trending axes (Some of these folds are overturned towards the north, as indicated by inverted bedding). Major anticlinal axes, their terminations plunging to the ESE, run along the line of the Tsitsikammaberge - Kareedouwberge Range, the Suuranysberge Range as well as the mega-anticline north of Humansdorp that ends near Jeffreys Bay. In the Cape Fold Belt the northern limbs of such mega-anticlines are often complicated by smaller scale cascade or parasitic folds. A broad band of Bokkeveld Group sediments to the west and south of Humansdorp, characterised by less rugged, hilly terrain of the southern Cape coastal plain, infills a major synclinal region between the anticlinal ridges of the Cape Fold Belt. The comparatively readily-weathered Bokkeveld rocks have been incised by numerous small rivers, such as the Geelhoutboomrivier and Leeubosrivier in the study area. The mudrock-dominated successions of the Cederberg and Gydo Formations in this part of the Cape Fold Belt are usually highly cleaved, and locally faulted- or squeezed-out, but levels of metamorphism within the Cape Fold Belt are generally low.

Due to protracted chemical weathering of bedrocks beneath the southern coastal plain and within the south-eastern margins of the Cape Fold Belt in Tertiary times, many of these older sedimentary rocks have been converted to poorly consolidated, easily eroded *saprolite* (*in situ* weathered bedrock), often pale or multi-hued due to the formation of kaolinitic clays and secondary ferruginous mineralisation respectively (Figs. 11, 12 & 15, for example). Subdued relief and extensive chemical weathering ensures that bedrock exposures here often very limited, and mainly restricted to artificial excavations such as quarries, borrow pits, road and rail cuttings, dams and trenches. Under these circumstances, accurate geological mapping is impossible, and so the outcrop areas shown in Fig. 2 must be regarded as a provisional "best guess" pending further subsurface data.

A substantial portion of the Palaeozoic bedrocks within the study area are mantled by a veneer of **Late Caenozoic superficial sediments**; most of these are not mapped at 1: 250 000 scale, however. They include various clay-rich and gravelly soils overlying the Cederberg and Gydo Formations, colluvial and down-wasted sandstone or quartizte gravels overlying the arenitic Table Mountain Group units, as well as fine-grained, sandy to bouldery gravel alluvium along river and stream courses. Relict patches of ancient alluvial gravels (Late Caenozoic / Pleistocene "High Level Gravels") are mapped within the Humansdorp area (*e.g.* northwest of Melkhout Substation and north of Dieprivier Substation) where they generally overlie ancient elevated land surfaces or pediment surfaces incised into the upper Table Mountain Group or Lower Bokkeveld Group rocks (Tg in map Fig. 2). Some of these older gravels, which are broadly subsumed into the **Grahamstown Formation** (**Tg**), have been secondarily cemented to form pedocretes, such as silica-rich **silcretes** and iron-rich **ferricretes** (*e.g.* Roberts 2003). Reworked and downwasted ferricrete gravels are well represented overlying the weathered Table Mountain and Bokkeveld Group outcrop areas, for example in the vicinity of Dieprivier Substation (See also separate report on the Kareedouw – Dieprivier 132 kV transmission line project by this author).

