Palaeontological heritage assessment: desktop study

PROPOSED GAMMA – PERSEUS SECOND 765KV TRANSMISSION POWERLINE AND SUBSTATIONS UPGRADE, NORTHERN CAPE & FREE STATE.

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August 2013

EXECUTIVE SUMMARY

Eskom Holdings SOC Limited are proposing to construct a second new 765 kV transmission power line of some 400 km length linking the existing Gamma electrical substation near Hutchinson, close to Victoria West in the Northern Cape with the existing Perseus substation near Dealesville, close to Bloemfontein (Free State). Construction of the transmission line will take place within a servitude of 80 m width while a corridor of 2 km width is being assessed by impact specialists.

Negative impacts on local fossil heritage are mainly anticipated during the construction phase of the transmission line development in connection with excavations for transmission tower footings and stays as well as surface clearance and new cuttings made for access, construction and maintenance roads and laydown areas. Upgrading of existing substations, installation of a telecommunication mast and construction camps are unlikely to generate significant additional palaeontological impacts. Once constructed, the operational and decommissioning phases of the transmission line are unlikely to entail further adverse impacts on palaeontological heritage.

Transmission line Routes 1 and 2 are very similar in terms of their underlying geology as well as the palaeontological sensitivity of the rock units concerned. These mainly comprise Palaeozoic to Mesozoic bedrocks of the Lower Beaufort Group, Ecca Group and Karoo Dolerite Suite as well as overlying superficial sediments (alluvium, colluvium, calcrete, wind-blown sands *etc*) of Late Caenozoic age. Along both routes significant impacts on fossil heritage such as mammal-like reptiles and other vertebates, plant remains and trace fossils are likely to be largely confined to the south-western portions of the line, between Hutchinson and De Aar (*i.e.* Victoria West, Britstown and Colesberg 1: 250 000 sheet areas). Here highly sensitive Permian sediments of the Lower Beaufort Group (Abrahamskraal and Teekloof Formations) and uppermost Ecca Group (Waterford Formation) crop out. Most sectors of the two routes to the northeast of De Aar, including diversions along Routes 2a, 2b and 2c, are of low overall palaeontological sensitivity, with the possible exception of sporadic occurrences of older (pre-Holocene) pan and alluvial sediments. However, this can only be determined through fieldwork. In terms of anticipated impacts on fossil heritage resources at or beneath the ground surface there is no significant difference between transmission line Routes 1 and 2, and no marked preference for any of the diversions 2a, 2b or 2c over the Route 2 alternatives.

Route 3 is underlain by a significantly greater variety of bedrock units, including a wider range of Karoo Supergroup formations (Dwyka, Ecca and Lower Beaufort Groups) as well as Precambrian basement rocks (Ventersdorp Supergroup). Because it is longer than the other two main routes, and also traverses sediments of high palaeontological sensitivity (*e.g.* basal and uppermost Ecca Group, Lower Beaufort Group) over a greater part of its length, Route 3 is the least favoured option in terms of potential fossil heritage impacts. Significant impacts on fossil heritage are most likely to occur along sectors of the line within the Victoria West, Britstown, and Koffiefontein 1: 250 000 sheet areas where the line crosses the outcrop areas of the Lower Beaufort Group (Abrahamskraal and Teekloof Formations) and the more fossiliferous subunits of the Ecca Group (Prince Albert, Whitehill and Waterford Formations). As elsewhere, fossil heritage within unmapped older alluvium (*e.g.* possible Tertiary deposits of the Koa River Valley drainage system, Britstown sheet) and pan sediments may also be compromised.

The No-go option (no construction of transmission line or substation upgrade) will have a neutral impact on fossil heritage.

A realistic palaeontological heritage impact assessment for the Gamma – Perseus second 765 kV transmission line project, with recommendations for any necessary monitoring or mitigation, is only possible once the chosen transmission line corridor has been surveyed in the field by a professional palaeontologist. It is recommended that such a pre-construction field-based assessment be carried out at the earliest opportunity once the route is chosen so that any significant palaeontological heritage issues may be addressed at the project design stage. The recommended pre-construction palaeontological field survey should focus on areas of good sedimentary rock exposure along, or close to, the chosen transmission line corridor. The focus of the study should be on identifying those sectors of the corridor (if any) that are evidently, or inferred to be, of high palaeontological sensitivity so that detailed recommendations regarding mitigation of impacts during the pre-construction or construction phases may be developed.

1. INTRODUCTION AND BRIEF

Eskom Holdings SOC Limited are proposing to construct a second new 765 kV transmission power line of some 400 km length that will link the existing Gamma electrical substation near Hutchinson, close to Victoria West (Ubuntu Local Municipality, Pixelyka Seme District Municipality, Northern Cape) and the existing Perseus substation near Dealesville, close to Boshof (Tokologo Local Municipality, Lejweleputswa District Municipality, Free State). Construction of the transmission line will take place within a servitude of 80 m width while a corridor of 2 km width is being assessed by impact specialists.

According to the Draft Environmental Scoping Report of November 2012 submitted to the National Department of Environmental Affairs by Mokgope Consulting (DEA Ref: 14/12/16/3/3/2/356) the proposed development falls within the jurisdiction of various municipalities, namely: Tokologo Local Municipality; Letsemeng Local Municipality; Sol Plaatje Local Municipality; Ubuntu Local Municipality; Renosterberg Local Municipality; Siyancuma Local Municipality; Thembelihle Local Municipality; Emthanjeni Local Municipality and Kareeberg Local Municipality and may run through various farms which will be identified during the Public Participation Phase.

Infrastructure developments of relevance to the present palaeontological heritage assessment include:

- Installation of “V’ towers supporting the above-ground cableways. The towers have a small point of contact on the ground where there will be a small concrete base (*c*. 1 m x 1 m) and the guys and stays will be drilled in. A working area of 100 m x 50 m is needed for each of the proposed towers to be constructed. Support structures will be located at an average interval of 400 m along the transmission line.

- Construction of a new construction and maintenance road along the transmission line corridor as well as widening of existing access roads. Existing road infrastructure would be used as far as possible to provide access for vehicles during the construction and maintenance of the line
- Upgrade of substations. Confirmation regarding the upgrading of the Perseus and Gamma Substations will be provided in the EIR.
- Installation of a telecommunication mast.
- Construction camps and laydown areas.

The various route options under consideration for the Gamma – Perseus 765 kV transmission line are shown in Figure 1. Three basic routes are under consideration at this stage:

1. An **eastern route** (**Alternative Route 1**, brown line in Figs. 1 & 2) that follows existing servitudes and takes a fairly direct, SW to NE trending line between the Gamma and Perseus Substations *via* De Aar. This is currently the most favoured route.

2. A **central route** (**Alternative Route 2**, lilac line in Figs. 1 & 2) with three deviations (**Alternative Routes 2a** yellow, **2b** dark green and **2c** blue lines) that runs broadly parallel to and northwest of the existing servitude. The deviations provide alternative crossing points along the Orange, Riet and Modder Rivers.

3. A **western route** (**Alternative Route 3**, pale green in Figs. 1 & 2) which takes a longer arc through the Northern Cape, entering the Free State from the west, and runs well the northwest of the existing servitude. This route faces several challenges in terms of cultural heritage and conservation issues and is therefore unlikely to be selected in its current form (T. Hart, ACO, pers. comm., 2013).

The No-go or “do nothing” alternative refers to the option of not undertaking the proposed development, which implies that the 765kV overhead line would not be constructed and the substations not upgraded.

Mokgope Consulting (Address: 49 3rd Avenue, Highlands North, 2192. Tel: 086 607 9481. E-mail: mokgope@gmail.com. Website: www.mokgope.co.za) has been appointed by Eskom to conduct a full EIA process for the proposed Gamma – Perseus 765 kV transmission line development, which comprises the Scoping phase and the EIA phase in terms of the National Environmental Management Act (NEMA) (Act 107 of 1998, amended in 2008).

This desktop palaeontological heritage specialist report provides a brief comparative assessment of the observed or inferred palaeontological heritage along the various transmission line routes under consideration for the second new Gamma – Perseus 765 transmission powerline project with recommendations for further specialist palaeontological studies where these are considered necessary. This desktop study forms part of a broad-based heritage assessment for the project conducted by ACO Associates cc (Contact: Tim Hart. Unit c26 Prime Park, 21 Mocke Road, 7800 Diep River. Tel: 021 7064104. Email: tim.hart@aco-associates.com) and which falls under Sections 35 and 38 (Heritage Resources Management) of the South African Heritage Resources Act (Act No. 25 of 1999).

The approach to this palaeontological heritage study is briefly as follows. Fossil bearing rock units occurring beneath the various transmission line route options are determined from geological maps and satellite images (Sections 2, 4; Fig. 2 and Appendices 1 to 4). Known fossil heritage from each rock unit is inventoried from scientific literature, previous assessments of the broader study region, and the author’s field experience and palaeontological database (Section 3 and Table 1). Based on this data the palaeontological heritage sensitivity of the route options are assessed and compared, with recommendations for any further specialist studies (Section 5).

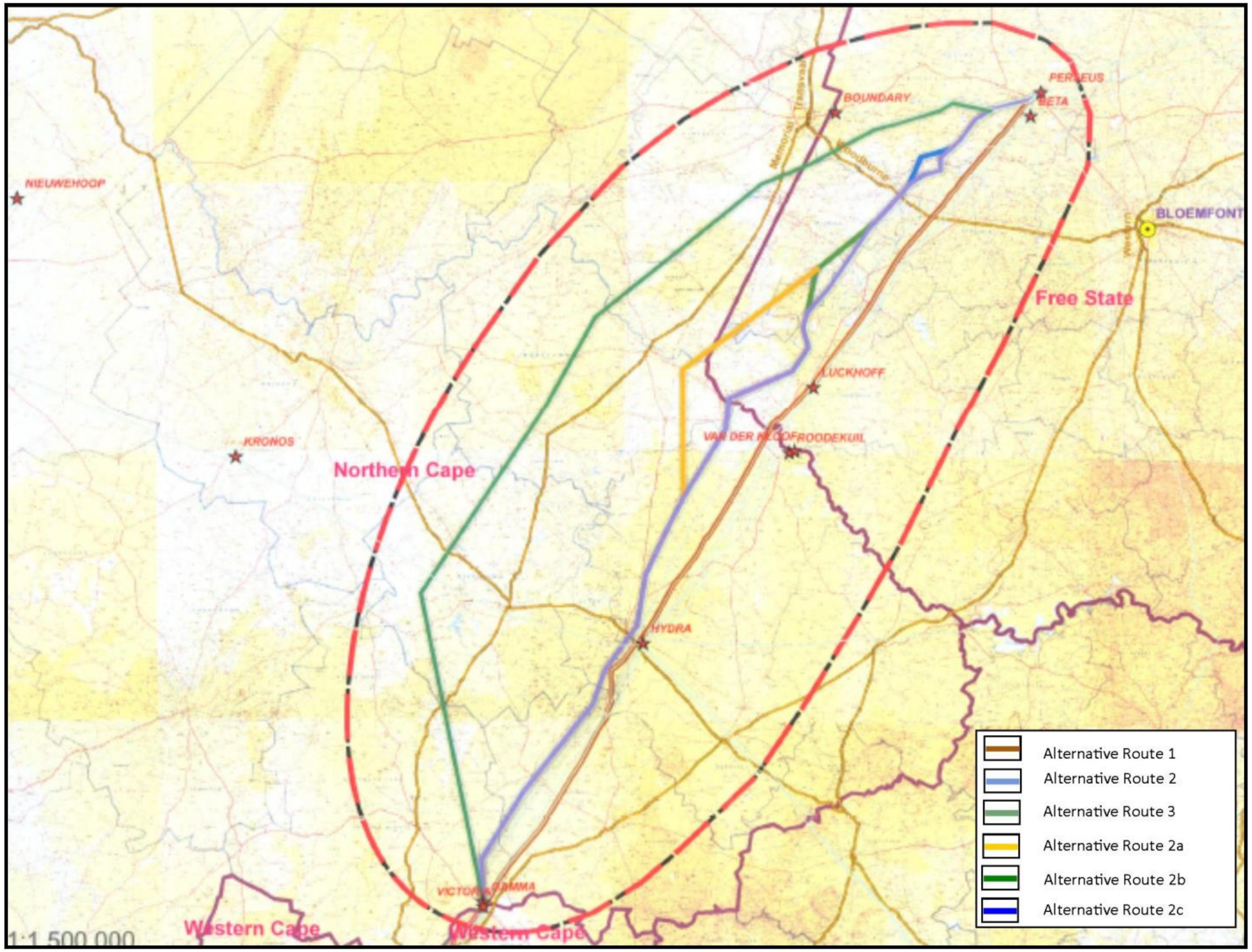


Fig. 1. Outline map showing the various route options under consideration for the new 765 kV transmission line between the existing Gamma Substation near Victoria West (Northern Cape) and existing Perseus Substation near Bloemfontein (Free State) (Image kindly provided by Mokgope Consulting, Highlands North).

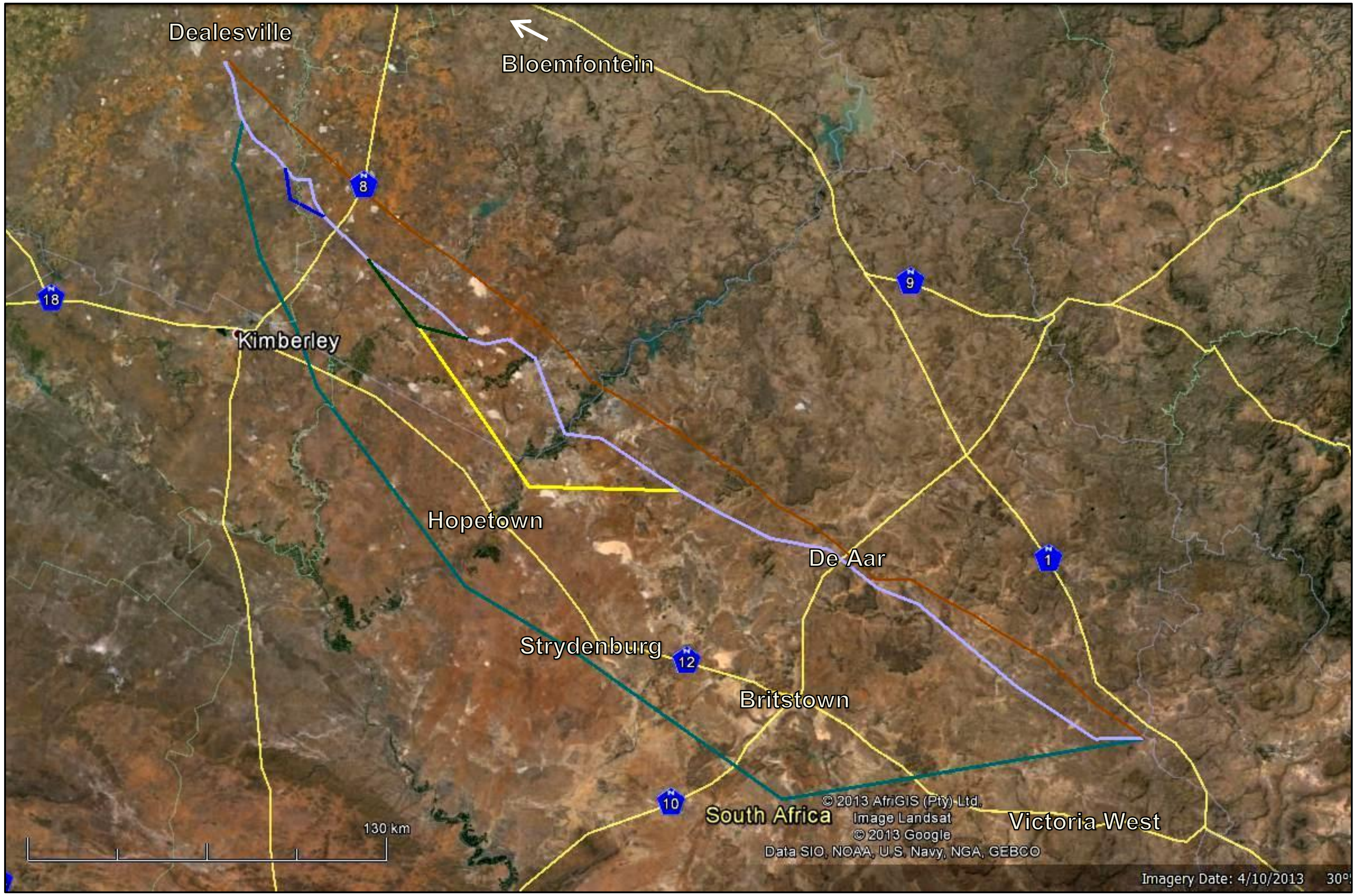


Fig. 2. Google earth© satellite image of the Gamma – Perseus transmission line study area between Victoria West and Dealesville showing the various route options. These routes are: Route 1 (brown), Route 2 (lilac) with possible diversions 2a (yellow), 2b (dark green) and 2c (blue), and Route 3 (blue-green). *N.B.* North is towards the left.

1.1. Legislative context of this palaeontological study

The proposed Gamma – Perseus transmission line developments traverse areas of the Northern Cape and Free State that are underlain by potentially fossil-rich sedimentary rocks of Precambrian, Palaeozoic, Mesozoic and younger, Tertiary or Quaternary age (Sections 2 and 3). The construction phase of the development may entail substantial surface clearance and excavations into the superficial sediment cover as well as locally into the underlying bedrock, notably for transmission line tower installations. In addition, substantial areas of bedrock may be sealed-in or sterilized by infrastructure such as lay-down areas, construction camps as well as new gravel roads. All these developments may adversely affect fossil heritage preserved at or beneath the surface of the ground within the study area by destroying, disturbing or permanently sealing-in fossils that are then no longer available for scientific research or other public good. Once constructed, the operational and decommissioning phases of the transmission line developments 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 (1999) 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 have been developed by SAHRA (2013).

1.2. Approach to the palaeontological heritage assessment

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps (See Appendices 1-4). 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 (Table 1. Provisional tabulations of palaeontological sensitivity of all formations in the Northern Cape have already been compiled by J. Almond and colleagues; *e.g.* Almond & Pether 2008). The potential 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.* SAHRA for the Northern Cape and Free State Contact details: Mrs Colette Scheermeyer, P.O. Box 4637, Cape Town 8000. Tel: 021 462 4502. Email: cscheermeyer@sahra.org.za). It should be emphasized that, *providing appropriate mitigation is carried out*, the majority of developments involving bedrock excavation can make a *positive* contribution to our understanding of local palaeontological heritage.

