Palaeontological specialist assessment: desktop study

PROPOSED 16 MTPA EXPANSION OF TRANSNET'S EXISTING MANGANESE ORE EXPORT RAILWAY LINE & ASSOCIATED INFRASTRUCTURE BETWEEN HOTAZEL AND THE PORT OF NGQURA, NORTHERN & EASTERN CAPE.

Part 2: De Aar to the Coega IDZ, Northern and Eastern Cape

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EXECUTIVE SUMMARY

Transnet SOC Limited is planning to expand the capacity of the existing manganese ore export railway line between Hotazel (Northern Cape) and the Port of Ngqura (Coega IDZ, Eastern Cape) from the originally envisaged 12 Mtpa to 16 Mtpa. An additional fifteen rail loops that were not part of the previous EIA for the 12 Mtpa proposal will be extended and one new loop will be constructed close to Sishen in the Northern Cape. The 16 Mtpa expansion will require two rail compilation yards that are located at Mamathwane, Northern Cape, and the Coega IDZ in the Eastern Cape. Refurbishment of the second rail is required between Kimberley and De Aar in the Northern Cape. The present desktop report forms part of the Basic Assessment of five railway loop developments along the manganese ore railway line between Cradock and Kommadagga in the Eastern Cape.

The construction phase of the proposed extended railway loops along the Transnet Hotazel to Coega manganese ore railway may entail several substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock. These excavations may disturb, damage or destroy scientifically valuable fossil heritage exposed at the surface or buried below ground. Other infrastructure components (*e.g.* laydown areas) may seal-in buried fossil heritage. However, most of the direct impacts will occur within the existing railway reserve, which is already highly disturbed. The operational and decommissioning phases of the 16 Mtpa railway line are unlikely to involve significant adverse impacts on palaeontological heritage.

The proposed railway loop extensions at **Drennan** and **Thorngrove**, situated between Cradock and Cookhouse, are underlain by Late Permian sediments of the Balfour Formation (Lower Beaufort Group) that are known for their fossil remains of therapsids (mammal-like reptiles) and other terrestrial vertebrates as well as plants and trace fossils. The Beaufort sediments at both localities may well have been baked by nearby intrusions of the Early Jurassic Karoo Dolerite Suite and are in part mantled with alluvial sediments of the Great Fish River that are of low palaeontological sensitivity.

The extended railway loop between **Cookhouse and Golden Valley** is largely underlain by alluvium but near-surface rocks of the Late Permian Middleton Formation (Lower Beaufort Group) might be impacted in the northern part of the study area near Cookhouse. Comparatively few, but scientifically important, vertebrate remains (*e.g.* various dicynodonts) have been recorded from the Lower Beaufort rocks in the Cookhouse area during recent palaeontological impact assessments. A wide range of vertebrate remains, invertebrates, trace fossils, plant fossils and microfossils have been recorded from Late Caenozoic alluvial sediments in the Great Karoo region, but in general they are of low palaeontological sensitivity and of considerable lateral extent so impacts on fossil heritage here are likely to be of low significance.

The proposed railway loop at **Sheldon**, just south of the Great Fish River, is underlain by Middle Permian continental sediments of the Koonap Formation (Lower Beaufort Group). These rocks have yielded scientifically important vertebrates (*e.g.* dinocephalians, therocephalians) to the west and east of the study area but these fossils are generally very sparse and bedrock exposure levels are low. Fossil invertebrate burrows are recorded from Sheldon Bridge. The overlying superficial sediments (fluvial gravels, calcretes, soils) are of low palaeontological sensitivity.

The proposed loop extension between **Ripon and Kommadagga**, to the south of Cookhouse, traverses a range of Carboniferous to Middle Permian sedimentary rock units including the Kommadagga Subgroup (Witteberg Group), Elandsvlei Formation (Dwyka Group), as well as the Prince Albert, Whitehill, Collingham and Ripon Formations of the Ecca Group. All of these units, especially the Whitehill Formation that is known for its well-preserved fossil fish, insects, crustaceans and aquatic mesosaurid reptiles, are potentially fossiliferous.

It is recommended that a brief palaeontological field assessment of the sedimentary rock units exposed along the Cradock to Kommadagga sector of the Transnet manganese ore export railway be undertaken before construction commences to assess impacts of the proposed loop developments on local fossil heritage and to make recommendations for any further specialist palaeontological studies or mitigation that should take place before or during the construction phase. These recommendations should also be incorporated into the Environmental Management Plan for the proposed railway developments.