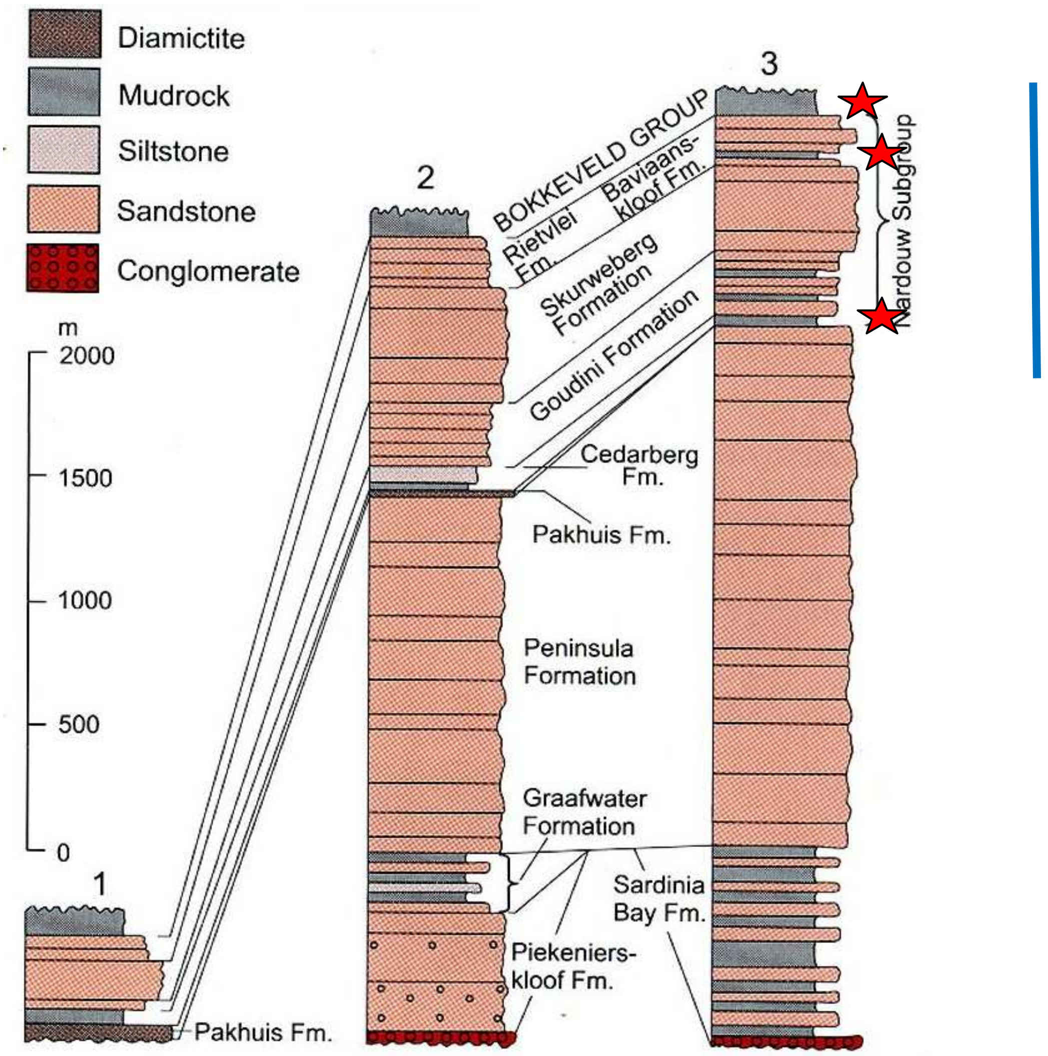

Fig. 3. Stratigraphy of the Table Mountain Group in the Western and Eastern Cape outcrop areas (From Thamm & Johnson 2006). Column 3 for the Eastern Cape is most relevant for the present study near Humansdorp. The vertical blue line indicated formations represented within the Kareedouw – Dieprivier study area. Table Mountain Group formations above the Cederberg Formation are grouped within the Nardouw Subgroup. Note the greater frequency of mudrock interbeds within the Goudini succession in the Eastern Cape, where the Cederberg Formation is often less well-defined. The fossiliferous mudrocks of the basal Bokkeveld Group belong to the Ceres Subgroup that crops out in a broad band west and south of Humansdorp. The three marine rock units indicated with a red asterisk – *i.e.* Cederberg, Baviaanskloof and Ceres Subgroup - are potentially of high palaeontological sensitivity, but only where their fossil content is not compromised by chemical weathering and tectonism. The remaining units are predominantly non-marine and generally have a poor fossil record, dominated by low-diversity trace fossil assemblages.

In the following section of this report the main geological units represented within the broader Humansdorp study region are briefly described, with short notes on representative exposures from the Dieprivier – Melkhout transmission line study area, paying special attention to those formations that may be of palaeontological heritage significance. GPS data for all numbered localities mentioned in the text is provided in the Appendix.