1.4. Assumptions & limitations

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

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

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

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

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

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

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

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

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

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

In the case of the Gamma – Perseus second 765 kV transmission line study areas a major limitation for fossil heritage studies is the frequently low level of exposure of potentially fossiliferous bedrocks such as the Karoo Supergroup, as well as the paucity of previous specialist palaeontological studies in the Northern Cape region as a whole. Little palaeontological data is available in the relevant geological sheet map explanations (See Almond & Pether 2008). However, a number of field-based palaeontological heritage assessments carried out by the author in the Victoria West, De Aar and Kimberley regions in recent years (see reference list) usefully supplement the limited published scientific literature relevant to this project that is available.

1.5. Information sources

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

1. A short project outline provided in the Draft Environmental Scoping Report produced by Mokgope Consulting (November 2012) *plus* kmz files and maps provided by ACO;

2. 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 Victoria West – De Aar – Kimberley region by the author (See reference list).

3. The author's previous field experience with the formations concerned and their palaeontological heritage (See also review of Northern Cape fossil heritage by Almond & Pether 2008).

2. GEOLOGICAL OUTLINE OF THE STUDY AREA

The study area for the new Gamma-Perseus 765 kV transmission line between Victoria West and Dealesville is situated on the Interior Plateau of South Africa at elevations of between 1100 – 1400 m amsl. It lies within the Upper Karoo physiographic region according to the scheme used by Visser *et al.* (1989). In the more recent physiographic scheme of Partridge *et al.* (2010), with a strong emphasis on drainage patterns, most of the study area lies within their Upper Karoo geomorphic province that is largely underlain by flat-lying sediments of the Karoo Supergroup which here are extensively intruded by dolerite dykes and sills. The readily-eroded Karoo Supergroup sediments mainly generate gentle hillslopes and *vlaktes*, in many cases representing relict pediment surfaces, while the resistant dolerites are associated with flat-topped *tafelkoppies* (mesas) and rocky ridges. With predominantly semi-arid climates, most river systems are ephemeral and associated with wide, open valleys and braided floodplains (*ibid*.). The Gamma – Perseus transmission line study area also traverses two other geomorphic provinces, *viz*: the Lower Vaal and Orange Valleys province where it crosses the Orange River between the Vanderkloof Dam and Douglas, and the Southern Highveld portion of the Highveld Province in the region north of the Modder River. Close to the Orange River denudation of the Karoo sedimentary cover has exposed ancient Precambrian basement rocks while sets of older (Tertiary - Quaternary) alluvial terraces are well-preserved in the Kimberley region. The Southern Highveld region is largely underlain by Karoo Supergroup bedrocks generating a gently undulating landscape with shallow, open valleys, relict palaeodrainage systems marked by pans, and low levels of bedrock incision.

The geology of the Gamma-Perseus transmission line study area is covered on six adjoining 1: 250 000 geological maps published by the Council for Geoscience, Pretoria. These are geology sheets 3122 Victoria West (explanation by Le Roux & Keyser 1988), sheet 3022 Britstown (explanation by Prinsloo 1989), sheet 3014 Colesberg (explanation by Le Roux 1993), sheet 2922 Prieska (explanation not yet published), sheet 2914 Koffiefontein (explanation by Zawada 1992), and sheet 2824 Kimberley (explanation by Bosch 1993). The geology along the various 765 kV transmission line route options between Hutchinson and Dealesville is shown a series of 52 strip maps or "sections" abstracted from these 1: 250 000 geological maps (Appendices 1 to 4). These strip maps form the main basis for the present desktop assessment of potential palaeontological heritage impacts for the transmission line project. A more regional geological map at 1: 1 000 000 scale is also available (sheet explanation by Visser *et al.* 1989) but differs in several respects from the more detailed 1: 250 000 maps that form the preferred basis for the present desktop study (*e.g.* regarding the outcrop area of the Dwyka Group).

The Gamma-Perseus 765 kV transmission line study area traverses the northern margins of the Main Karoo Basin of South Africa along a roughly SW-NE trending band. In very broad terms, progressively older sediments of the Karoo Supergroup are intersected from SW to NE. Routes 1 and 2 are fairly closely aligned and are entirely underlain by Middle to Late Permian bedrocks of the Lower Beaufort Group and upper Ecca Group, together with numerous dolerite intrusions (See stratigraphic column in Figs. 3 & 4). Route 3, which makes a longer excursion to the NW, closer to the edge of the Main Karoo Basin, crosses in addition the outcrop areas of older, Late Carboniferous to Early Permian, Karoo Supergroup bedrocks, namely the lower Ecca Group and Dwyka Group. Furthermore, small outcrop areas of pre-Karoo igneous and sedimentary basement rocks (Late Archaean Ventersdorp Supergroup) are intersected close to the Orange River as well as to the south of Kimberley.

In the following section of the report, the rock units encountered along each of the transmission line route options are briefly reviewed. All major rock units mapped along the transmission line corridors between Hutchinson and Dealesville are listed in Table 1, together with a brief summary of their geology, age, known fossil heritage and inferred palaeontological sensitivity (data largely based on Almond & Pether 2008). The location of these rock units within the stratigraphic column for South Africa is shown in Figs. 3 and 4. They include a wide range of sedimentary and igneous rocks ranging in age from Late Archaean (2.7 Ga = billion years old) to Recent. The igneous rocks (*e.g.* lavas, dolerite and kimberlite intrusions) are entirely unfossiliferous while a high proportion of the sedimentary rocks are of low palaeontological sensitivity. The main exceptions are various subunits of the Karoo Subgroup including interglacial to post-glacial sediments of the Dwyka and Lower Ecca Groups, shallow marine shelf sediments of the uppermost Ecca Group, continental sediments of the Lower Beaufort Group (Adelaide Subgroup) and possible Late Tertiary (Neogene) to Pleistocene alluvial gravels along the major drainage courses such as the Orange River. Based on the known fossil record of the geological units concerned (Section 3), potential impacts on palaeontological heritage of the various route options are then assessed and compared *plus* recommendations for further specialist palaeontological input made in Sections 4 and 5.

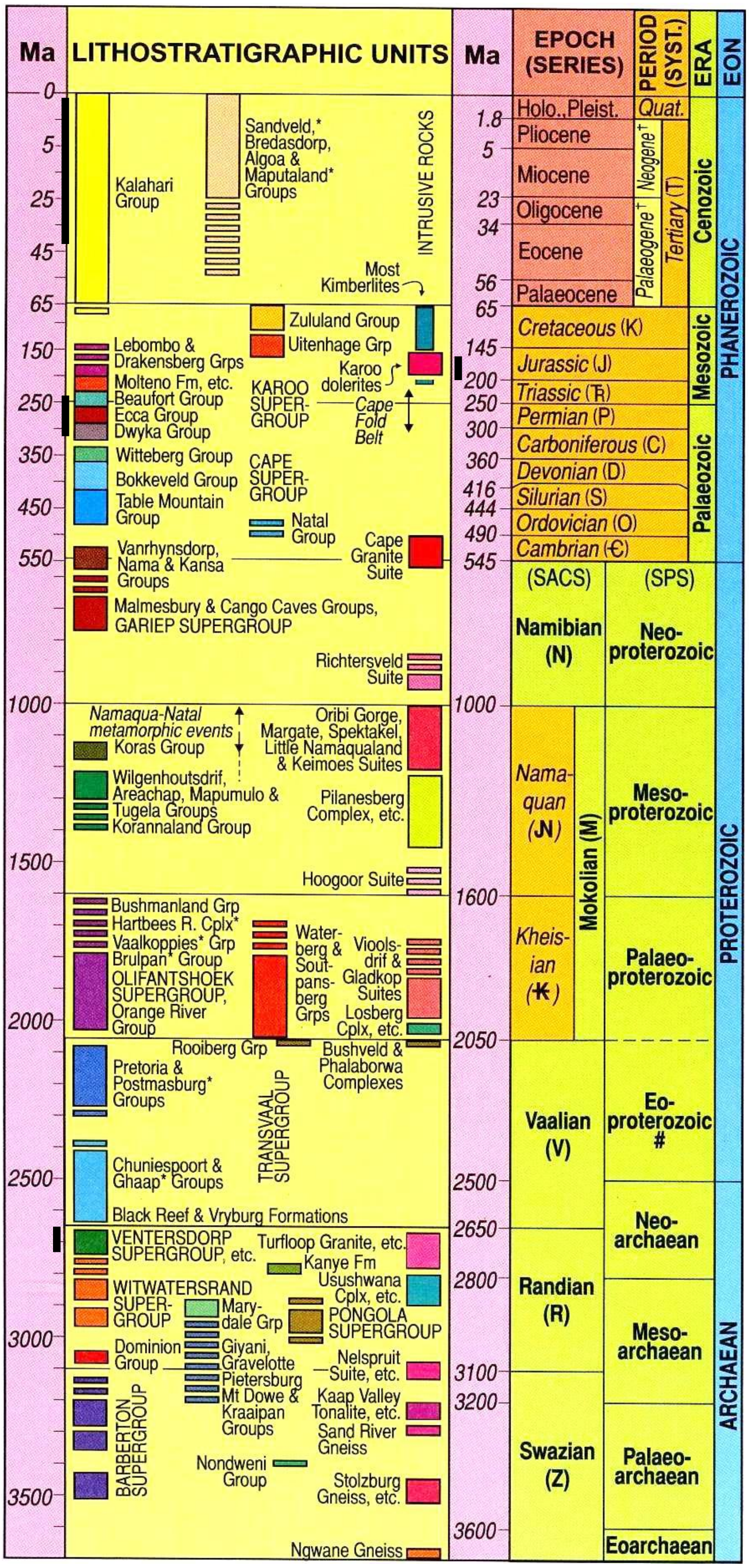


Fig. 3. Stratigraphic column for southern Africa showing the main rock units represented within the Gamma – Perseus 765 kV transmission line study area, Northern Cape & Free State (thick vertical black lines) (Modified from Johnson *et al.* 2006).

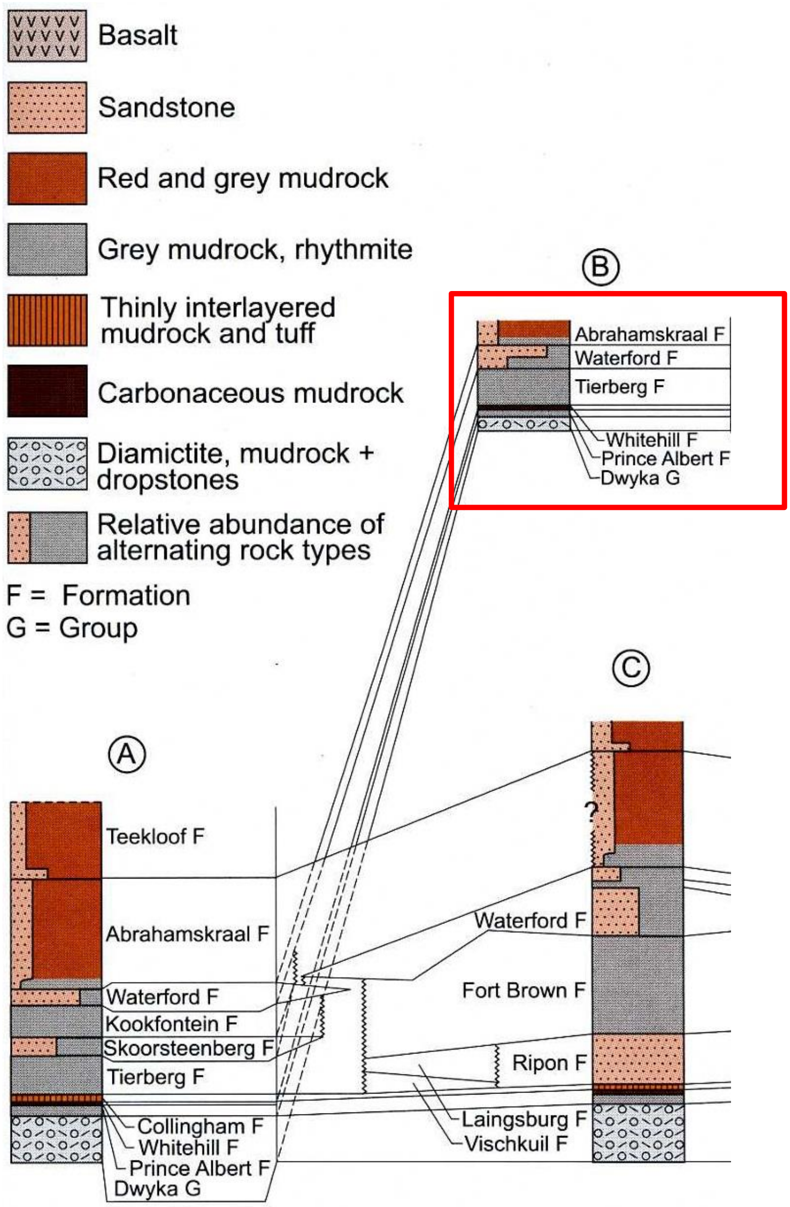


Fig. 4. Stratigraphic column of the Karoo Supergroup (Dwyka, Ecca and Beaufort Groups) in the western half of the Main Karoo Basin with the formations represented in the Gamma – Perseus study area towards the northern basin margin emphasised in red (Modified from Johnson *et al*. 2006). *N.B.* The Teekloof Formation is also well-represented above the Abrahamskraal Formation in the study area, as shown in Fig. A.

2.1. Ventersdorp Supergroup

The **Ventersdorp Supergroup** represents a major episode of igneous extrusion (LIP = Large Igneous Province) that is associated with fracturing of the Kaapvaal Craton some 2.7 Ga (billion years) ago. The basal lava pile termed the Klipriviersberg Group - mainly basaltic lavas welling up in fissure eruptions, totalling up to two kilometres thick and 100 000 km^2 in extent - accumulated over a comparatively short period of some six million years (McCarthy & Rubidge 2005). The overlying **Platberg Group** comprises a range of felsic to mafic volcanic rocks, including lavas and pyroclastics, as well as subordinate carbonate and siliclastic sediments. Porphyritic lavas with lenses of tuff, sedimentary arkoses derived from weathering of local granitic rocks *plus* dacitic rocks make up the '**Tkuip Formation** (Rt). This rock succession was previously placed within the Sodium Group (Britstown sheet, Prinsloo 1989) but is now assigned to the **Kameeldoorns Formation** at the base of the Platberg Group (Van der Westhuizen *et al.* 2006). Porphyritic felsites (lavas) and pyroclastic flows of the **Makwassie Formation** near Kimberley are associated with rift-related sediments, including colluvial, alluvial fan and lacustrine deposits (Bosch 1993, Van der Westhuizen *et al.* 2006). They are overlain by fluvial polymict conglomerates and quartzites of the **Bothaville Formation**. At the top of the Ventersdorp succession are the greyish-green amydaloidal and porphyritic lavas - mainly basaltic andesites - of the **Allanridge Formation**. Here can be recognised lava flows up to 14 m-thick with vesicular tops, pipe-like structures due to lava degassing, and pillow structures formed during subaqueous eruptions (Bosch 1993). Gas vesicles within the amygdaloidal lavas are infilled with a range of secondary minerals including reddish chalcedony, quartz, calcite, chlorite and epidote. A thin lenticular succession of conglomerate and cross-bedded quartzites occurs locally just above the base of the succession.

A rusty-brown to metallic surface weathering patina (desert varnish) has developed on many surface boulders of Allanridge lavas. This patina has been exploited locally by Later Stone Age rock engravers (*e.g.* Wildebeest Kuil rock art centre near Kimberley). A number of glacial pavements - glacially-striated and eroded bedrocks - of Dwyka age (*i.e.* Permo-Carboniferous, *c*. 300 Ma) are mapped within the Allanridge Formation outcrop area in the same region. These features, which here indicate consistent ice transport directions to the southwest, are of geological conservation significance (Almond 2012c).

2.2. Dwyka Group

The geology of the Dwyka Group has been summarized by Visser (1989), Visser *et al.* (1990) and Johnson *et al.* (2006), among others. The Dwyka Group along the north-western margin of the Main Karoo Basinhas been reviewed by Visser (1982, 1985). The relatively thin Dwyka succession here mainly comprises massive clast-rich diamictites and clast–poor argillaceous diamictites ("boulder shale") overlain by a thin zone of laminated dropstone argillite with outsized clasts composed mainly of quartzite and gneiss (Visser 1985). Isolated peaks (*monadnocks*) of Proterozoic basement rocks emerge through the Dwyka cover rocks in some areas. Ice transport directions initially towards the south and later towards the southwest are reconstructed by Visser (1985).

Further detailed observations on the Dwyka beds on the northern edge of the Britstown 1: 250 000 sheet are provided by Prinsloo (1989). Good surface outcrops of the Dwyka beds are rare here due to extensive cover by thin surface gravels. Massive tillites at the base of the Dwyka succession were deposited by dry-based ice sheets in deeper basement valleys. Later climatic amelioration led to melting, marine transgression and the retreat of the ice sheets onto the continental highlands in the north. The valleys were then occupied by marine inlets within which drifting glaciers deposited dropstones onto the muddy sea bed ("boulder shales"). The upper Dwyka beds are typically heterolithic, with shales, siltstones and fine-grained sandstones of deltaic and / or turbiditic origin. These upper successions are typically upwards-coarsening and show extensive soft-sediment deformation (loading and slumping). Varved (rhythmically laminated) mudrocks with gritty to fine gravely dropstones indicate the onset of highly seasonal climates, with warmer intervals leading occasionally even to limestone precipitation.

According to maps in Visser *et al.* (1990) and Von Brunn and Visser (1999) the Dwyka rocks in the area close to the northern edge of the Main Karoo Basin belong to the **Mbizane Formation**. This is equivalent to the Northern (valley and inlet) Facies of Visser *et al*. (1990). The Mbizane Formation, up to 190 m thick, is recognized across the entire northern margin of the Main Karoo Basin where it may variously form the whole or only the *upper* part of the Dwyka succession. It is characterized by its extremely heterolithic nature, with marked vertical and horizontal facies variation (Von Brunn & Visser 1999). The proportion of diamictite and mudrock is often low, the former often confined to basement depressions. Orange-tinted sandstones (often structureless or displaying extensive soft-sediment deformation, amalgamation and mass flow processes) may dominate the succession. The Mbizane-type heterolithic successions characterize the thicker Dwyka of the ancient palaeovalleys cutting back into the northern basement rocks.