Fig. 4. View northwards from the R62 showing gently rolling hilly terrain dissected by small stream valleys in the Lower Bokkeveld Group outcrop area just east of the Dieprivier Substation. Low mountains in the background are built of older Table Mountain Group rocks.

Fig. 5. View south-westwards along the proposed transmission line route in the vicinity of Kerkplaas Station. Note very low levels of bedrock exposure that characterise most of the transmission line corridor.

2.1. Table Mountain Group

Useful overviews of Table Mountain Group geology in general include Rust (1967, 1981), Hiller (1982), Malan & Theron (1989), Broquet (1992), Johnson *et a*l., (1999), De Beer (2002), Thamm & Johnson (2006), and Tankard *et al*., (2009). For the Port Elizabeth sheet area specifically, these rocks are briefly described by Toerien and Hill (1989) and Le Roux (2000) as well as in older sheet explanations such as those by Engelbrecht *et al*. (1962) and Haughton *et al*., (1937). Also useful are various reports by the South African Committee for Stratigraphy (SACS), such as those by Malan *et al*. (1989), Malan and Theron (1989) and Hill (1991). Due to poor exposure and high levels of bedrock weathering in the study region it is not always possible to differentiate the arenitic subunits of the Table Mountain Group in the field with full confidence.

The Mid to Late Ordovician **Peninsula Formation** is a very thick succession of resistant-weathering, well-washed, braided fluvial sandstones and quartzites with subordinate pebbly lenses and thin (< 1m) heterolithic (mudrock / sandstone) intervals with sparse trace fossils that are attributed to intermittent marine transgressive events (Toerien & Hill 1989, Le Roux 2000). Common sedimentary structures include unidirectional cross-bedding and over-turned cross-bedding. The thickness of the formation is unclear due to the frequent occurrence of tectonic reduplication but is unlikely to be more than 3000m.

Rugged-weathering pale grey quartzites of the Peninsula Formation were examined on mountain slopes north of Kruisfontein and the N2 (Fig. 6, Loc. 051). No heterolithic sedimentary packages (commonly associated elsewhere with trace fossil assemblages) were observed. The Peninsula Formation bedrocks are overlain by thick, rubbly, semi-consolidated, ferruginised colluvial gravels.

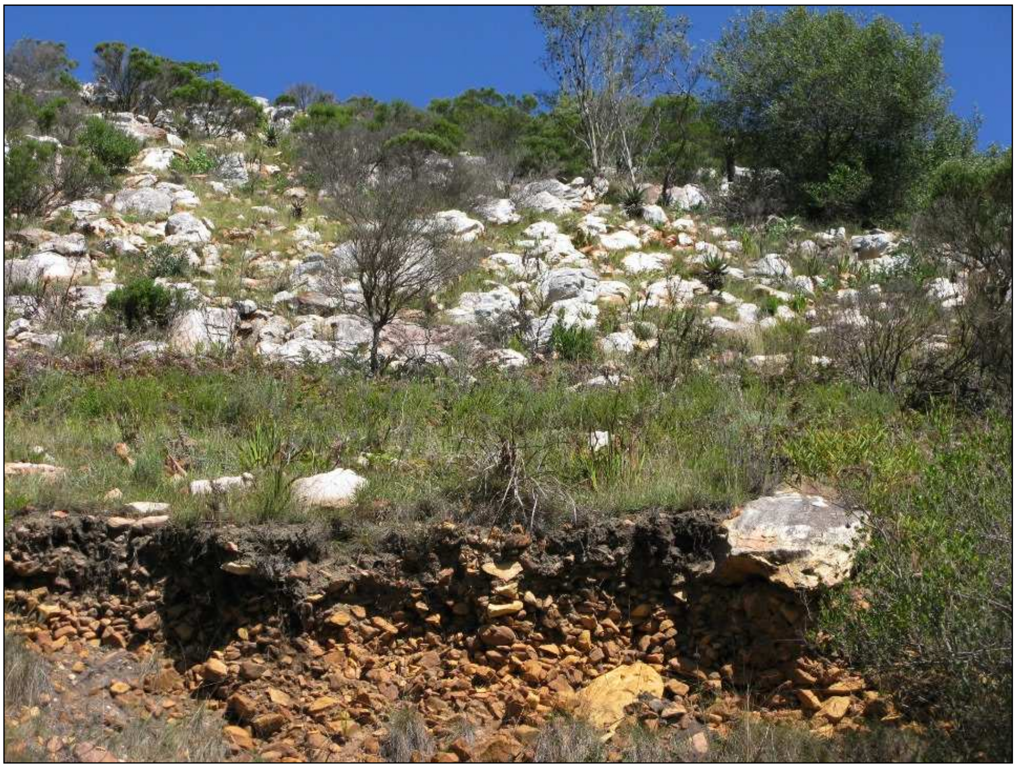

Fig. 6. Peninsula Formation quartzites north of Kruisfontein (Loc. 051) with thick mantle of rubbly, ferruginised colluvial gravels.

The **Cederberg Formation** of Latest Ordovician (Hirnantian) age is a thin, coarsening-upwards succession of mudrocks, siltstones and sandstones that was deposited within shallowing, frigid post-glacial seas following a short-lived, multiple Gondwana glacial event. The Cederberg rocks are generally recessive-weathering and poorly-exposed; pervasive cleavage formation may be expected in the Port Elizabeth sheet area. Dark, carbonaceous, finely-laminated shales with occasional dropstones typify the lower part of the succession. Glacial rocks (sandy, muddy and pebbly diamictites) of the **Pakhuis Formation** that occur directly below the Cederberg mudrocks in the Western Cape are not separately mapped in the study area. However, Toerien and Hill (1989) mention sporadically-developed glacial diamictites within the lower part of the "Cederberg Formation" (technically Winterhoek Subgroup) outcrop area in the Humansdorp District. They are exposed, for example, on the banks of the Kouga River. As shown in the stratigraphic column for the Table Mountain Group in the Eastern Cape (Fig. 3) the Cederberg / Goudini transition zone is characterised by heterolithic interbedding of arenitic and mudrock units or packages. Recognition of a discrete Cederberg Formation under these circumstances is difficult, and complicated by enhanced tectonism at this horizon in the eastern Cape Fold Belt.

As noted earlier, a discrete Cederberg Formation is *not* mapped between the Peninsula and Goudini Formation outcrop areas along the proposed transmission line route, but is shown just north of Melkhout Substation. Exposures of the Cederberg Formation mudrocks examined by the author to the north and west of the present study area show that they have generally been pervasively cleaved and deeply weathered.

The **Goudini Formation** (Sg) consists predominantly of quartzose sandstones, frequently cross-bedded, that characteristically display reddish to brownish tints due to higher levels of iron and / or manganese impurities compared with the purer underlying and overlying Peninsula and Skurweberg Formations. Sandstone beds are generally thinner, and heterolithic successions (*i.e.* interbedded sandstones and mudrocks) commoner, than in the overlying Skurweberg Formation. Consequently exposures of the Goudini rocks are more recessive weathering. The mudrocks, which are often reddish in colour, are rarely exposed. In the Western Cape at least, occasional trace fossil assemblages within the Goudini Formation suggest intermittent marine influence but the bulk of the succession is probably fluvial in origin.

Good exposures of unequivocal Goudini Formation sediments were not encountered during the present field study. Heterolithic packages of thin to medium bedded sandstones and mudrocks that may belong to this unit are seen in the Langkloof near Kareedouw (Almond, pers. obs.). In all cases these rocks appear to be highly weathered, leached and kaolinitised.