2.3. 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). A thick succession of the predominantly fine-grained, basinal Ecca sediments underlies a high proportion of the Gamma-Perseus transmission line study area to the north of De Aar. As far as the Karoo Supergroup is concerned, the De Aar region is of special geological and palaeontological interest in that the stratigraphic boundary between the Ecca Group, largely composed of marine (actually freshwater inland sea) rocks, and the overlying continental sediments of the Beaufort Group runs along the base of the major escarpment to the east of town. It is also mapped around the slopes of isolated Karoo *koppies* to the north such as the Renosterberg and Tierberg ranges. This marine-to-land transition across the ancient Ecca Sea shoreline has been much discussed in the geological literature, but many details remain to be resolved (*e.g.* Visser & Loock 1974, Visser *et al.* 1978, Smith & Zawada 1988, 1989, Rust *et al.* 1991, Zawada 1992, Rubidge *et al.* 2000, Viljoen 2005). As discussed below (Section 2.3.3.), the precise stratigraphic position and classification of the Ecca and Beaufort Group rocks in the De Aar – Philipstown region remain ambiguous, and the identification and distribution of the various formations as shown on geological maps (*e.g.* 1: 250 000 Colesberg sheet) does not accord with palaeoenvironmental data shown by the rocks on the ground (Almond 2013a, 2013d).

2.3.1. Prince Albert Formation (Ecca Group)

The post-glacial basinal mudrocks of the **Prince Albert Formation** (**Ppr**) form the lowermost subunit of the Ecca Group. This thin-bedded to laminated mudrock-dominated succesion 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 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. The brittle rocks are well-jointed and often display a well-developed tectonic cleavage that results in sharp, elongate cleavage flakes ("pencil cleavage"). Extensive bedding planes are therefore rarely encountered in the southern outcrop area close to the Cape Fold Belt while Northern Cape outcrops are much less deformed.

The Prince Albert Formation (Ppr, Ppw) in the study area consists predominantly of dark, well-laminated basinal mudrocks (shales, siltstones) with minor thin-bedded fine-grained sandstone and siltstone lenses. The mudrocks are sometimes micaceous, carbonaceous or pyritic and typically contain a variety of diagenetic concretions enriched in iron and carbonate minerals (Visser *et al.* 1977, Zawada 1992, Bosch 1993). Some of these carbonate concretions are richly fossilferous (See Section 3.3.1). Much of the Ecca shale outcrop area has been modified by extensive near-surface calcretization as well as baking by Karoo dolerite intrusions (*e.g.* Almond 2013c).

2.3.2. Whitehill Formation (Ecca Group)

The Whitehill Formation (Ppw / Ppr) is a thin (*c*. 20-30m) 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, 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.

Occurrences of the Whitehill Formation within the Northern Cape study region are described by Visser *et al.* (1977), Prinsloo (1989), Zawada (1992) and Bosch (1993). Due to its soft-weathering nature natural outcrops are scarce, and exposures of this formation are usually restricted to artificial excavations such as road cuttings, quarries and borrow pits.

2.3.3. Tierberg and Waterford Formations (Ecca Group)

The **Tierberg Formation** (**Pt**) (Ecca Group, Karoo Supergroup) is a recessive-weathering, mudrock-dominated succession consisting predominantly of dark, well-laminated, carbonaceous shales with subordinate thin, fine-grained sandstones (Visser *et al.* 1977, Prinsloo 1989, Zawada 1992, Bosch 1993, Le Roux 1993, Viljoen 2005, Johnson *et al*., 2006). The Tierberg shales are Early to Middle Permian in age and were deposited in a range of offshore, quiet water environments below wave base. These include basin plain, distal turbidite fan and distal prodelta settings in ascending order (Viljoen 2005, Almond 2008a). Thin coarsening-upwards cycles occur towards the top of the formation with local evidence of soft-sediment deformation, ripples and common calcareous concretions (often with well-developed cone-in-cone structures). A restricted, brackish water environment is reconstructed for the Ecca Basin at this time. Close to the contact with Karoo dolerite intrusions the Tierberg mudrocks are baked to a dark grey hornfels with a reddish-brown crust or patina (Prinsloo 1989).

It should be noted here that the stratigraphic as well as palaeoenvironmental interpretation of the Ecca / Beaufort boundary rocks in the De Aar – Philipstown area is more complex and unresolved than that suggested by the brief treatment in the Britstown and Colesberg geology sheet explanations by Prinsloo (1989) and Le Roux (1993) respectively. For mapping purposes, the base of the first prominent-weathering sandstone within the Ecca / Beaufort boundary succession has been taken as the base of the Beaufort Group in this region (Le Roux 1993, p. 4, following Nel 1977). The marine or lacustrine, uppermost Ecca Group rocks here, though mapped as offshore / basinal Tierberg Formation, have in fact many features in common with the shallow shelf, storm-dominated, sandstone-rich facies seen at the top of the Ecca succession in the Carnarvon area to the west (Almond 2012b, 2013a, 2013d). These uppermost Ecca Group rocks were previously assigned to the Carnarvon Formation that has since been incorporated into the **Waterford Formation** (*e.g.* Johnson *et al.* 2006). They tend to be more sandstone-rich than the overlying Beaufort Group. The "Carnarvon Facies" is characterised by upward-coarsening, yellowish-weathering, sandstone-rich successions containing storm-generated hummocky cross-stratification and wave ripples, large ferruginous carbonate concretions (*koffieklip*), ball-and-pillow load structures, and pervasive low intensity bioturbation by low diversity trace fossil assemblages. In contrast to the *Mermia* Ichnofacies traces of the basinal Tierberg mudrocks *sensu stricto*, the Carnarvon facies trace fossil assemblages have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Siebrits 1987, Smith & Zawada 1988, 1989, Prinsloo 1989, Rust *et al.* 1991 and references therein). Petrified wood and other plant remains (*e.g.* leaf compressions) are locally abundant. The inshore shelf (shoreface) Carnarvon facies rocks have a gradational contact with the underlying offshore Tierberg mudrocks and are in turn conformably overlain by continental (subaerial), fluvial sediments of the Lower Beaufort Group.

For the purpose of the present fossil heritage study, the upper Ecca Group sediments within the study area near De Aar are assigned to the Waterford Formation, despite their attribution to the Tierberg Formation on the published 1: 250 000 geological maps (See Appendices) and the key SACS publication by Viljoen (2005). It is important to note that the key holostratotype (Stratotype A) section through the Tierberg Formation identified by Viljoen (2005) is located just to the north of Tierberg, just to the west of the Route 1 transmission line corridor. On the basis of both sedimentary facies and fossil assemblages, the rocks here closely resemble the tempestite-dominated nearshore "Carnarvon-type" facies of the Waterford Formation (Almond 2012c).

2.4. Lower Beaufort Group

The study area is largely underlain by Mid to Late Permian continental sediments of the Lower Beaufort Group (Adelaide Subgroup, Karoo Supergroup). A useful overview of this internationally famous rock succession has been given by Johnson *et al.* (2006). The Beaufort Group succession within the Northern Cape and Free State study area is largely flat-lying and undeformed. However, these Permian sediments are extensively intruded and thermally metamorphosed (baked) by sills and dykes of the Early Jurassic Karoo Dolerite Suite (Jd).

Geological and palaeoenvironmental analyses of the Lower Beaufort Group sediments in the Great Karoo region have been conducted by a number of workers. Key references within an extensive scientific literature include various papers by Roger Smith (e.g. Smith 1979, 1980, 1986, 1987, 1988, 1989, 1990, 1993a, 1993b) and Stear (1978, 1980), as well as several informative field guides (e.g. Cole & Smith 2008). In brief, these thick successions of clastic sediments were laid down by a series of large, meandering rivers within a subsiding basin over a period of some ten or more million years within the Late Permian Period (c. 265-251 Ma). Sinuous sandstone bodies of lenticular cross-section represent ancient channel infills, while thin (<1.5m), laterally-extensive sandstone beds were deposited by crevasse splays during occasional overbank floods. The bulk of the Lower Beaufort sediments are greyish-green to reddish-brown or purplish mudrocks ("mudstones" = fine-grained claystones and slightly coarser siltstones) that were deposited over the floodplains during major floods. Thin-bedded, fine-grained playa lake deposits also accumulated locally where water ponded-up in floodplain depressions and are associated with distinctive fossil assemblages (*e.g.* fish, amphibians, coprolites or fossil droppings, arthropod, vertebrate and other trace fossils).

Frequent development of fine-grained pedogenic (soil) limestone or calcrete as nodules and more continuous banks indicates that semi-arid, highly seasonal climates prevailed in the Late Permian Karoo. This is also indicated by the frequent occurrence of sand-infilled mudcracks and silicified gypsum "desert roses" (Smith 1980, 1990, 1993a, 1993b). Highly continental climates can be expected from the palaeogeographic setting of the Karoo Basin at the time – embedded deep within the interior of the Supercontinent Pangaea and in the rainshadow of the developing Gondwanide Mountain Belt. Fluctuating water tables and redox processes in the alluvial plain soil and subsoil are indicated by interbedded mudrock horizons of contrasting colours. Reddish-brown to purplish mudrocks probably developed during drier, more oxidising conditions associated with lowered water tables, while greenish-grey mudrocks reflect reducing conditions in waterlogged soils during periods of raised water tables. However, diagenetic (post-burial) processes also greatly influence predominant mudrock colour (Smith 1990).

2.4.1. Abrahamskraal Formation

Middle to Late Permian continental sediments of the **Abrahamskraal Formation** (Adelaide Subgroup, Lower Beaufort Group) underlie Gamma-Perseus transmission line corridor options on the Victoria West and Britstown 1: 250 000 geology sheets where they indicated by the symbol "Pa". However, it should be noted that "Pa" on the adjoining Colesberg sheet (*e.g.* in the De Aar area) denotes the entire Lower Beaufort Group (Adelaide Subgroup), much of which here belongs to equivalents of the Teekloof Formation. The Abrahamskraal succession consists of a wide range of fluvial deposits, including river channel sandstones and minor intraformational breccio-conglomerates, well-bedded floodplain mudrocks with common pedocrete horizons (ancient soils) and sheet-like crevasse splay sandstones, as well as more localized playa lake deposits (*e.g.* laminated mudrocks) (Rossouw & De Villiers 1952, Johnson & Keyser 1979, Smith 1980, Theron 1983, Theron *et al*., 1991, Smith 1979, 1980, 1990, 1993a, 1993b, Smith & Keyser 1995a, Loock *et al*., 1994, Johnson *et al*., 2006).

2.4.2. Teekloof Formation

Compared with the underlying Abrahamskraal Formation succession the fluvial sediments of the **Teekloof Formation** have a generally higher proportion of sandstones while reddish mudrocks are more abundant here (Johnson & Keyser 1988). Multi-storied sandstones are common in the basal arenaceous **Poortjie Member**, as are thin, impersistent lenses of pinkish "cherts" that are probably altered volcanic ashes (Johnson & Keyser 1979, Smith & Keyser 1995a). This member is about 80 m thick in the Victoria West area, thinning eastwards. Several economically interesting uranium ore deposits occur within the Poortjie Member in association with brown-weathering, ferruginous channel sandstones ("koffieklip") and transported plant material. Interesting accounts of the sedimentology and palaeontology of the Poortjie Member in the southern Karoo are given by Stear (1978) as well as by Cole and Smith (2008). Stratigraphic equivalents of the Poortjie Member have recently been recognised in the lower escarpment slopes to the east of De Aar, based on palaeontological evidence (Almond 2012a, Day *et al.* 2013). The geology of the overlying **Hoedemaker Member**, which is up to 240 m thick, is outlined by Smith (1980, 1993a, b) and later by Smith and Keyser (1995b) as well as Cole and Smith (2008). The Hoedemaker succession is dominated by greenish-grey to purple-brown overbank mudrocks, with occasional single-storey sheet sandstones. Palaeosol (ancient soil) horizons characterized by calcrete nodules and rhizocretions (root casts) are common, as are also lacustrine (transient to long-lived playa lake) sediments deposited in depressions on the Late Permian floodplain. These last are associated with limestone crusts, gypsum crystals ("desert roses") as well as a range of fine-scale sedimentary features such as wave rippled sandstones, falling water marks, mudcracks, and trace fossils (Stear 1978, Smith 1980, 1986, 1993a).

2.5. Karoo Dolerite Suite

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

2.6. Kimberlite intrusions

Numerous **kimberlite pipes** of Jurassic to Cretaceous age intrude the Karoo Supergroup rocks north of Victoria West, including several examples to the east of De Aar. They are variously assigned to the Victoria West and Group II Provinces (Skinner & Truswell 2006) and do not contain diamonds. According to Le Roux (1993) the ultramafic kimberlite pipe rocks in the Colesberg sheet area are highly weathered with no obvious surface expression. They can usually be located only on the basis of characteristic mineral assemblages (garnet, phlogopite mica) found in ant heaps, termite mounds and prospecting holes.

WSW to ENE trending **Kimberlite fissure intrusions** dated to 77-120 Ma are mapped in the Kimberley area where they intrude the Precambrian to Mesozoic bedrocks (Bosch 1993 Table 8.1, Skinner & Truswell 2006). Weathered Kimberlite fissure fills appear at surface as a yellowish-green micaceous material and may enclose xenoliths of country rocks (Bosch 1993).

It is unlikely that any of the Gamma – Perseus transmission line route options directly overlies a major kimberlite intrusion. However, this possibility cannot be entirely discounted, especially since many such intrusive bodies are likely to be hidden beneath a mantle of superficial sediments and therefore have not been mapped.

2.3. Late Caenozoic superficial sediments (calcretes, aeolian sands)

Relict patches of elevated Late Tertiary to Quaternary **alluvial gravels** ("High Level Gravels") are mapped along both the Vaal and Orange Rivers in the Windsorton – Kimberley – Douglas - Prieska area, where they have been associated with diamond mining (De Wit *et al*., 2000). In the Windsorton area to the north of Kimberley heavily calcretized "Older Gravels" have been grouped into the **Windsorton Formation** and are suspected to be Miocene-Pliocene in age (Partridge & Brink 1967, De Wit *et a*l., 2000, Partridge *et al.* 2006). The "Younger Gravels" (**Rietputs Formation**) of the Vaal River system, at lower elevations, are associated with Acheulian stone tools and are therefore considered to be Early to Middle Pleistocene (Cornelian) in age (Klein 1984, Table 2, Butzer *et al*., 1973, Partridge *et al*., 2006). Recent cosmogenic nuclide dating of coarse gravels and sands in the Rietputs Formation gave an age of *c*. 1.57 Ma (Gibbon *et al.,* 2009). These older "High Level Gravels" are *not* mapped within the Gamma – Perseus transmission line corridors where these cross the Orange River, however.

Large sections of the Gamma - Perseus 765 kV transmission line study area are mantled by a wide spectrum of **superficial sediments** of probable Late Caenozoic (*i.e.* Late Tertiary or Neogene to Recent) age, many of which are assigned to the **Kalahari Group**. The geology of the Late Cretaceous to Recent Kalahari Group is reviewed by Thomas (1981), Dingle *et al.* (1983), Thomas & Shaw 1991, Haddon (2000) and Partridge *et al.* (2006). Other superficial sediments whose outcrop areas are often not indicated on geological maps include colluvial or slope deposits (scree, hillwash, debris flows *etc*), sandy, gravelly and bouldery river alluvium (*e.g.* along the Orange, Riet and Modder Rivers), surface gravels of various origins, diverse soils, as well as spring and pan sediments. These last are sometimes associated with abandoned ancient drainage courses, such as the Koa River system of the Northern Cape. The colluvial, alluvial and pan deposits may be extensively calcretised (*i.e.* cemented with pedogenic limestone), especially in the neighbourhood of dolerite intrusions.

Large mappable exposures of **calcrete** or **surface limestone** (**Ql / Qc**) occur in the Colesberg, Koffiefontein, Prieska and Kimberley 1: 250 000 sheet areas in particular. These pedogenic limestone deposits reflect seasonally arid climates in the region over the last five or so million years and are briefly described by Truter *et al.* (1938) as well as Visser (1958), Le Roux (1993) and Bosch (1993) (See also Almond 2013c). The surface limestones may reach thicknesses of over 20 m, but are often much thinner, and are locally conglomeratic with clasts of reworked calcrete as well as exotic pebbles. The limestones may be secondarily silicified and incorporate blocks of the underlying Precambrian basement, Karoo Supergroup or dolerite bedrocks. The older, Pliocene - Pleistocene calcretes in the broader Kalahari region, including sandy limestones and calcretised conglomerates, have been assigned to the **Mokalanen Formation** of the Kalahari Group and are possibly related to a globally arid time period between 2.8 and 2.6 million years ago, *i.e.* late Pliocene (Partridge *et al.* 2006).

Large areas of unconsolidated, reddish-brown to grey aeolian (*i.e.* wind-blown) sands of the Quaternary **Gordonia Formation** (Kalahari Group; **Qs**) are mapped in the Gamma – Perseus study region, especially in the Koffiefontein, Prieska and Kimberley 1: 250 000 sheet areas. According to Bosch (1993) the Gordonia sands in the Kimberley area reach thicknesses of up to eight meters and consist of up to 85% quartz associated with minor feldspar, mica and a range of heavy minerals. The Gordonia dune sands are considered to range in age from the Late Pliocene / Early Pleistocene to Recent, dated in part from enclosed Middle to Later Stone Age stone tools (Dingle *et al*., 1983, p. 291). Note that the recent extension of the Pliocene - Pleistocene boundary from 1.8Ma back to 2.588 Ma would place the Gordonia Formation almost entirely within the Pleistocene Epoch.

3. OVERVIEW OF PALAEONTOLOGICAL HERITAGE WITHIN THE STUDY AREA

Fossil biotas recorded from each of the main sedimentary rock units mapped along the Gamma – Perseus 765 kV transmission line route options are briefly reviewed below and summarized in Table 1, where an indication of the palaeontological sensitivity of each rock unit is also given (Based largely on Almond & Pether 2008 and references therein). The quality of fossil preservation may compromised in some areas due to intense near-surface chemical weathering. Furthermore, extensive dolerite intrusion (resulting in thermal metamorphism as well as secondary chemical alteration) and calcrete formation has compromised fossil heritage in many portions of the Karoo Supergroup outcrop area (*e.g.* Ecca Group) (*cf* Almond 2013c).

3.1. Fossils within the Ventersdorp Supergroup

The Kameeldoorns Formation, to which the 'Tcuip succession of mixed lavas and sediments is now assigned (Van der Westhuizen *et al.* 2006, p. 194), contains carbonate sediments with stromatolitic bioherms near Taung (Christiana 1: 250 000 sheet area; Schutte 1994). Domical stromatolites are recorded from shallow water lacustrine calcarenites within the volcano-sedimentary succession of the Rietgat Formation at the top of the Platberg Group (Schopf 2006, Van der Westhuizen *et al.* 2006). The overlying predominantly siliciclastic Bothaville Formation contains conical stromatolites, probably also developed within lacustrine settings (Schopf 2006). Carbonate sediments are not reported in association with the Allanridge Formation lavas at the top of the Ventersdorp Supergroup, however.

3.2. Fossils within the Dwyka Group

The fossil record of the Permo-carboniferous Dwyka Group is generally poor, as expected for a glacial sedimentary succession (McLachlan & Anderson 1973, Anderson & McLachlan 1976, Visser 1989, Visser *et al*., 1990, MacRae 1999, Visser 2003, Almond 2008a, 2008b). Sparse, low diversity trace fossil biotas from the Elandsvlei Formation along the southern basin margin mainly consist of delicate arthropod trackways (probably crustacean) and fish swimming trails associated with recessive-weathering dropstone laminites (Savage 1970, 1971, Anderson 1974, 1975, 1976, 1981). Sporadic vascular plant remains (drifted wood and leaves of the *Glossopteris* Flora) are also recorded (Anderson & Anderson 1985, Bamford 2000, 2004), while palynomorphs (organic-walled microfossils) are 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 (Plumstead 1969). There are biogeographically interesting records of limestone glacial erratics from tillites along the southern margins of the Great Karoo that contain Cambrian eodiscid trilobites as well as diverse assemblages of archaeocyathid sponges. Such derived fossils provide important data for reconstructing the movement of Gondwana ice sheets (Cooper & Oosthuizen 1974, Stone & Thompson 2005).

Low diversity ichnoassemblages dominated by non-marine arthropod trackways are widely associated with cold water periglacial mudrocks, including dropstone laminites, within the Mbizane Formation in the Main Karoo Basin (Von Brunn & Visser, 1999, Savage 1970, 1971, Anderson 1974, 1975, 1976, 1981, Almond 2008a, 2009). They are assigned to the non-marine / lacustrine *Mermia* ichnofacies that has been extensively recorded from post-glacial epicontinental seas and large lakes of Permian age across southern Gondwana (Buatois & Mangano 1995, 2004). These Dwyka ichnoassemblages include the arthropod trackways *Maculichna*, *Umfolozia* and *Isopodichnus*, the possible crustacean resting trace *Gluckstadtella*, sinuous fish-fin traces (*Undichna*) as well as various unnamed horizontal burrows. The association of these interglacial or post-glacial ichnoassemblages with rhythmites (interpreted as varvites generated by seasonal ice melt), the absence of stenohaline marine invertebrate remains, and their low diversity suggest a restricted, fresh- or brackish water environment. Herbert and Compton (2007) also inferred a freshwater depositional environment for the Dwyka / Ecca contact beds in the SW Cape based on geochemical analyses of calcareous and phosphatic diagenetic nodules within the upper Elandsvlei and Prince Albert Formations respectively. Well-developed U-shaped burrows of the ichnogenus *Rhizocorallium* are recorded from sandstones interbedded with varved mudrocks within the upper Dwyka Group (Mbizane facies) on the Britstown sheet (Prinsloo 1989). Similar *Rhizocorallium* traces also described from the Dwyka Group of Namibia (*e.g.* the Hardap Shale Member, Miller 2008). References to occurrences of the complex helical spreiten burrow *Zoophycos* in the Dwyka of the Britstown sheet and elsewhere (*e.g.* Prinsloo 1989) are probably in error, since in Palaeozoic times this was predominantly a shallow marine to estuarine ichnogenus (Seilacher 2007).

Scattered records of fossil vascular plants within the Dwyka Group of the Main Karoo Basin record the early phase of the colonisation of SW Gondwana by members of the *Glossopteris* Flora in the Late Carboniferous (Plumstead 1969, Anderson & McLachlan 1976, Anderson & Anderson 1985 and earlier refs. therein). These records include fragmentary carbonized stems and leaves of the seed ferns *Glossopteris* / *Gamgamopteris* and several gymnospermous genera (*e.g. Noeggerathiopsis, Ginkgophyllum*) that are even found within glacial tillites. More "primitive" plant taxa include lycopods (club mosses) and true mosses such as *Dwykea*. It should be noted that the depositional setting (*e.g.* fluvial *versus* glacial) and stratigraphic position of some of these records are contested (cf Anderson & McLachlan 1976). Petrified woods with well-developed seasonal growth rings are recorded from the upper Dwyka Group (Mbizane Formation) of the northern Karoo Basin (*e.g.* Prinsloo 1989) as well as from the latest Carboniferous of southern Namibia. The more abundant Namibian material (*e.g. Megaporoxylon*) has recently received systematic attention (Bangert & Bamford 2001, Bamford 2000, 2004) and is clearly gymnospermous (pycnoxylic, *i.e.* dense woods with narrow rays) but most woods cannot be assigned to any particular gymnosperm order.

3.3. Fossils within the 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) and many of the same fossil groups can be expected in the Northern Cape and Free State outcrop areas that form part of the same Main Karoo Basin.

3.3.1. Prince Albert Formation

The fossil biota of the post-Dwyka mudrocks of the Prince Albert Formation has been summarized by Cole (2005) and Almond (2008a, 2008b), among others. Typical *Umfolozia / Undichna* – dominated trace fossil assemblages of the non-marine *Mermia* Ichnofacies are commonly found in basinal mudrock facies of the Prince Albert Formation throughout the Ecca Basin. Low diversity Prince Albert trace fossil assemblages within the Kimberley sheet area are briefly mentioned by Bosch (1993). 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*) 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 most diverse as well as biostratigraphically, palaeobiogeographically and palaeoecologically interesting fossil biota from the Prince Albert Formation is that described from calcareous concretions exposed along the Vaal River in the Douglas area of the Northern Cape (McLachlan and Anderson

1971, Visser *et al.,* 1977-78). The important Douglas biota contains petrified wood (including large tree trunks), palynomorphs (miospores), orthocone nautiloids, nuculid bivalves, articulate brachiopods, spiral and other “coprolites” (probably of fish, possibly including sharks) and fairly abundant, well-articulated remains of palaeoniscoid fish. Most of the fish have been assigned to the palaeoniscoid genus *Namaichthys* but additional taxa, including a possible acrolepid, may also be present here (Evans 2005). The invertebrates are mainly preserved as moulds.

3.3.2. Fossils within the Whitehill Formation

In palaeontological terms the Whitehill Formation is one of the richest and most interesting 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 / notocarid 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)
- 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, 1994) and Evans (2005). Kensley (1975) reported notocarid crustaceans from the Whitehill Formation near Oranjerivier.

3.3.3. Fossils within the Tierberg and Waterford Formations

The fossil record of the **Tierberg Formation** has been reviewed in detail by Almond (2008a, 2008b). Rare body fossil records include disarticulated microvertebrates (*e.g.* fish teeth and scales) from calcareous concretions in the Koffiefontein sheet area (Zawada 1992) and allochthonous plant remains (drifted leaves, petrified wood). The latter become more abundant in the upper, more proximal (prodeltaic) facies of the Tierberg (*e.g.* Wickens 1984). Prinsloo (1989) records numerous plant impressions and unspecified “fragmentary vertebrate fossils” (possibly temnospondyl amphibians) within fine-grained sandstones in the Britstown sheet area. Dark carbonaceous Ecca mudrocks are likely to contain palynomorphs (*e.g.* pollens, spores, acritarchs). Bosch (1993) and Visser *et al.* (1977) briefly mention body fossils within the Tierberg mudrocks in the broader Kimberley region. Concretions within the lower part of the formation at Kaffirs Kop 193 (southeast of Belmont) and on Klippiespan 205, for example, contain fish scales, coprolites and sponge spicules. Records of abundant silicified wood within the uppermost Tierberg succession are mostly referred to the Waterford Formation (see below). Siliceous nodules containing ornamented fish scales as well as enamel- or bone-like material (probably pseudofossils in the last two cases) were recently reported from the De Aar area by Almond (2013d).

The commonest fossils by far in the Tierberg Formation are sparse to locally concentrated assemblages of trace fossils that are often found in association with thin event beds (*e.g.* distal turbidites, prodeltaic sandstones) within more heterolithic successions. A modest range of ten or so different ichnogenera have been recorded from the Tierberg Formation (*e.g.* Abel 1935, Anderson 1974, 1976, Wickens 1980, 1984, 1994, 1996, Prinsloo 1989, De Beer *et al*., 2002, Viljoen 2005, Almond 2008a). These are mainly bedding parallel, epichnial and hypichnial traces, some preserved as undertracks. Penetrative, steep to subvertical burrows are rare, perhaps because the bottom sediments immediately beneath the sediment / water interface were anoxic. Most Tierberg ichnoassemblages display a low diversity and low to moderate density of traces. Apart from simple back-filled and / or lined horizontal burrows (*Planolites, Palaeophycus*) they include arthropod trackways (*Umfolozia*) and associated resting impressions (*Gluckstadtella*), undulose fish swimming trails (*Undichna*) that may have been generated by bottom-feeding palaeoniscoids, horizontal epichnial furrows (so-called *Scolicia*) often attributed to gastropods (these are also common in the co-eval Collingham Formation; Viljoen 1992, 1994), arcuate, finely-striated feeding excavations of an unknown arthropod (*Vadoscavichnia*), beaded traces ("*Hormosiroidea*" or "*Neonereites*"), small sinusoidal surface traces (*Cochlichnus*), small star-shaped feeding burrows (*Stelloglyphus*) and zigzag horizontal burrows (*Beloraphe*), as well as possible narrow (<1cm) *Cruziana* scratch burrows. The symmetrical, four-pronged trace *Broomichnium* (= *Quadrispinichna* of Anderson, 1974 and later authors) often occurs in groups of identical size (*c*. 3.5cm wide) and similar orientation on the bedding plane. This trace has frequently been misinterpreted as a web-footed tetrapod or arthropod trackway (*e.g.* Van Dijk *et al*. 2002 and references therein). However, Braddy and Briggs (2002) present a convincing case that this is actually a current-orientated arthropod resting trace (cubichnion), probably made by small crustaceans that lived in schools of similar-sized individuals and orientated themselves on the seabed with respect to prevailing bottom currents. Distinctive broad (3-4cm), strap-shaped, horizontal burrows with blunt ends and a more-or-less pronounced transverse ribbing occur widely within the Tierberg mudrocks. They have been described as "fucoid structures" by earlier workers (*e.g.* Ryan 1967) by analogy with seaweeds, and erroneously assigned to the ichnogenera *Plagiogmus* by Anderson (1974) and *Lophoctenium* by Wickens (1980, 1984). Examples up to one metre long were found in Tierberg mudrocks near Calvinia in 1803 by H. Lichtenstein, who described them as "eel fish". These are among the first historical records of fossils in South Africa (MacRae 1999). These as yet unnamed burrows are sometimes infilled with organized arrays of faecal pellets (Werner 2006). Good examples of these strap-shaped burrows up to 10 cm across were recent described from the De Aar area by Almond (2013d). Sandstone sole surfaces with casts of complex networks of anastomosing (branching and fusing) tubular burrows have been attributed to the ichnogenus *Paleodictyon* (Prinsloo 1989) but may more appropriately assigned to *Megagrapton* (Almond 1998). These so-called graphoglyptid burrows are associated with turbidite facies from the Ordovician to Recent times and have been interpreted as gardening burrows or *agrichnia* (Seilacher, 2007). Microbial mat textures, such as *Kinneyia*, also occur in these offshore mudrocks but, like the delicate grazing traces with which they are often associated, are generally under-recorded.

As discussed previously (Section 2.3.3) it is considered likely that the uppermost Ecca Group rocks in the De Aar region belong to the **Waterford Formation** rather than the Tierberg Formation as mapped. Rare fragments of poorly-preserved tetrapod bone are recorded in channel lags within the upper Waterford Formation in the Williston sheet area (Viljoen 1989) and the southern Great Karoo. These probably belong to aquatic temnospondyl amphibians ("labyrinthodonts") but large fish and terrestrial therapsids might also be represented. Scattered palaeoniscoid fish scales and fish coprolites are common in the Waterford Formation, and several genera of non-marine bivalves have been described from the southern Karoo (Bender *et al*. 1991, Cooper & Kensley 1984).

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

Petrified wood and other plant material of the *Glossopteris* Flora (*e.g. Glossopteris, Phyllotheca*) is also common in the Waterford Formation (Theron 1983, Anderson & Anderson 1985, Viljoen 1989, Wickens 1984, 1996, Rubidge *et al*. 2000). Leaves and stems of arthrophytes (horsetails) such as *Schizoneura* have been observed in vertical life position. Substantial fossil logs (so-called "*Dadoxylon*") showing clearly developed seasonal growth rings are mostly permineralised with silica but partially or completely calcified material is also known (Viljoen 1989). At least two different genera of gymnospermous woods, *Prototaxoxylon* and *Australoxylon,* have been identified so far (Bamford 1999, 2004). Fragments of silicified gymnospermous woods, some showing the original xylem tissue preserved in fine detail (*e.g.* clear seasonal growth rings), are among the commonest fossil remains from the Ecca Group outcrop area near De Aar reported in the various recent field studies by Almond (2012a, 2012b, 2012c, 2013a to d). Sheetwash and other near-surface gravels overlying the upper Ecca Group outcrop area consistently contain small cherty fragments of silicified woods reworked from the underlying bedrocks. Larger petrified wood samples also occur within subsurface gravels overlying Ecca bedrocks where these are exposed at surface near De Aar.

The storm-dominated shelf sediments of the Carnarvon-type facies of the Waterford Formation, as seen near De Aar, are typically associated with pervasive low intensity bioturbation by low diversity trace fossil assemblages. The latter have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Rust *et al.* 1991 and references therein). Good examples of these traces are illustrated by Siebrits (1987), Prinsloo (1989) and Rust *et al.* (1991). Abundant *Cruziana* ichnofacies traces have been recorded from uppermost Ecca beds near De Aar by Almond (2013d). Prominent "Carnarvon" trace fossil taxa include cm-sized horizontal to oblique burrows with striated walls (*cf Palaeophycus striatus*) and vertical spreiten burrows of the ichnogenus *Teichichnus*. Non-marine arthropod feeding and resting scratch burrows of the ichnogenera *Cruziana* and *Rusophycus* are also reported here; they may have been generated by crustaceans rather than trilobites. Possibly limb and belly impressions of large temnospondyl amphibians were recorded from a wave-rippled surface northeast of De Aar (Almond 2012a). The Holostratotype section through the Tierberg Formation designated by Viljoen (2005) features a variety of *Cruziana* ichnofacies trace fossil occurrences as well as occasional fossil wood material, supporting its assignment to the Waterford Formation.

3.4. Fossils in the Lower Beaufort Group

The overall palaeontological sensitivity of the Beaufort Group sediments is high to very high (Almond & Pether 2008). These continental sediments have yielded one of the richest fossil records of land-dwelling plants and animals of Permo-Triassic age anywhere in the world (MacRae 1999, Rubidge 2005, McCarthy & Rubidge 2005). Bones and teeth of Late Permian tetrapods have been collected in the Great Karoo region since at least the 1820s and this region remains a major focus of palaeontological research in South Africa.

Mid to Late Permian age vertebrate fossil assemblages of the lower Beaufort Group are dominated by a variety of small to large true reptiles and – more especially – by a wide range of therapsids. This last group of animals are also commonly, but misleadingly, known as "mammal-like reptiles" or protomammals (*e.g.* Cluver 1978, Rubidge 1995, MacRae 1999). By far the most abundant group among the Late Permian therapsids are the dicynodonts, an extinct group of two-tusked herbivorous therapsids. Other important therapsid subgroups are the dinocephalians, gorgonopsians, therocephalians and cynodonts. Aquatic animals include large, crocodile-like temnospondyl amphibians and various primitive bony fish (palaeoniscoids). Note that fossil dinosaurs are *not* found within the Great Karoo area *sensu stricto* (*i.e.* below the Great Escarpment); this group only evolved some thirty million years *after* the Lower Beaufort Group sediments were deposited.

A high proportion of the tetrapod (*i.e.* four-limbed, terrestrial vertebrate) fossils from the Beaufort Group are found within the overbank mudrocks. They are very commonly encased within calcrete or pedogenic limestone that often obscures their anatomy and makes such fossils difficult to recognise in the field, even for experienced palaeontologists (Smith 1993a, b). Rarer fossil specimens preserved within the Beaufort Group sandstones are usually disarticulated and fragmentary due to extensive, pre-burial transport. Occasionally vertebrate fossils are found embedded within baked (thermally metamorphosed) mudrocks or hornfels in the vicinity of dolerite intrusions. However, such fossils are extremely difficult to prepare out in the laboratory and so are generally of limited scientific value.

Key studies on the taphonomy (pre-burial history) of Late Permian vertebrate remains in the Great Karoo have been carried out in the Beaufort West area and have yielded a wealth of fascinating data on Late Permian terrestrial wildlife and palaeoenvironments (*e.g.* Smith 1980, 1993a). Therapsid fossils are most abundant and best preserved (well-articulated) within muddy and silty overbank sediments deposited on the proximal floodplain (*i.e.* close to the river channel). Here they are often associated with scoured surfaces and mature palaeosols (ancient soils), these last indicated by abundant calcrete nodules. In the distal floodplain sediments, far from water courses, fossils are rarer and mostly disarticulated. Channel bank sediments usually contain few fossils, mostly disarticulated, but occasionally rich concentrations of calcrete-encrusted remains, some well-articulated, are found. These dense bone assemblages may have accumulated in swale fills or chute channels which served as persistent water holes after floods (Smith 1993a, 1993b). Such detailed interdisciplinary field studies re-emphasise how essential it is that fossil collecting be undertaken by experienced professionals with a good grasp of relevant sedimentology as well as palaeontology, lest invaluable scientific data be lost in the process.

Plant fossils in the lower Beaufort Group are poorly represented and often very fragmentary (*cf*. Anderson & Anderson 1985, dealing primarily with material from the eastern Karoo Basin, Gastaldo *et al*. 2005, dealing with Permo-Triassic boundary floras in the Main Karoo Basin). They belong to the *Glossopteris* Flora that is typical of Permian Gondwana and include reedy sphenophytes or "horsetails" (Arthrophyta, now recognised as a fern subgroup) and distinctive tongue-shaped leaves of the primitive, tree-sized gymnosperm *Glossopteris*. Well-preserved petrified wood ("*Dadoxylon*") occurs widely and may prove of biostratigraphic and palaeoecological value in future (*e.g.* Bamford 1999, 2004) Elongate plant root casts or *rhizoliths* are frequently found associated with calcrete nodule horizons. Transported plant debris preserved within channel sandstones is often associated with secondary iron ("*koffieklip*") and uranium mineralization (Cole & Smith 2008 and refs. therein).