The **Skurweberg Formation** (Ss) is dominated by very pale, resistant-weathering sandstones and quartzites that typically show well-developed unidirectional (current) cross-bedding and sometimes thin quartz pebble lenticles (These last far less common in the Eastern than Western cape outcrops). Bedding is often thick (thicknesses of one or more meters are common) and although thin, lenticular, dark mudrock intervals also occur, these are rarely exposed at outcrop. Sedimentological features within this formation indicate deposition across an extensive sandy alluvial braidplain.

Good exposures of Skurweberg arenites were not observed during the present field study but are known from the Langkloof near Kareedouw shortly to the west (Almond, pers. obs.). Deeply weathered, friable and lightly ferruginised Nardouw Subgroup sandstones seen in a small quarry on the northern outskirts of Humansdorp (Loc. 050, Fig. 7) may belong here.

Fig. 7. Small exposure of weathered, lightly ferruginised Nardouw Subgroup sandstones in a quarry on the northern outskirts of Humansdorp (Loc. 050) (Hammer = 27 cm). These rocks probably belong to the Skurweberg Formation.

The **Baviaanskloof Formation** (S-Db) is typically less clean-washed than the older subunits of the Nardouw Subgroup, with a higher proportion of lithic grains and clay minerals giving darker hues and more recessive weathering patterns. Sandstones are often (but not invariably) greyish, impure wackes and may be massive or ripple cross-laminated. Dark grey to black carbonaceous and micaceous mudrock intervals are quite common but rarely well exposed (A *c.* 15m-thick band of micaceous shale within the upper Baviaanskloof Formation in the Gamtoos area is mentioned by Haughton *et al*., 1937, for example). The heterolithic "passage beds" of the Baviaanskloof Formation incorporate the sedimentary transition between the fluvial-dominated lower units of the Nardouw Subgroup and the marine shelf sediments of the Lower Bokkeveld Group (Fig. 3). Locally abundant shelly fossils such as articulate brachiopods, trace fossils as well as wave ripple lamination demonstrate the shallow marine origins of at least some of the upper sandstones, while the dark mudrocks with dense mats of vascular plant remains may be lagoonal in origin (See Section 3).

Several good road cuttings through the Baviaanskloof Formation are seen along the R62 tar road close to its intersection with the N2, but good bedding plane exposures are rare. Comparatively fresh (unweathered) greyish to grey-green, medium- to thick-bedded micaceous wackes with locally developed *en echelon* quartz veins are seen at Loc. 046 (Figs. 8 & 9). Despite high levels of weathering, leached, friable sandy saprolite at Loc. 045 nevertheless preserves large scale trough cross-beds indicating southerly-directed palaeocurrents (Fig. 10). Interbedded weathered gritty sandstones and darker grey mudrocks at Loc. 045 probably belong to the transitional contact zone between the Table Mountain and Bokkeveld Groups (Fig. 11).

Fig. 8. Comparatively unweathered, steeply dipping wackes of the Baviaanskloof Formation, R62 road cutting (Loc. 046).

Fig. 9. Greyish wackes of the Baviaanskloof Formation showing *en echeleon* quartz veining (Loc. 046)(Hammer = 27 cm).

Fig. 10. Large scale trough cross-bedding preserved within weathered Baviaanskloof arenites, R62 road cutting near intersection with the N2 (Loc. 045).

Fig. 11. Heterolithic transition zone between the Baviaanskloof and Gydo Formations showing highly-weathered, steeply-dipping, interbedded arenites and mudrocks, R62 road cutting (Loc. 047).

2.2. Lower Bokkeveld Group

The lower **Bokkeveld Group** (= **Ceres Subgroup**) is a thick succession of fine- to medium-grained sedimentary rocks that were laid down in a range of shallow to moderately deep continental shelf environments during the Early to Middle Devonian Period (*c*. 140 to 390 Ma, *i.e*. Emsian to Eifelian; Ma = million years ago). Throughout this period of deposition the Cape Basin was situated at high palaeolatitudes (over 70º S) and was gradually approaching the southern palaeopole. In the eastern outcrop area of the Bokkeveld Group, near Port Elizabeth, it reaches a total thickness of *c*. 3.5km. Precise figures are difficult to obtain due to tectonic thickening and reduplication (folding, thrust faulting *etc*) as well as generally poor exposure. Key geological references for the Bokkeveld Group succession include Tankard and Barwis (1982), Theron and Loock (1988), Hiller and Theron (1988), as well as Theron and Johnson (1991), Broquet (1992), Thamm & Johnson (2006). Brief accounts of the Bokkeveld Group in the Port Elizabeth region have been given by Toerien and Hill (1989), and Le Roux (2000).