Late Permian invertebrate fossils from the western Karoo Basin comprise almost exclusively relatively featureless, thin-shelled freshwater bivalves, while fairly low diversity insect faunas are recorded from plant-rich horizons further east. The most prominent vertebrate trace fossils in the Lower Beaufort Group are well-preserved tetrapod trackways attributed to various groups of reptiles and therapsids (Smith 1993a), as well as substantial, inclined to helical scratch burrows that were probably constructed by smaller therapsids as an adaptation to the highly seasonal, and occasionally extreme, continental climates at high palaeolatitudes of 60-70º S. (Smith 1987). Invertebrate trace fossils from the Karoo National Park at Beaufort West include the locally abundant scratch burrows of the ichnogenus *Scoyenia* that are generally attributed to infaunal arthropods such as insects or even earthworms. Diverse freshwater ichnofaunas (trace fossil assemblages) with trails, burrows and trackways generated by fish, snails, arthropods, worms and other animals have been recorded by Smith (1993a, Smith & Almond 1998).

A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995, 2005). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Kitching (1977), Keyser and Smith (1977-78) and Rubidge (1995, 2005). An updated version based on a comprehensive GIS fossil database has recently been published (Van der Walt *et al.* 2010). Three successive Middle to Late Permian fossil assemblage zones are represented within the Abrahamskraal and Teekloof Formations in the Gamma – Perseus study area (Fig. 5). These are the *Tapinocephalus*, *Pristerognathus* and *Tropidostoma* AZ. Radiometric age constraints for these assemblage zones have recently been published by Rubidge *et al.* (2013).

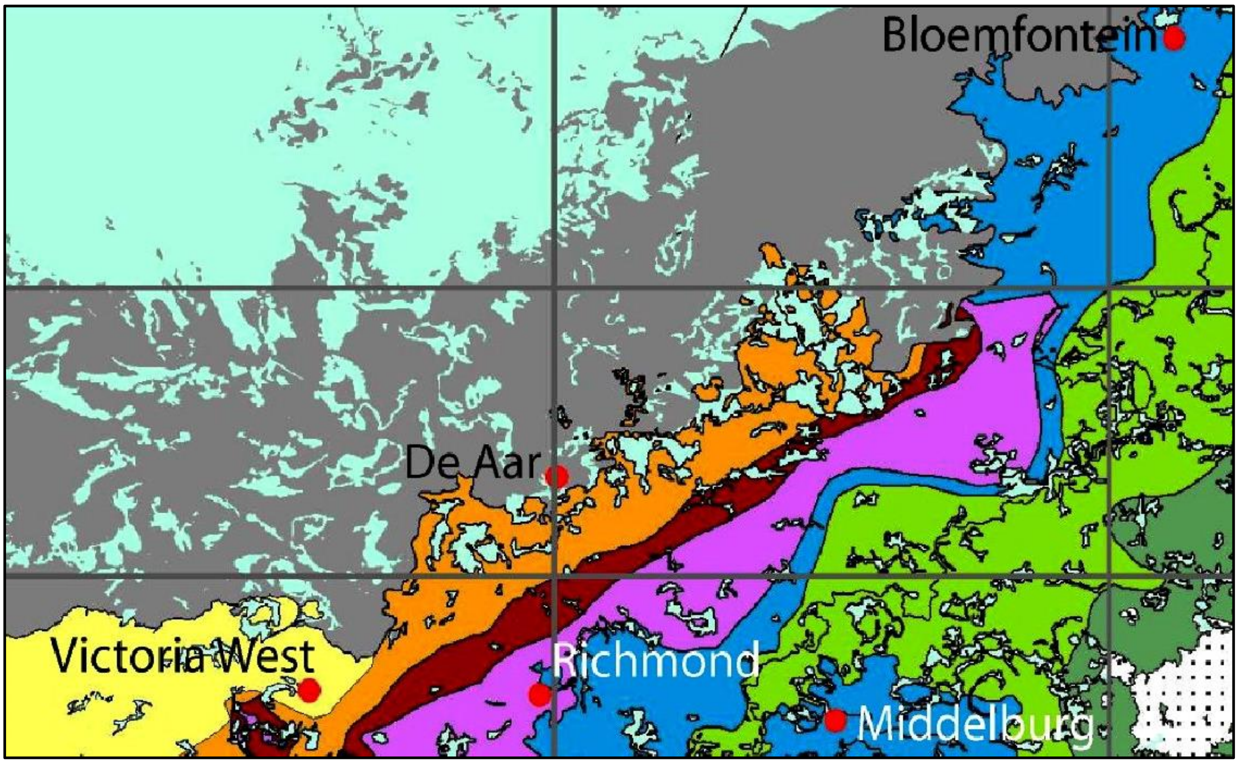


Fig. 5. Extract from the new Karoo vertebrate biozone map by Van der Walt *et al.* (2010) showing the distribution of the three Middle to Late Permian biozones represented in the Lower Beaufort Group sediments cropping out within the broader Gamma – Perseus transmission line study area between Victoria West and Bloemfontein. In biostratigraphic order these biozones are: (1) *Tapinocephalus* Assemblage Zone (buff), (2) *Pristerognathus* Assemblage Zone (orange) and (3) *Tropidostoma* Assemblage Zone (reddish-brown).

It should be noted that on the basis of international faunal correlation, the *Tropidostoma* and following *Cistecephalus* Assemblage Zones of the Lower Beaufort Group have until recently been assigned to the Wuchiapingian Stage of the Late Permian Period, with an approximate age range of 260-254 Ma.

The underlying *Tapinocephalus* and *Pristerognathus* AZ were referred to the preceding Capitanian Stage (266-260 Ma) of the Middle Permian (Rubidge 2005 and refs. therein). The end-Guadalupian (*i.e.* end – Middle Permian) mass extinction event was inferred to lie at the contact between the *Tapinocephalus* and *Pristerognathus* AZ within the uppermost Abrahamskraal and Koonap Formations (Retallack *et al.* 2006). Recent radiometric dates for the Lower Beaufort Group tuffs assign a late Guadalupian (Capitanian) age to the *Pristerognathus* AZ (261-260.36 Ma), an early Lopingian (Wuchiapingian) age to the *Tropidostoma* AZ (259.3 Ma), and a later Wuchiapingian age to the *Cistecephalus* AZ (256.6-255.2Ma) (Rubidge *et al.* 2013). This places the Mid / Late Permian boundary and End Guadalupian mass extinction event, if it is indeed reflected on land, between the *Pristerognathus* and *Tropidostoma* AZs within the Teekloof and Middleton Formations, rather than at the base of the *Pristerognathus* AZ as previously assumed.

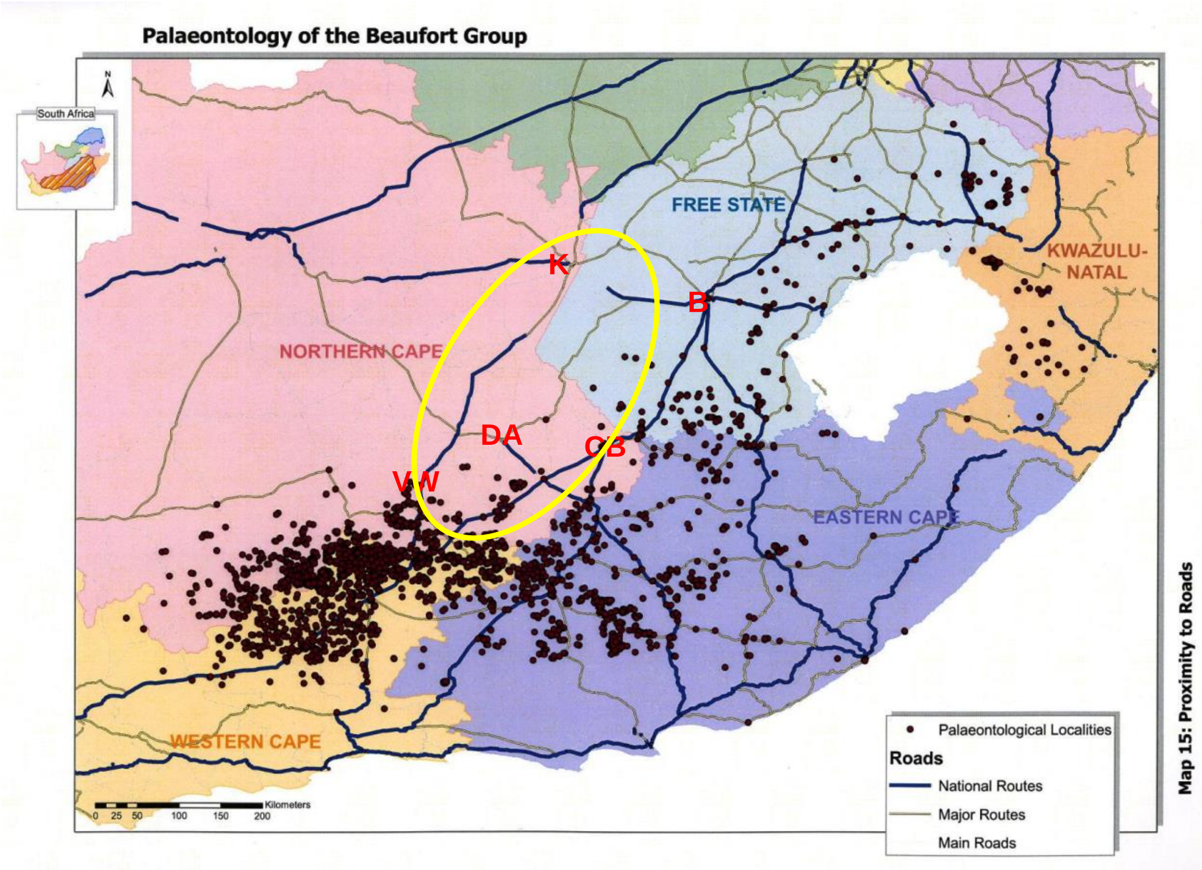


Fig. 6. Distribution map of recorded vertebrate fossil sites (dots) within the Beaufort Group of the Main Karoo Basin around the junction of the Western, Northern and Eastern Cape and the Free State (From Nicolas 2007). Vertebrate fossil sites within the broader Gamma-Perseus study region in the Northern Cape and Free State (yellow ellipse) are concentrated in the southwest part in the area near Victoria West and De Aar. The comparative paucity of fossil records here is in large part probably due to the low levels of bedrock exposure, as well as generally lower abundance of fossils in the *Pristerognathus* Assemblage Zone. Rare vertebrate fossils have been recorded recently during field studies by Almond (2012a).

3.4.1. The *Tapinocephalus* Assemblage Zone

The fossil biota of the greater part of the Abrahamskraal Formation is assigned to the *Tapinocephalus* Assemblage Zone of Middle Permian (Capitanian) age on the basis of key tetrapod fossils, notably large dinocephalian therapsids *plus* smaller carnivorous therocephalians. The main categories of fossils recorded within the *Tapinocephalus* fossil biozone (Boonstra 1969, Keyser & Smith 1977-78, Kitching 1977, Anderson & Anderson 1985, Smith & Keyser 1995a, MacRae 1999, Rubidge 2005, Nicolas & Rubidge 2010, Almond 2010) include:

- isolated petrified bones as well as rare articulated skeletons of tetrapods (*i.e.* air-breathing terrestrial vertebrates) such as true reptiles (notably large herbivorous pareiasaurs like *Bradysaurus*, small insectivorous millerettids), rare pelycosaurs, and diverse therapsids or "mammal-like reptiles" (Fig. 7). The last group includes numerous genera of large-bodied dinocephalians, smaller herbivorous dicynodonts as well as flesh-eating biarmosuchians, gorgonopsians and therocephalians

- aquatic vertebrates such as large temnospondyl amphibians (*Rhinesuchus*, usually disarticulated), and palaeoniscoid bony fish (*e.g. Atherstonia*, *Namaichthys*) that are often represented by scattered scales rather than intact corpses (Bender 2004)

- freshwater bivalves (*Palaeomutela*)

- trace fossils such as worm, arthropod and tetrapod burrows and trackways, coprolites (fossil droppings) and plant root casts

- vascular plant remains (usually sparse and fragmentary), including leaves, twigs, roots and petrified woods ("*Dadoxylon*") of the *Glossopteris* Flora, especially glossopterid trees and arthrophyte ferns or "horsetails" (Anderson & Anderson 1985, Bamford 1999)

In general, tetrapod fossil assemblages in this zone are dominated by a wide range of dinocephalian genera and small therocephalians *plus* pareiasaurs while relatively few dicynodonts are present (Nicolas 2007, Day & Rubidge 2010, Jirah & Rubidge 2010 and refs. therein). Vertebrate fossils in this zone are generally much rarer than in younger assemblage zones of the Lower Beaufort Group, with almost no fossils to be found in the lowermost beds (Loock *et al.* 1994).

Despite their comparative rarity, there has been a long history of productive fossil collection from the *Tapinocephalus* Assemblage Zone in the Great Karoo area, as summarized by Rossouw and De Villiers (1952) and Boonstra (1969). Well-preserved fossil remains of robust dinocephalians and pareiasaurs as well as smaller-bodied therapsids and previously under-recorded vertebrate burrows, vascular plants and coprolites can still be found at the surface in the Koup region, as noted in the recent impact study by Almond (2010). Fossil skeletal material from the *Tapinocephalus* Assemblage Zone is found within several different taphonomic settings, including:

1. disarticulated, usually ferruginised bones within thin intraformational conglomerates (*beenbreksie*) at the base of shallow, unistorey channel sandstones (Rossouw & De Villiers 1952, Turner 1981, Smith & Keyser 1995). The bones here vary from fragmentary and rounded to intact and well-preserved. They occur at the base of, within, or floating at the top of the conglomerates in association with calcrete nodules, mudflakes, petrified wood and gypsum pseudomorphs. Bones in these channel lags were variously eroded out of riverbanks or washed from upland areas, riverine areas and floodplains into drainage channels during floods or episodes of landscape denudation.

2. disarticulated bones within or at the top of channel sandstones.

3. bones coated with calcrete or embedded within calcrete nodules associated with palaeosols (ancient soils). These bones are often suncracked, showing that lay exposed on the land suface for a long time before burial.

4. isolated bones or articulated skeletons embedded within levee or floodplain mudrocks .

5. well-articulated skeletons preserved within fossil burrows (Botha-Brink & Modesto 2007).

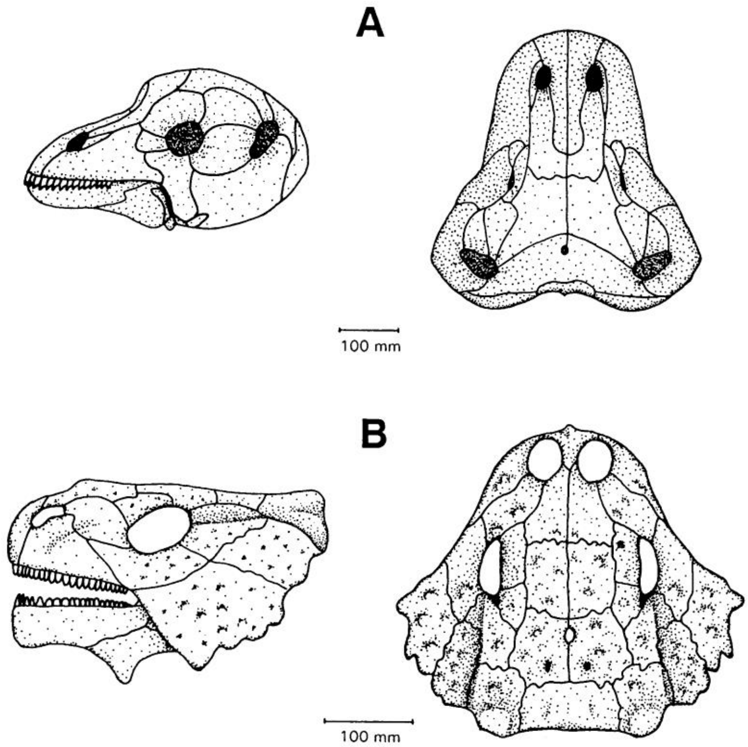


Fig. 7. Skulls of two key herbivorous tetrapods of the *Tapinocephalus* Assemblage Zone: A – the dinocephalian therapsid *Tapinocephalus*; B – the pareiasaur *Bradysaurus* (From Smith & Keyser 1995a).

There have been a number of attempts, hitherto only partially successful, to subdivide the very thick Abrahamskraal Formation succession in both lithostratigraphic and biostratigraphic terms. Among the most recent these was the study by Loock *et al.* (1994) in the Moordenaarskaroo area north of Laingsburg. Detailed geological mapping here led to the identification of six lithologically-defined members within the Abrahamskraal Formation. Intensive fossil collection within the middle part of the succession suggested that a significant faunal turnover event may have occurred at or towards the top of the sandstone-rich Koornplaats Member as defined by these authors, with the replacement of a more archaic, dinocephalian-dominated fauna (with primitive therapsids like the biarmosuchians) by a more advanced, dicynodont-dominated one at this level. This is the “faunal reversal” previously noted by Boonstra (1969) as well as Rossouw and De Villiers (1953). Other fossil groups such as therocephalians and pareiasaurs do not seem to have been equally affected. Problems have arisen in trying to correlate the lithologically-defined members recognized within the Abrahamskraal Formation by different authors across the whole outcrop area, with evidence for complex lateral interdigitation of the sandstone-dominated packages (D. Cole, pers. com., 2009). A research project is currently underway to further subdivide the *Tapinocephalus* Assemblage Zone on a biostratigraphic basis, emphasizing the range zones of various genera of small dicynodonts such as *Eodicynodon, Robertia* and *Diictodon* (Rubidge & Angielczyk 2009, Day & Rubidge 2010, Jirah & Rubidge 2010).

3.4.2. The *Pristerognathus* Assemblage Zone

Fossils of the *Pristerognathus* Assemblage Zone characterize the arenaceous Poortjie Member and the uppermost beds of the underlying Abrahamskraal Formation in the western Main Karoo Basin as well as the beds spanning the Koonap / Middleton Formation boundary in the eastern Karoo (Smith & Keyser 1995b). This important terrestrial biota is dominated by various therapsids ("mammal-like reptiles") such as the moderate-sized therocephalian carnivore *Pristerognathus* as well as several gorgonopsian predators / scavengers and herbivorous dicynodonts (Fig. 8). The commonest genus by far is the small burrowing dicynodont *Diictodon* (Keyser and Smith 1977-78, Smith & Keyser 1995b, MacRae 1999, Cole *et al*., 2004, Rubidge 2005, Almond 2010, Nicolas 2007, Nicolas & Rubidge 2010). There are also large, rhino-sized herbivorous reptiles (*Bradysaurus* spp.), crocodile-like temnospondyl amphibians (*Rhinesuchus*), palaeoniscoid fish, vascular plant fossils of the *Glossopteris* Flora (fossil wood, leaves *etc*) and various trace fossils, including invertebrate burrows and tetrapod trackways. The comparatively low number of specimens and major taxa represented in fossil collections from this biozone demonstrated by Nicolas (2007). The fossil biota of the *Pristerognathus* AZ is of special interest because it *possibly* represents an impoverished post-extinction recovery fauna following a late Mid Permian extinction event that preceded the well-known end-Guadalupian biotic crisis (*cf* Benton 2003, Retallack *et al.,* 2006, Lucas 2009, Rubidge *et al.* 2013).

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

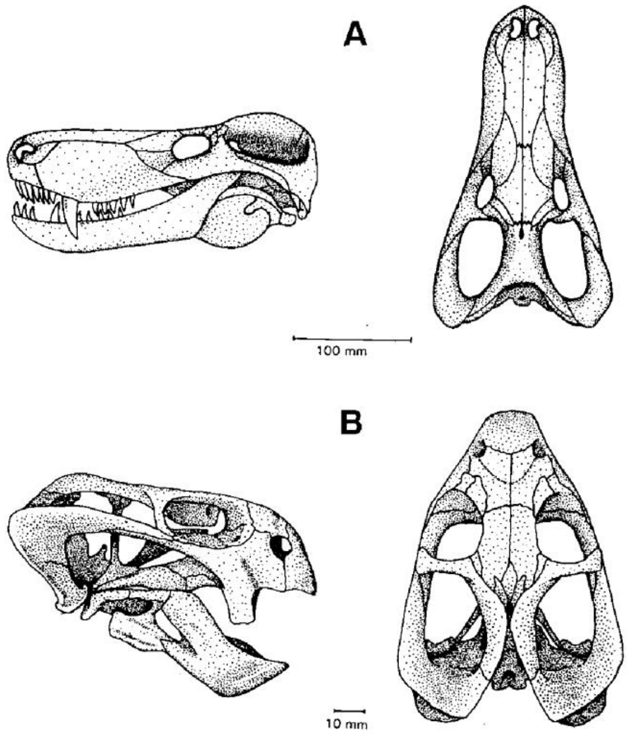


Fig. 8. Skulls of typical therapsids from the *Pristerognathus* Assemblage Zone: A. the dog-sized carnivorous therocephalian *Pristerognathus* and B. the small herbivorous dicynodont *Diictodon* (From Smith & Keyser 1995b).

3.4.3. The *Tropidostoma* Assemblage Zone

The *Tropidostoma* Assemblage Zone (AZ) characterizes the Hoedemaker Member of the Teekloof Formation in the western Karoo and the middle part of the Middleton Formation in the eastern Karoo (Le Roux & Keyser 1988, Smith & Keyser, 1995c).

The following major categories of fossils are recorded within *Tropidostoma* AZ sediments (Kitching 1977, Keyser & Smith 1977-78, Le Roux & Keyser 1988, Anderson & Anderson 1985, Smith & Keyser 1995c, MacRae 1999, Cole *et al*., 2004, Nicolas 2007, Nicolas & Rubidge 2010, Almond 2010):

- isolated petrified bones as well as rare articulated skeletons of terrestrial vertebrates (tetrapods) such as true reptiles (notably large herbivorous pareiasaurs) and therapsids or “mammal-like reptiles” (*e.g.* diverse herbivorous dicynodonts, flesh-eating gorgonopsians, and insectivorous therocephalians) (Fig. 9)

- aquatic vertebrates such as large temnospondyl amphibians (*Rhinesuchus* spp., usually disarticulated), and palaeoniscoid bony fish (*Atherstonia*, *Namaichthys*, often represented by scattered scales rather than intact fish)

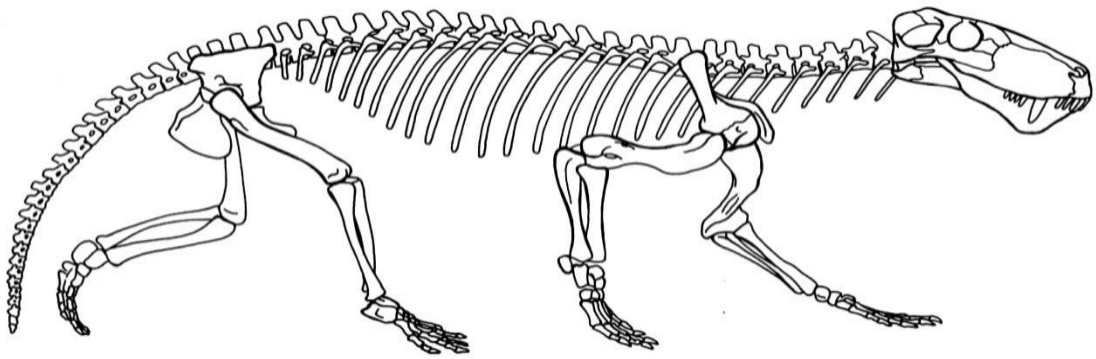
- freshwater bivalves (*e.g. Palaeomutela*)

- trace fossils such as worm, arthropod and tetrapod burrows and trackways, coprolites (fossil droppings), fish swimming trails

- vascular plant remains including leaves, twigs, roots and petrified woods ("*Dadoxylon*") of the *Glossopteris* Flora (usually sparse, fragmentary), especially glossopterid trees and arthrophytes (horsetails).

According to Smith and Keyser (1995c) the tetrapod fauna of the *Tropidostoma* Assemblage Zone is dominated by the small burrowing dicynodont *Diictodon* that constitutes some 40% of the fossil remains recorded here. There are several genera of small toothed dicynodonts (*e.g. Emydops, Pristerodon*) as well as medium-sized forms like *Rachiocephalus* and *Endothiodon* (*cf* Cluver & King 1983, Botha & Angielczyk 2007). Carnivores are represented by medium-sized gorgonopsians (*e.g. Lycaenops, Gorgonops;* Fig. 9) as well as smaller, insectivorous therocephalians such as *Ictidosuchoides*. Among the large (2.3-3 m long), lumbering pareiasaur reptiles the genus *Pareiasaurus* replaces the more primitive *Bradysaurus* seen in older Beaufort Group assemblages.

Fig. 9. Skull and skeleton of a saber-toothed carnivore, the gorgonopsian *Lycaenops* – a typical member of the *Tropidostoma* Assemblage Zone.



The marked increase in fossil abundance and high level taxonomic diversity within the *Tropidostoma* AZ compared with the underlying impoverished *Pristerognathus* AZ is clear from recent Karoo fossil database analyses (Nicolas 2007). The *Tropidostoma* assemblage may represent a post-extinction recovery fauna following the major end-Guadalupian exctinction event.

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

(See also Smith 1993b for a benchmark study of the taphonomy of vertebrate remains in the Hoedemaker Member.

3.5. Fossils in the Karoo Dolerite Suite

The dolerite outcrops in the Renosterberg / De Aar study area are in themselves of no palaeontological significance. These are high temperature igneous rocks emplaced at depth within the Earth's crust so they do not contain fossils. However, as a consequence of their proximity to large dolerite intrusions in the Great Escarpment zone, some of the Ecca and Beaufort Group sediments in the study area have been thermally metamorphosed or "baked" (*i.e*. recrystallised, impregnated with secondary minerals). Embedded fossil material of phosphatic composition, such as bones and teeth, is frequently altered by baking – bones may become blackened, for example - and can be very difficult to extract from the hard matrix by mechanical preparation (Smith & Keyser 1995). Thermal metamorphism by dolerite intrusions therefore tends to reduce the palaeontological heritage potential of Beaufort Group sediments. In some cases (*e.g.* trace fossils such as *Plagiogmus*, fossil moulds of mesosaurid reptiles and palaeoniscoid fish) baking may enhance the visibility or quality of preservation of Ecca fossils while other fossil groups (*e.g*. carbonaceous remains of plants, organic-walled palynomorphs) are more likely to be compromised.

3.6. Fossils associated with Kimberlite intrusions

Kimberlite rocks themselves are unfossiliferous. However, where crater-lake sediments associated with Kimberlite pipes are preserved beneath cover sands they sometimes prove to be highly fossiliferous, as in the case of rich Cretaceous to Paleocene fossil assemblages recorded from Bushmanland (*e.g.* Scholtz 1985, Smith 1986a, 1986b, 1988b, 1995d).

3.7. Fossils within the Late Caenozoic superficial sediments

The fossil record of the **Kalahari Group** is generally sparse and low in diversity. The **Gordonia Formation** dune sands were mainly active during cold, drier intervals of the Pleistocene Epoch that were inimical to most forms of life, apart from hardy, desert-adapted species. Porous dune sands are not generally conducive to fossil preservation. However, mummification of soft tissues may play a role here and migrating lime-rich groundwaters derived from the underlying bedrocks (including, for example, dolerite) may lead to the rapid calcretisation of organic structures such as burrows and root casts. Occasional terrestrial fossil remains that might be expected within this unit include calcretized rhizoliths (root casts) and termitaria (*e.g. Hodotermes*, the harvester termite), ostrich egg shells (*Struthio*) and shells of land snails (*e.g. Trigonephrus*) (Almond 2008a, Almond & Pether 2008). Other fossil groups such as freshwater bivalves and gastropods (*e.g. Corbula, Unio*) and snails, ostracods (seed shrimps), charophytes (stonewort algae), diatoms (microscopic algae within siliceous shells) and stromatolites (laminated microbial limestones) are associated with local watercourses and pans. Microfossils such as diatoms may be blown by wind into nearby dune sands (Du Toit 1954, Dingle *et al*., 1983). These Kalahari fossils (or subfossils) can be expected to occur sporadically but widely, and the overall palaeontological sensitivity of the Gordonia Formation is therefore considered to be low. Underlying calcretes of the **Mokolanen Formation** might also contain trace fossils such as rhizoliths, termite and other insect burrows, or even mammalian trackways. Mammalian bones, teeth and horn cores (also tortoise remains, and fish, amphibian or even crocodiles in wetter depositional settings such as pans) may be expected occasionally expected within Kalahari Group sediments and calcretes, notably those associated with ancient, Plio-Pleistocene alluvial gravels.

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

Table 1. Fossil heritage previously recorded within the main rock units cropping out along the various Gamma – Perseus 765 kV transmission line corridor options

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
OTHER LATE CAENOZOIC TERRESTRIAL DEPOSITS OF THE INTERIOR (Qs, T-Qc) (Most too small to be indicated on 1: 250 000 geological maps)	Fluvial, pan, lake and terrestrial sediments, including diatomite (diatom deposits), pedocretes (e.g. calcrete), spring tufa / travertine, cave deposits, peats, colluvium, soils, surface gravels including downwasted rubble MOSTLY QUATERNARY TO HOLOCENE (Possible peak formation 2.6-2.5 Ma)	bones and teeth of wide range of mammals (*e.g.* mastodont proboscideans, rhinos, bovids, horses, micromammals), reptiles (crocodiles, tortoises), ostrich egg shells, fish, freshwater and terrestrial molluscs (unionid bivalves, gastropods), crabs, trace fossils (*e.g.* termitaria, horizontal invertebrate burrows, stone artefacts), petrified wood, leaves, rhizoliths, diatom floras, peats and palynomorphs. calcareous tufas at edge of Ghaap Escarpment might be highly fossiliferous (*cf* Taung in NW Province – abundant Makapanian Mammal Age vertebrate remains, including australopithecines)	LOW to MEDIUM Scattered records, many poorly studied and of uncertain age	pre-construction field assessment by professional palaeontologist any substantial fossil finds to be reported by ECO to SAHRA
Gordonia Formation (Qs) KALAHARI GROUP *plus* SURFACE CALCRETES (Tl / Qc)	Mainly aeolian sands *plus* minor fluvial gravels, freshwater pan deposits, calcretes PLEISTOCENE to RECENT	calcretised rhizoliths & termitaria, ostrich egg shells, land snail shells, rare mammalian and reptile (*e.g.* tortoise) bones, teeth freshwater units associated with diatoms, molluscs, stromatolites *etc*	LOW	any substantial fossil finds to be reported by ECO to SAHRA
Windsorton & Rietputs Formations HIGH LEVEL ALLUVIAL GRAVELS (Qa) e.g. Orange & Vaal Rivers	Ancient alluvial gravels, locally diamondiferous and calcretised MIOCENE TO PLEISTOCENE	sparse Tertiary vertebrates in older gravels. Rich Pleistocene mammalian fauna (bones, teeth) in younger gravels (*e.g.* equids, elephants, hippo) associated with Acheulian stone artefacts	HIGH	pre-construction field assessment by professional palaeontologist
KIMBERLITE INTRUSIONS (diamond symbol)	Kimberlite / olivine melilitite / carbonatite volcanic pipes and related intrusions (fissure fills), sometime diamondiferous. JURASSIC, CRETACEOUS TO PALAEOCENE *c*. 200-60 Ma	rare fossiliferous xenoliths of country rocks (*e.g.* Beaufort Group sediments with fossil fish). Bryophytes, vascular plants (leaves, wood, fruit), fish, pipid frogs (adults, tadpoles), reptiles (tortoises, lizards), rare dinosaurs, birds (ratites), insects, ostracods, palynomorphs (bryophytes, ferns, gymnosperms, angiosperms) within crater lake sediments	LOW	none

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
KAROO DOLERITE SUITE **(Jd)**	**Intrusive dolerites (dykes, sills), associated diatremes** **EARLY JURASSIC** **(182-183 Ma)**	**no fossils recorded**	**ZERO** (also cause baking of adjacent fossiliferous sediments)	**None**
ADELAIDE SUBGROUP (LOWER BEAUFORT GROUP) **Adelaide Subgroup** **Abrahamskraal Fm (Pa)** **Teekloof Fm (Pt, Ptp, Pth, Pto)**	**Fluvial sediments with channel sandstones (meandering rivers), thin mudflake conglomerates interbedded with floodplain mudrocks (grey-green, purplish), pedogenic calcretes, playa lake and pond deposits, occasional reworked volcanic ashes** **Late Permian**	**diverse continental biota dominated by a variety of therapsids (*e.g.* dinocephalians, dicynodonts, gorgonopsians, therocephalians, cynodonts) and primitive reptiles (*e.g.* pareiasaurs), sparse *Glossopteris* Flora (petrified wood, rarer leaves of *Glossopteris*, horsetail stems), tetrapod trackways, burrows & coprolites. Freshwater assemblages include temnospondyl amphibians, palaeoniscoid fish, non-marine bivalves, phyllopod crustaceans and trace fossils (esp. arthropod trackways and burrows, "worm" burrows, fish fin trails, plant rootlet horizons).**	**HIGH**	**Pre-construction field assessment by professional palaeontologist**
Waterford Fm **(Pwa/Pw=Pko, Pc in part)**	**Prodelta to delta plain sediments (mudrocks, sandstones / wackes, ferruginous carbonate diagenetic nodules)**	**low diversity non-marine trace assemblages (especially arthropod scratch burrow *Scoyenia*), common petrified logs (silicified/ calcified), twigs and other remains of *Glossopteris* Flora (*e.g.* horsetails), palaeoniscoid fish scales, rare rolled fragments of tetrapod bone (probably from large temnospondyl amphibians)**	**HIGH**	**Pre-construction field assessment by professional palaeontologist**
Tierberg and Waterford Formations (Pt) **ECCA GROUP**	**Dark basinal, prodelta and submarine fan mudrocks with minor sandstones (Tierberg Fm) OR Storm-influenced coastal sandstones and mudrocks (Carnarvon facies of Waterford Fm)** **EARLY TO MIDDLE PERMIAN**	**locally abundant non-marine trace fossils (*Mermia* and *Cruziana* ichnofacies), common petrified wood, plant debris, microvertebrates incl. fish scales as well as sponge spicules, coprolites in diagenetic concretions**	**MEDIUM**	**Pre-construction field assessment by professional palaeontologist**

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Whitehill Formation (Pp / Ppw in part) ECCA GROUP	Carbonaceous offshore non-marine mudrocks within minor volcanic ashes, dolomite nodules EARLY PERMIAN	well-preserved mesosaurid reptiles, rare cephalochordates, variety of palaeoniscoid fish, small eocarid crustaceans, insects, low diversity of trace fossils (*e.g.* king crab & eurypterid trackways, possible shark coprolites), palynomorphs, petrified wood and other sparse vascular plant remains (*Glossopteris* leaves, lycopods *etc*)	HIGH	Pre-construction field assessment by professional palaeontologist
Prince Albert Formation (Ppr/ Ppw in part; locally mapped within C-Pd) ECCA GROUP	Basinal mudrocks with calcareous concretions EARLY PERMIAN	marine invertebrates (esp. molluscs, brachiopods), coprolites, palaeoniscoid fish & sharks, trace fossils, various microfossils, petrified wood	HIGH IN KIMBERLEY - DOUGLAS REGION	Pre-construction field assessment by professional palaeontologist
Mbizane Formation (C-Pd) DWYKA GROUP	Tillites, interglacial mudrocks, deltaic & turbiditic sandstones, minor thin limestones LATE CARBONIFER-OUS – EARLY PERMIAN	sparse petrified wood & other plant remains, palynomorphs, trace fossils (*e.g.* arthropod trackways, fish trails, U-burrows) possible stromatolites in limestones	LOW TO MODERATE (*N.B.* stratotype section in the Douglas area)	Pre-construction field assessment by professional palaeontologist
Allanridge Formation (Ra / Ral) VENTERSDORP SUPERGROUP	Basic lavas and volcaniclastic sediments LATE ARCHAEAN 2.7 Ga	no fossils recorded	ZERO	None recommended Any substantial fossil finds to be reported by ECO to SAHRA
Bothaville Formation (Rb) VENTERSDORP SUPERGROUP	Conglomerates & quartzites with minor volcanic ashes LATE ARCHAEAN 2.7 Ga	conical stromatolites (probably lacustrine)	LOW TO MODERATE	Pre-construction field assessment by professional palaeontologist

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Makwassie Formation **(Rm)** **VENTERSDORP SUPERGROUP**	**Porphyritic felsite lavas (ash flows)** **LATE ARCHAEAN** **2.67 Ga**	**no fossils recorded or expected**	**ZERO**	**None recommended** **Any substantial fossil finds to be reported by ECO to SAHRA**
"SODIUM GROUP" **'TCuip Formation** **(Rt)** **= PLATBERG GROUP (Kameeldoorns Formation)** **VENTERSDORP SUPERGROUP**	**Porphyritic lavas with lenses of tuff and arkose, *plus* dacite** **LATE ARCHAEAN** **2.7 Ga**	**No fossils recorded** **(Kameeldoorns Fm near Taung contains stromatolitic carbonates)**	**LOW**	**None recommended** **Any substantial fossil finds to be reported by ECO to SAHRA**

4. BRIEF DESCRIPTION OF TRANSMISSION LINE ROUTE OPTIONS IN TERMS OF GEOLOGY AND PALAEONTOLOGICAL SENSITIVITY

Each of the various proposed Gamma – Perseus transmission line route options shown in Figs. 1 and 2 are discussed separately in this section with reference to the underlying geology along each route, from south to north. The geology along each route is shown on a series of strip 52 maps or sections that have been abstracted from the relevant 1: 250 000 geology sheets (See Appendices 1 to 4). The route options are then briefly compared in terms of their potential impacts on fossil heritage resources, emphasising sectors of high palaeontological sensitivity. These more sensitive sectors are indicated by red fonts beneath the relevant geological maps in the appendices.