The rocks forming the Bokkeveld Group are predominantly fine-grained mudrocks – *claystones* formed from soft muds (mainly clay minerals) and *siltstones* formed from slightly larger, silt-sized particles including small quartz grains and micas. Extensive fresh outcrops are rare due to post-Gondwana weathering as well as drift (scree, soil *etc*) and vegetation cover. Sandstone-dominated successions with total thicknesses in the range of 50-100m also occur and are sometimes mapped as separate formations. The Ceres Subgroup has accordingly been subdivided into a series of six laterally persistent formations, alternately dominated by mudrocks and sandstones. However, with the exception of the basal **Gydo Formation** (Dg) with an estimated thickness of some 500m, these formations are generally grouped together as a single stratigraphic unit (Dc) on the published 1: 250 000 geology map of the Port Elizabeth region, due to poor exposure and locally intense folding towards the eastern end of the Cape Fold Belt (Toerien and Hill 1989). The clay-rich sediments of the lower Bokkeveld Group have often suffered extensive cleavage formation in the Humansdorp area (Haughton *et al.* 1937) and deep Tertiary-age chemical weathering is also evident here.

The Bokkeveld sandstones are typically thin-bedded (dm scale to 50 cm or more), poorly-sorted by grain-size, and compositionally "impure"; *i.e.* they contain a small proportion of clay or mica minerals, tiny rock fragments (*lithic* grains), and feldspar in addition to the dominant mineral quartz. The technical term for quartz sandstones that contain over 15% of other (non-quartz) grain types is *wackes*, in contrast to purer quartz sandstones (> 85% quartz) such as those of the Table Mountain Group which are called *arenites*. The readily decomposed impurities give the Bokkeveld sandstones / wackes slightly darker, buff to brownish colours and a more friable or crumbly texture than pure sandstones or quartzites. Due to their higher clay and mica content the former are also more likely to develop a pronounced cleavage as a result of tectonic deformation than are purer sandstones, and are therefore more prone to weathering. Quartz cements are less well developed in the impure Bokkeveld sandstones than in the Table Mountain Group arenites.

Lower Bokkeveld Group (Ceres Subgroup) sediments within the study area are generally poorly exposed with the exeption of several extensive road cuttings along the R62 as well as the R102 that runs west of Humansdorp subparallel to the N2 highway (*e.g.* Locs. 043, 044, 046, 047, 048) (Figs. 12 to 17). The Bokkeveld succession here is typically highly dominated by mudrocks and is invariably deeply weathered so that the original bedding is often obscure. Where preserved, the bedding is tabular and usually steeply dipping. The mudrocks (claystones, siltstones) are multi-hued (pale grey, ochreous, buff, rusty red, pinkish *etc*), kaolinitic, often secondarily mineralised, with prominent-weathering veins or lenticles of secondary ferromanganese minerals and honeycomb weathering styles. They display a pervasive, steeply-dipping to subvertical tectonic cleavage with a regional NW-SE strike (parallel to the synclinal axis). Sandstone interbeds are sparse, also highly weathered, and bedding plane exposures are rarely available. The Bokkeveld bedrocks are typically mantled in brick red terra rossa-type soils, locally gravelly, beneath less ferruginous, brownish modern soils.

Fig. 12. Deeply-weathered, multi-hued Lower Bokkeveld Group rocks in a road cutting along the R102 (Loc. 044).

Fig. 13. Detail of exposure seen in previous figure showing gently dipping, thinly-bedded to laminated Bokkeveld Group mudrocks cut by a pervasive subvertical cleavage (Hammer = 27 cm).