4.1. Gamma – Perseus Route 1 (preferred option)

4.1.1. Topography

Route 1 – the currently preferred option - is the easternmost of the route options and follows existing servitudes, taking a fairly direct SW to NE line from Hutchinson (Northern Cape) *via* De Aar to Dealesville (Free State) (Brown line in Figs. 1 & 2). It traverses five 1: 250 000 geological sheets.

On the **Victoria West sheet 3122** (VW) the line starts at Gamma Substation near Hutchinson (on the De Aar railway line), *c*. 40 km SE of Victoria West. It heads NE subparallel to the N1 trunk road across a typical Bo Karoo landscape of flat-topped *koppies*, rocky *rante* and extensive *vlaktes*, traversing Platberg and Bloukop but passing west of Blouberg. Northwest of Richmond it crosses the Ongersrivier drainage system and the Richmond-Britstown road, then crosses the R348 Richmond – De Aar road close to northern edge of the Victoria West sheet.

Route 1 crosses only the SE corner of the **Britstown sheet 3022** (BT), running southeast of the Hutchinson – De Aar railway line. It then heads northwards subparallel to and east of the R348 Richmond – De Aar road, to the east of the Maanhaarberg / Platberg mountain range.

On the western margin of **Colesburg sheet 3024** (CB) Route 1 crosses the N10 tar road between De Aar and Hanover, running to the west of the large Hydra substation. On the eastern side of De Aar it skirts the major dolerite-capped plateau here on its western side before crossing the R48 De Aar – Philipstown tar road. The line passes over a range of hills to the NW of Philipstown, running just east of Tierberg. From there on Route 1 traverses an extensive stretch of *vlaktes* most of the way to the Orange River, passing west of Petrusville towards the northern edge of the Colesberg sheet.

On **Koffiefontein sheet 2924** (KF) Route 1 crosses the Petrusville – Orania road (R369) and then the Orange River itself, just west of the R48 bridge and *c*. 24 km SE of Orania. After crossing the R48 and Goemansberg range south of Luckoff and passing through Luckhoff substation the line continues north-eastwards, subparallel and east of the R48 towards Koffiefontein, passing a large pan to the south of Koffiefontein along its eastern edge. Having crossed the Rietrivier just east of Koffiefontein it continues in a more-or-less straight line across the Free State *vlaktes*, passing west of Petrusburg, and through or close to several pans in the vicinity of this town.

On **Kimberley sheet 2824** (KB) Route 1 continues north-eastwards across a similar landscape of *vlaktes* and *pannetjieveld* up to the Perseus substation located *c*. 4 km NW of Dealesville, having crossed the Modderrivier close to southern edge of Kimberley sheet and the R64 Bloemfontein – Kimberley road just south of Perseus.

4.1.2. Geology & palaeontology

The geology underlying Route 1 can be subdivided into the following seven sectors for convenience (Please refer to the 15 numbered geological strip maps, referred to here as sections, in Appendix 1):

1. (Sections 38-41, VW sheet). To the northeast of Gamma Substation Route 1 traverses Karoo *koppie* and *vlaktes* terrain underlain by Lower Beaufort Group sediments. These mainly belong to the Teekloof Fm (Poortjie and Hoedemaker Members) with small outcrop areas of the Abrahamskraal Formation in the northeast. The Beaufort Group bedrocks are extensively intruded by dolerite intrusions. Many of the *koppies* are capped by dolerite sills, while dykes weather positively to form bouldery ridges. Extensive mantles of doleritic colluvium obscure bedrock on mountain slopes. Bands of silty to gravely alluvium are encountered along a network of shallow ephemeral river beds (*e.g.* Ongersrivier system).

Where Beaufort Group bedrocks are exposed at or near surface, the palaeontological sensitivity along this sector is locally HIGH. Recent field studies in the area by the author show that the bedrocks are often mantled by superficial deposits of low sensitivity, however.

2. (Sections 41-42, VW-BT-CB sheets). Lower Beaufort Group bedrocks in the SE corner of the Britstown sheet and the SW corner of Colesberg sheet (in part referred to the Abrahamskraal Fm) are extensively intruded by Karoo dolerites but may be locally be of HIGH palaeontological sensitivity where exposure levels are good. A desktop palaeontological assessment for the Maanhaarberg / Platberg range to the southwest of De Aar was completed by Almond (2010a). Steeper mountain slopes are likely to be extensively mantled by doleritic colluvium of low palaeontological sensitivity.

3. (Sections 42 – 44, CB sheet). Flat-lying to gently hilly terrain to the east of De Aar is underlain by sediments mapped as Tierberg Formation (Pt) but actually belonging to the Carnarvon-type shelf facies of the Waterford Formation. The bedrocks are intruded by dolerite and extensively mantled by alluvial soils. Recent palaeontological field studies in this region have reported locally abundant trace fossil assemblages and transported plant remains, including the widespread occurrence of well-preserved fossil wood (Almond 2012c, 2013a, 2013d). Where Ecca bedrocks are exposed, the palaeontological sensitivity within this sector is locally HIGH.

4. (Sections 44 – 45, CB sheet). Extensive Karoo *vlaktes* on the northern portion of the Colesberg sheet are underlain by well-developed calcrete hardpans (Qc) and alluvium overlying Ecca mudrocks of the Tierberg Formation *sensu stricto* (Pt) with numerous dolerite intrusions. Due to poor Ecca bedrock exposure, calcrete disruption and baking by dolerite the palaeontological sensitivity of this sector is generally LOW (*cf* Almond 2013c).

5. (Sections 45-46, CB-KF sheets). Close to the Orange River as far north as Luckhoff exposure of Ecca Group bedrocks (Tierberg Formation) may be locally good due to river incision, but this may be counterbalanced by extensive dolerite intrusions (baking of mudrocks, mantling of hillslopes with doleritic colluvium). Older alluvial deposits such as relict High Level Gravels are not mapped along this stretch of the Orange River. The palaeontological sensitivity of this sector is rated as LOW

6. (Sections 47 – 50, KF-KB sheet). Across the greater part of the Koffiefontein sheet area, from Luckhoff northwards onto the southern margin of the Kimberley sheet, the Route 1 corridor mainly comprises Karoo *vlaktes* mantled by alluvium, calcrete and aeolian sands. There are occasional patches of pan sediments (often calcretised) and only small outcrop areas of Tierberg mudrocks, often baked in the vicinity of dolerite intrusions. The overall palaeontological sensitivity of this long sector is LOW.

7. (Sections 51-52, KB sheet). In this sector Route 1 is largely underlain by Tierberg Formation mudrocks that are extensively intruded by dolerite dykes. Substantial areas of superficial sediments

are mapped here, including aeolian sands (Qs), calcrete (Qc) and alluvium and bedrock exposure in this flat terrain is likely to be poor. The overall palaeontological sensitivity of this long sector is LOW.

4.2. Gamma – Perseus Route 2

4.2.1. Topography

Route 2 is a central transmission line option that runs broadly subparallel to and within *c*. 20 km of the existing servitude between Gamma and Perseus substations, also passing just to the east of De Aar (Lilac line in Figs. 1 & 2). This central route is slightly longer than Route 1 and likewise traverses the same five 1: 250 000 sheet areas. Three comparatively short alternative diversions from the basic Route 2, termed Routes 2a, 2b and 2c, are considered separately below.

On the **Victoria West sheet 3122** (VW) Route 2 commences at Gamma Substation near Hutchinson, *c*. 40 km SE of Victoria West, and then heads north-eastwards close to the railway line between Hutchinson and De Aar. It crosses the R389 Richmond – Britstown road near Merriman siding and the railway itself twice to the SW of De Aar.

On the south-eastern corner of the **Britstown sheet 3022** (BT) Route 2 passes just to the east of several dolerite mountains (including the Maanhaarberg / Platberg) before crossing the R388 Richmond – De Aar road just south of De Aar.

On **Colesburg sheet 3024** (CB) the line skirts De Aar over flat to gently hilly terrain to the south and east of town, crossing the N10 tar road *c.* 6 *k*m NW of Hydra substation. It then heads north close to the De Aar – Kimberley railway line and the Renosterberg koppies before turning again towards the northeast, passing on the western side of Tierberg. Fairly flat-lying terrain is then travsersed most of the way to the Orange River.

On the southern margins of **Koffiefontein sheet 2924** (KF) Route 2 crosses the R369 Hopetown road and then the River Orange itself some 3 km east of Orania. It then turns sharply north-eastwards within the southern Free State towards a point *c*. 10 km NW of Luckoff. The route continues across flat-lying terrain with numerous small pans, crossing the Rietrivier *c*. 14 km NE of Koffiefontein, the R705 Jacobsdal road, and the N8 Kimberley – Bloemfontein road at the northern edge of the map sheet.

On **Kimberley sheet 2824** (KB) Route 2 continues across flat-lying *pannetjieveld*, crossing the Modderrivier at a point *c*. 57 km ESE of Kimberley and then the R64 some 6 km NW of Dealesville before terminating at Perseus substation.

4.2.2. Geology & palaeontology

The geology underlying Route 2 can be subdivided into the following seven sectors for convenience (Please refer to the 17 numbered geological strip maps in Appendix 2, referred to here as sections):

1. (Sections 1, 37, VW sheet). To the northeast of Gamma Substation Route 2 traverses Karoo *koppie* and *vlaktes* terrain underlain by Lower Beaufort Group sediments. These mainly belong to the Teekloof Fm (Poortjie and Hoedemaker Members) with small outcrop areas of the Abrahamskraal Formation in the northeast. The Beaufort Group bedrocks are extensively intruded by dolerite intrusions. Many of the *koppies* are capped by dolerite sills, while dykes weather positively to form bouldery ridges. Extensive mantles of doleritic colluvium obscure bedrock on mountain slopes. Bands of silty to gravely alluvium are encountered along a network of shallow ephemeral river beds.

Where Beaufort Group bedrocks are exposed at or near surface, the palaeontological sensitivity along this sector is locally HIGH. Recent field studies in the area by the author show that the bedrocks are often mantled by superficial deposits of low sensitivity, however.

2. (Sections 36-34, VW & BT sheets). In the north-eastern corner of the Victoria West sheet and south-eastern corner of the Britstown sheet Route 2 overlies the Abrahamskraal Formation (here differentiated from the Teekloof Formation) which is intruded by several ring-shaped dolerite intrusions and frequently mantled by alluvium to the southwest of De Aar. Where Beaufort Group bedrocks are exposed at or near surface, the palaeontological sensitivity along this sector is locally HIGH.

3. (Sections 34-32, CB sheet). Close to De Aar the transmission line crosses the contact between the uppermost Ecca Group rocks (here assigned to the Waterford Formation but mapped as Tierberg) and the overlying Adelaide Subgroup continental sediments. The palaeontological sensitivity here is reduced by dolerite intrusion and cover by superficial sediments (*e.g.* alluvium of the Brakrivier, calcrete, surface gravels *etc*) but may be locally HIGH (fossil wood and other plant remains, abundant trace fossils, possible Beaufort Group vertebrate remains) (Almond 2013a to d).

4. (Sections 32, 27, 31, CB & KF sheets). Extensive Karoo *vlaktes* on the northern portion of the Colesberg sheet are underlain by well-developed calcrete hardpans (Qc) and alluvium overlying Ecca mudrocks of the Tierberg Formation *sensu stricto* (Pt) with numerous dolerite intrusions. Due to poor Ecca bedrock exposure, calcrete disruption and baking by dolerite the palaeontological sensitivity of this sector is generally LOW (*cf* Almond 2013c).

5. (Sections 31-28, 22, KF sheet) In the Koffiefontein sheet area to the N and S of the Orange River Tierberg Formation bedrocks have been very extensively intruded by dolerite and are frequently mantled by alluvium, calcrete and aeolian sands. Route 2 crosses several pans, usually associated with heavily calcretised sediments, that might be of palaeontological interest. Due to poor Ecca bedrock exposure, calcrete disruption and baking by dolerite the palaeontological sensitivity of this sector is generally LOW (*cf* Almond 2013c).

6. (Sections 22-20, KF & KB sheets). On the borders of the Koffiefontein and Kimberley sheets the Ecca Group (Tierberg) bedrocks are largely covered by aeolian sand and calcrete as well as intruded by dolerite. The palaeontological sensitivity of this sector is generally LOW.

7. (Sections 19-18, KB sheet). The Tierberg Formation bedrocks here are extensively intruded by dolerite, locally mantled with calcrete and alluvium. Several pans crossed by the Route 2 line may be of palaeontological interest but the palaeontological sensitivity of this sector is generally LOW.

Three short deviations from Route 2, termed Routes 2a, 2b and 2c, are also under consideration and are considered briefly below.

4.3. Gamma – Perseus Route 2a

Alternative Route 2a (yellow line in Figs. 1 & 2) comprises a lengthy (*c*. 122 km) deviation to the northwest from Route 2 in the Northern Cape / Free State border region (Colesberg and Koffiefontein 1: 250 000 sheet areas). It involves crossing the Orange River much closer to Hopetown, 22.5 km NW of Route 2, while the Rietrivier is crossed c. 12 km further to the west.

Route 2a diverges from Route 2 near Tafelkop on the east side of the R388 De Aar-Kimberley road, some 60 km NNE of De Aar. It heads NNW and then turns abruptly to the NE just south of the Orange River which is then crossed *c*. 20.5 km east of Hopetown. The line continues in a straight line across low relief terrain north-eastwards to join Route 2b shortly after crossing Rietrivier, *c*. 21 km NW of Koffiefontein.

The geology underlying Route 2a can be subdivided into the following three sectors for convenience (Please refer to the five numbered geological strip maps in Appendix 3, referred to here as sections):

1. (Sections 27-25, CB and KF sheets). From Tafelkop most of the way to the Orange River the line traverses *vlaktes* mantled by superficial sediments (calcrete, alluvium) with limited exposure of Tierberg Formations, locally intruded by dolerite. Pans sediments close to or beneath the line may be fossiliferous but otherwise this sector is of LOW overall palaeontological sensitivity.

2. (Section 25, KF sheet). Levels of bedrock exposure along the Orange River are generally quite high. Route 2a here traverses major dolerite intrusions with minor outcrop of the Tierberg Formation and extensive alluvial cover. While older (pre-Holocene) alluvial sediments are expected, High Level Gravels are not mapped in this area. Route 2a narrowly misses palaeontologically sensitive outcrops of the Lower Ecca Group (Ppw, brown) just north of the Orange River (Ribbokrant). The palaeontological sensitivity of this sector is rated as LOW.

3. (Sections 25-23, KF sheet). Within the southern Free State, between the Orange and Rietriviers, the topographically subdued landscape traversed by Route 2a is underlain by the Tierberg Formation that is extensively intruded by Karoo dolerite and mantled by superficial deposits (calcrete, alluvium, aeolian sands). The line passes NW of the main concentration of large pans in this region. The overall palaeontological sensitivity of this sector is assessed as LOW.

4.4. Gamma – Perseus Route 2b

Alternative Route 2b (dark green line in Figs. 1 & 2), approximately 48 km long, comprises a short deviation to the northwest from Route 2 in the Free State (Koffiefontein 1: 250 000 sheet area). It involves crossing the Rietrivier some 9.5 km further west than Route 2. The terrain involved is topographically subdued.

Route 2b diverges from Route 2 about 23 km SW of Koffiefontein and heads north across the Rietrivier which is crossed c. 22 km WNW of Koffiefontein. It is joined by Route 2a just north of the river where it turns sharply to the NE. After crossing the R705 Jacobsdal road it re-joins Route 2 some 30 km north of Koffiefontein.

The geology underlying Route 2b can be subdivided into the following two sectors for convenience (Please refer to the four numbered geological strip maps in Appendix 3, referred to here as sections):

1. (Sections 28, 23, 22, KF sheet). Route 2b traverses fairly flat-lying terrain underlain by the Tierberg Formation that is extensively intruded by Karoo dolerite and mantled with superficial sediments, including calcrete, aeolian sands, alluvium and occasional pans. The overall palaeontological sensitivity of this sector is LOW.

2. (Sections 22 & 21, KF sheet). This sector of the route is mainly covered by aeolian sands with inliers of Karoo dolerite. Its palaeontological sensitivity is LOW.

4.4. Gamma – Perseus Route 2c

Alternative Route 2c (dark blue line in Figs. 1 & 2), approximately 25 km long, comprises a short deviation to the northwest from Route 2 in the Free State (Kimberley 1: 250 000 sheet area). It involves crossing the Modderrivier some 8.8 km further west than Route 2. The terrain involved is topographically subdued with occasional dolerite *koppies* and pans.

Route 2c diverges from Route 2 some 6 km NE of the N8 Bloemfontein – Kimberley road, *c*. 50 km SE of Kimberley. It heads northeast across Modder, then turns ENE shortly N of river. It rejoins Route 2 just east of Loogkop, some 5.8 km north of the Modderrivier.

The geology underlying Route 2c is shown on a single map section in Appendix 3. Tierberg Formation mudrocks here are intruded by Karoo dolerite and extensively covered by calcrete, alluvium (*e.g.* of the Modderrivier) and aeolian sands. The line skirts the western edge of Banksdrif Pan, which may be palaeontologically sensitive. Older alluvial deposits (High Level Gravels) are not mapped along the Modderrivier here. The overall palaeontological sensitivity of this sector is LOW.

4.5. Gamma – Perseus Route 3

4.5.1. Topography

Route 3 is the westernmost and longest alternative for the new Gamma – Perseus 765 kV transmission line (Blue-green line on Figs. 1 & 2). It traverses five 1: 250 000 geological sheets. From Hutchinson it takes a curving path through the Northern Cape, heading initially NNW towards Britstown, then NNE to cross the Orange River between Douglas and Hopetown, shortly before which it turns NE to cross the Modder River just west of Ritchie. The line then bends ENE, passing Kimberley on the southern side and crossing into the Free State. Here a series of bends brings the line round into a more easterly direction until it finally joins Route 2 some 22 km WSW of Dealesville.

On the **Victoria West sheet 3122** (VW) Route 3 heads NNW from Gamma Substation near Hutchinson, *c*. 40 km SE of Victoria West, close to N Cape W Cape border. It crosses the De Aar railway line *c*. 20 km ENE of Victoria West and heads for the western edge of the Stormberge at the northern edge of the map sheet. The terrain here is typical Bo Karoo *koppies* and *vlaktes* with numerous ephemeral water courses.

On the **Britstown sheet 3022** (BT) the Route 3 line crosses the N12 Victoria West- Britstown tar road and runs well to the west of the Smartt-Syndicate Dam. Just north of the R384 Britstown – Vosburg road it turns sharply NNE, crossing the N10 Britstown – Prieska road and railway line as well as the Ongersrivier some 35 km NW of Britstown and then the Brakrivier close to the northern edge of the map sheet.

On the **Prieska sheet 2922** (PK) Route 3 continues in a straight line to the NNE across fairly subdued topography with scattered pans, crossing the R387 some 7.5 km NW of Strydenberg and the R369 *c*. 30 km west of Hopetown. Just before crossing the Orange River *c*. 24 km NW of Hopetown, where the terrain is more rugged due to river incision, the transmission line bends more to the NE.

On the **Koffiefontein sheet 2924** the northeasterly trend of Route 3 takes it across the R385 Hopetown – Douglas road and then over a fairly subdued Karoo landscape with scattered pans until it crosses the Modderrivier about 9 km west of Ritchie.

On the **Kimberley sheet 2824** Route 3 skirts Kimberley well to the south, crossing the N12 and N8, and passing some 21 km south of Boshoff. The terrain over this stretch is fairly flat with scattered pans. Route 3 finally joins Route 2 some 22 km WSW of Dealesville, carrying on north-eastwards to the Perseus Substation some 90 km ENE of Kimberley and 4 km NW of Dealesvillle

4.5.2. Geology and palaeontology

The geology underlying Route 3 can be subdivided into the following eight sectors for convenience (Please refer to the 18 numbered geological strip maps in Appendix 4, referred to here as sections):

1. (Sections 1, 2, VW sheet). From Gamma Substation NNW to the railway line east of Victoria West Route 3 traverses hilly Karoo *koppie* and *vlaktes* terrain underlain by fluvial sediments of the Teekloof Fm (Poortjie and Hoedemaker Members). The sedimentary bedrocks are extensively intruded by dolerite sills and dykes. Mantles of doleritic colluvium obscure bedrock on slopes. Alluvial deposits are associated with ephemeral streams. Where Lower Beaufort Group bedrocks are exposed, the palaeontological sensitivity within this sector is locally HIGH.

2. (Sections 2-3, VW sheet). North of the railway line to the northern edge of the Victoria West sheet the transmission line route descends stratigraphically down-section from the Abrahamskraal Formation (Lower Beaufort group), across the Beaufort / Ecca contact into uppermost Ecca Group beds, here represented by shelf sediments ("Carnarvon" facies) of the Waterford Formation. Alluvial sediments (*e.g.* along the Brakrivier, Ongersrivier) mantle large parts of the Karoo Supergroup bedrock but where this is exposed, the palaeontological sensitivity within this sector is HIGH.

3. (Sections 3 to 6, BT sheet). Over this long sector recessive-weathering mudrocks of the Tierberg Formation and extensively mantled with superficial deposits, such as alluvium (*e.g.* Ongersrivier, Groenrivier) and calcrete hardpans. There are also numerous dolerite intrusions and locally thin kimberlite dykes (section 6, Kk). The ancient (Tertiary) Koa River valley drainage system is crossed towards the middle of the Britstown sheet (sections 5 & 6). Relict Tertiary alluvial sediments within the Koa River Valley further to the west contain important Miocene mammalian faunas (Senut *et al.* 1996, Almond *in* Macey *et al.* 2011). The palaeontological sensitivity of this sector is generally LOW but locally HIGH (*e.g.* Koa River valley).

4. (Sections 6 & 7, BT sheet). From just south of the N10 Britstown – Prieska road and railway to the northern edge of the Britstown sheet Route 3 is underlain by Lower Ecca Group basinal sediments – a wide outcrop area of Prince Albert Formation *plus* a narrow outcrop area of Whitehill Formation. The Lower Ecca mudrocks are intruded at intervals by Karoo dolerites (often associated with the Whitehill Formation), with locally extensive colluvial and alluvial cover (*e.g.* Soutsloot drainage systems) and extensive calcrete pedocretes. The palaeontological sensitivity of this sector is HIGH.

5. (Sections 7 to 10, BT & PK sheets). The Route 3 traverses geological heterogeneous terrain from the northern margins of the Britstown sheet, past Strydenburg and across the R369 Hopetown – Preiska road to the Orange River. Here the Dwyka Group glacial rocks at the base of the Karoo Supergroup unconformably overlie varied Precambrian basement rocks of the Ventersdorp Supergroup that usually occur as small inliers (*e.g.* Ra, Allanridge lavas; Rt, lavas, tuffs and sediments of the 'Tcuip / Kameeldoorns Formation). The Dwyka outcrop is frequently overlain by well-developed calcrete pedocretes and downwasted surface gravels. Potentially fossiliferous, mudrock-dominated interglacial units are probably poorly exposed. Large areas in the NE are covered by windblown Kalahari Group and other sand deposits (Qs), while numerous pans also occur in this area. With the possible exception of the pans, the palaeontological sensitivity of this sector of the transmission line is LOW.

6. (Sections 10 to 13, PK and KF). Ventersdorp Supergroup basement rocks (Allanridge lavas), mantled with alluvium, calcrete and aeolian sands are exposed along the Orange and Modder Rivers at either end of this Route 3 sector. In between long stretches have only small basement and Karoo dolerite inliers protruding through the cover of aeolian sand and calcrete. Small isolated outcrops of the potentially fossiliferous Whitehill Formation (Ppw, probably baked by adjacent dolerites) as well as pan sediments occur along the line near the Salt Works on map section 12. With the exception of these last mentioned small occurrences, the overall palaeontological sensitivity of this sector is LOW.

7. (Sections 13 to 15, KB sheet). From the Modderrivier to an area *c*. 20 km ESE of Kimberley the Route 3 line traverses inliers of Archaean basement rocks (Allanridge Fm lavas), small areas of Lower Ecca Group mudrocks (Prince Albert Formation) and Karoo dolerite intrusions but most of the bedrocks here are mantled with calcrete, aeolian sand and occasional pans. The palaeontological sensitivity of this sector is rated as LOW (*cf* Almond 2013c).

8. (Sections 15 to 18, KB sheet). Over the final sector to the east of Kimberley the transmission line route overlies Tierberg Formation mudrocks that are very extensively intruded by dolerite and frequently covered by superficial sediments, notably calcrete and aeolian sands. Towards Perseus Substation the route crosses several pans that might be of palaeontological interest (*e.g.* Vleipan). Otherwise the overall sensitivity of this sector is LOW.

4.6. Brief comparison of route options in terms of palaeontological sensitivity

Route 1 (preferred option) has the advantage of being the shortest, most direct route between the Gamma and Perseus substations, running essentially SW – NE between Hutchinson (Northern Cape) and Dealesville (Free State) *via* De Aar along existing servitudes. The number of transmission line tower positions and length of new service roads are therefore at a minimum. The underlying bedrock geology is less varied than for Route 3 (see below). It mainly comprises Permo-Carboniferous lacustrine / marine to continental Karoo Supergroup sediments of the Ecca Group (Tierberg and Waterford Formations) and Lower Beaufort Group (Abrahamskraal and Teekloof Formations) that are extensively intruded by sills and dykes of the Early Jurassic Karoo Dolerite Suite. These older bedrocks are mantled by Late Caenozoic superficial sediments of generally low palaeontological sensitivity (*e.g.* alluvium, colluvium, calcrete hardpans, windblown sands, surface gravels) over large stretches of the proposed transmission line corridor. Potentially fossiliferous High Level Gravels of Tertiary / Quaternary age are not mapped along major drainage systems (*e.g.* Orange, Riet and Modder Rivers) within the Route 1 corridor. The overall palaeontological sensitivity along most sectors of the line is LOW, in large part due to poor exposure, near-surface calcretisation and weathering, as well as thermal metamorphism (baking) of potentially fossiliferous Palaeozoic bedrocks (notably the Lower Beaufort Group). Sectors of potentially HIGH palaeontological sensitivity are largely confined to the Victoria West, south-eastern Britstown and south-western Colesberg 1: 250 000 sheet areas between Hutchinson and De Aar. These sectors are underlain by the Lower Beaufort Group (Abrahamskraal and Teekloof Formations), well-known for its diverse Middle to Late Permian vertebrate faunas, and/or by shallow shelf facies of the Waterford Formation that are characterised by abundant trace fossils as well as well-preserved petrified wood and other plant remains. Small areas of pan sediments on flatter terrain within the Koffiefontein and Kimberley sheet areas may also be of palaeontological significance (*e.g.* for Caenozoic mammal remains). Older (pre-Holocene) alluvial sediments and surface gravels throughout the transmission line corridor may also contain important fossil biotas (e.g. mammalian skeletal remains, reworked petrified wood) but these deposits are not usually mapped at 1: 250 000 scale and can only be recognised through fieldwork.

Route 2 runs broadly subparallel to Route 1 and only some 20 km or less further to the west. The underlying geological is very similar to that already outlined for Route 1 and involves the same spectrum of rock units. As for the preferred route, sectors of HIGH palaeontological sensitivity due to the presence here of Lower Beaufort and uppermost Ecca Group bedrocks are confined to the south-western portion of the transmission line corridor (Victoria West, Britstown and Colesberg 1: 250 000 sheet areas). Most sectors are of LOW palaeontological sensitivity, with the possible exception of isolated pans. There is no marked preference between Routes 1 and 2 on palaeontological heritage grounds.

The three diversions from Route 2, known as Routes 2a, 2b and 2c, share a very similar geology to Route 2 itself, and are in all cases are assessed as having a LOW palaeontological sensitivity. **Route**

2a provides a longer, slightly more westerly route across the Orange and Riet Rivers. It passes close to, but does not cross, potentially fossiliferous Lower Ecca Group sediments close to the Orange River, and probably has a lower impact on pans than Route 2. **Route 2b** provides an alternative, more westerly crossing of the Riet River as does **Route 2c** with respect the Modder River. Apart from probable higher impacts on pans than Route 2 itself, they are not otherwise significantly different to the last in terms of palaeontological sensitivity. Consequently none of these diversions are preferred to the basic Route 2 on palaeontological heritage grounds.

Route 3 is by far the longest of the proposed transmission line corridors. From Hutchinson it follows a broadly curved route, convex towards the northwest, taking it fairly close to Britstown, Strydenburg, Hopetown, Ritchie, Kimberley and Boshof *en route* to Dealesville. It is also the most varied route in geological terms, cutting down-section through the Karoo Supergroup stratigraphy onto basement rocks along the northern margin of the Main Karoo Basin. In addition to the bedrock units and Late Caenozoic superficial sediments represented along Routes 1 and 2 (listed above), Route 3 also transects marine / lacustrine sediments of the Early to Middle Permian lower Ecca Group (Prince Albert and Whitehill Formations), Permo-carboniferous glacial sediments of the Dwyka Group, lavas and interbedded sediments of the Precambrian Ventersdorp Supergroup (*e.g.* Allanridge Formation) as well as very minor kimberlite intrusions of probable Cretaceous age. Of these, the lower Ecca formations may be highly fossiliferous (marine invertebrates, aquatic mesosaurid reptiles and fish, petrified wood, trace fossils *etc*). Sectors of HIGH palaeontological sensitivity along Route 3 include those underlain by Lower Beaufort Group and Waterford Formation rocks on the Victoria West sheet, by alluvial deposits of the ancient Koa River drainage system (known elsewhere for Tertiary mammal remains) towards the middle of the Britstown sheet, and by lower Ecca Group mudrocks (Prince Albert Formation) on the Britstown and (to a minor extent) Prieska sheets. The remaining sectors are assessed as having a LOW overall palaeontological sensitivity, with the possible exception of fairly numerous pans, for similar reasons to those given above for comparable sectors along Routes 1 and 2. Given its greater length (more tower positions, longer service roads) as well as better representation of palaeontologically sensitive rock units, Route 3 is anticipated to have a significantly higher overall impact on palaeontological heritage resources than Routes 1 and 2.

5. CONCLUSIONS & RECOMMENDATIONS

The proposed new Gamma – Perseus 765 kV transmission line and associated substation developments are situated in areas that are underlain by potentially fossiliferous sedimentary rocks of Precambrian, Late Palaeozoic and Late Tertiary or Quaternary age. The construction phase of the transmission line and associated infrastructure (*e.g.* tower footings, service roads, working and laydown areas, substations, construction camps, any borrow pits) may entail substantial excavations into or disturbance of the superficial sediment cover as well as the underlying bedrocks. 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 preserved 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.

Negative impacts on local fossil heritage are mainly anticipated during the construction phase of the transmission line development in connection with excavations for transmission tower footings and stays as well as surface clearance and new cuttings made for service roads and laydown areas. The magnitude of these impacts is largely determined by the transmission line corridor that is chosen. Upgrading of existing substations, installation of a telecommunication mast and construction camps are unlikely to generate significant additional palaeontological impacts. Once constructed, the operational and decommissioning phases of the transmission line are unlikely to involve further adverse impacts on palaeontological heritage.

The No-go option (no construction of transmission line or substation upgrade) will have a neutral impact on fossil heritage.

Transmission line Routes 1 and 2 are very similar in terms of their underlying geology as well as the palaeontological sensitivity of the rock units concerned. These mainly comprise Palaeozoic to Mesozoic bedrocks of the Lower Beaufort Group, Ecca Group and Karoo Dolerite Suite as well as overlying superficial sediments (alluvium, colluvium, calcrete, wind-blown sands *etc*) of Late Caenozoic age. Along both routes significant impacts on fossil heritage such as mammal-like reptiles and other vertebates, plant remains and trace fossils are likely to be largely confined to the south-western portions of the line, between Hutchinson and De Aar (*i.e.* Victoria West, Britstown and Colesberg 1: 250 000 sheet areas). Here highly sensitive Permian sediments of the Lower Beaufort Group (Abrahamskraal and Teekloof Formations) and uppermost Ecca Group (Waterford Formation) crop out. Most sectors of the two routes to the northeast of De Aar, including diversions along Routes 2a, 2b and 2c, are of low overall palaeontological sensitivity, with the possible exception of sporadic occurrences of older (pre-Holocene) pan and alluvial sediments. However, this can only be determined through fieldwork. In terms of anticipated impacts on fossil heritage resources at or beneath the ground surface there is no significant difference between transmission line Routes 1 and 2, and no marked preference for any of the diversions 2a, 2b or 2c over the Route 2 alternatives.

Route 3 is underlain by a significantly greater variety of bedrock units, including a wider range of Karoo Supergroup formations (Dwyka, Ecca and Lower Beaufort Groups) as well as Precambrian basement rocks (Ventersdorp Supergroup). Because it is longer than the other two main routes, and also traverses sediments of high palaeontological sensitivity (*e.g.* basal and uppermost Ecca Group, Lower Beaufort Group) over a greater part of its length, Route 3 is the least favoured option in terms of potential fossil heritage impacts. Significant impacts on fossil heritage are most likely to occur along sectors of the line within the Victoria West, Britstown, and Koffiefontein 1: 250 000 sheet areas where the line crosses the outcrop areas of the Lower Beaufort Group (Abrahamskraal and Teekloof Formations) and the more fossiliferous subunits of the Ecca Group (Prince Albert, Whitehill and Waterford Formations). As elsewhere, fossil heritage within unmapped older alluvium (*e.g.* possible Tertiary deposits of the Koa River Valley drainage system, Britstown sheet) and pan sediments may also be compromised.

5.2. Recommendations

Palaeontological heritage considerations are unlikely to play a major role in deciding between the various transmission line routes under consideration. A realistic palaeontological heritage impact assessment for the Gamma – Perseus second 765 kV transmission line project, with recommendations for any mitigation necessary, is only possible once the chosen transmission line corridor has been surveyed in the field by a professional palaeontologist. It is recommended that such a pre-construction field-based assessment be carried out at the earliest opportunity once the route is chosen so that any significant palaeontological heritage issues may be addressed at the project design stage.

It should be noted that the most likely outcome of such a field assessment study is that most - but not all - sectors of the transmission line corridor prove to be palaeontologically insensitive in practice because of a thick superficial sediment cover, high degree of near-surface weathering, baking by igneous intrusions, or sparse fossil content. No further specialist studies or mitigation is then required within these insensitive sectors, pending the discovery of significant new fossil remains during construction. However, short sectors of high palaeontological sensitivity, with a concentration of near-surface fossil material, may also be identified and mapped. These sensitive corridor sectors may require Phase 2 mitigation or, in exceptional cases, reconsideration of tower positions.

The recommended pre-construction palaeontological field survey should focus on areas of good sedimentary rock exposure along, or close to, the chosen transmission line corridor. The focus of the study should be on identifying those sectors of the corridor (if any) that are demonstrably, or inferred to be, of high palaeontological sensitivity so that detailed recommendations regarding mitigation of impacts during the pre-construction or construction phases may be developed.

Effective mitigation of palaeontological heritage within the transmission line corridor may only be feasible once the route and positions of individual structures (towers, substations, access roads, construction camps, borrow pits *etc*) have been finalised. However, pre-construction specialist mitigation of selected development sites and corridor sectors may be necessary in some more sensitive cases – for example, to:

- locate, record and judiciously sample any valuable fossil material already exposed at the ground surface which might be damaged during early development (*e.g.* vertebrate remains and petrified wood from the Karoo Supergroup), together with pertinent geological data, and
- make specific recommendations for mitigation during the construction phase, such as monitoring of key excavations, recording and sampling of newly exposed fossil material. These mitigation recommendations should be incorporated into the EMP for the transmission line development.

6. ACKNOWLEDGEMENTS

Mr Tim Hart of ACO Associates CC, Cape Town, is thanked for commissioning this study and providing the relevant background information. I am also very grateful to Ms Claire Browning (Council for Geoscience, Bellville) and colleagues for kindly assisting with preparation of the numerous geological strip maps required for this desktop study.

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8. 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 railway 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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