1. INTRODUCTION AND BRIEF

Manganese ore mined in the Hotazel area near Kuruman (Kalahari Manganese Field) in the Northern Cape is transported by rail to a bulk minerals handling terminal at Port Elizabeth, where it is unloaded and placed on stockpiles before being loaded onto ships for export. Transnet SOC Limited is planning to expand the capacity of the existing manganese ore export railway line between Hotazel (Northern Cape) and the Port of Ngqura (Coega IDZ, Eastern Cape) from the originally envisaged 12 Mtpa to 16 Mtpa. Twelve project areas involved were originally assessed when the recent 12 Mtpa Environmental Impact Assessment was completed. An additional fifteen rail loops that were not part of the previous EIA will be extended and one new loop will be constructed close to Sishen in the Northern Cape (Table 1). The 16 Mtpa expansion will require two rail compilation yards that are located at Mamathwane Northern Cape and Coega IDZ in the Eastern Cape. Refurbishment of the second rail is required between Kimberley and De Aar in the Northern Cape. The present desktop report forms part of the Basic Assessment of five railway loop developments along the manganese ore railway line between Cradock and Coega in the Eastern Cape (Tables 1, 2)..

Table 1: List of new loops or loop extensions forming part of the 16 Mtpa expansion of the Hotazel to Port of Ngqura manganese ore railway line (From BID kindly provided by ERM). The present report covers the five Eastern Cape loop extensions listed here between Cradock and Kommadagga.

Northern Cape	
Witloop	New loop
Wincanton	Loop extension
Sishen	Loop extension
Glosam	Loop extension
Postmasburg	Loop extension
Tsantsabane	Loop extension
Trewil	Loop extension
Ulco	Loop extension
Gong Gong	Loop extension
Fieldsview	Loop extension
Eastern Cape	
Drennan	Loop extension
Thorngrove	Loop extension
Cookhouse-Golden Valley	Loop extension
Sheldon	Loop extension
Ripon-Kommadagga	Loop extension

1.1. Legislative context for palaeontological assessment studies

ERM Southern Africa (Pty) Ltd (Block A, Silverwood House, Silverwood Close, Steenberg Office Park, Cape Town 7945, South Africa; tel: +27 21 702 9100) has been appointed as the Independent Environmental Assessment Practitioners to undertake a Basic Assessment of an additional fifteen railway loops between Hotazel and Ngqura as well as an Environmental Impact Assessment of the proposed new compilation yard at Mamathwane in terms of the National Environmental Management Act (NEMA) (Act 107 of 1998, amended in 2008).

The present desktop study forms part of the Basic Assessment of five of the fifteen additional loops, located between Cradock and Kommadagga in the Eastern Cape, and is to be followed by a brief field-based palaeontological assessment by the author. A list of the loops under consideration is given in Table 1 and these are also shown on the map in Fig. 1 (kindly provided by ERM). The present palaeontological heritage report also falls under Section 38 (Heritage Resources

Management) of the South African Heritage Resources Act (Act No. 25 of 1999), and it will also inform the Environmental Management Plan for this project.

The proposed railway line developments are located in areas that are underlain by potentially fossil-rich sedimentary rocks of Palaeozoic, Mesozoic and younger, Tertiary or Quaternary age (Sections 2 and 3). The construction phase of the developments may entail substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock. In addition, substantial areas of bedrock may be sealed-in or sterilized by railway infrastructure, lay-down areas as well as new gravel roads. All these developments may adversely affect potential fossil heritage 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 railway 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 include, among others:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

(d) recover the costs of such investigation from the owner or occupier of the land on which it is believed an archaeological or palaeontological site is located or from the person proposing to undertake the development if no application for a permit is received within two weeks of the order being served.

Minimum standards for the palaeontological component of heritage impact assessment reports (PIAs) have recently been published by SAHRA (1913).

1.2. Scope and brief for the desktop study

This desktop palaeontological specialist report provides an assessment of the observed or inferred palaeontological heritage within the five proposed loop study areas within the Eastern Cape between Cradock and Kommadagga (Fig. 1, Tables 1 & 2), with recommendations for further specialist palaeontological studies and / or mitigation where this is considered necessary.

The report has been commissioned by ERM Southern Africa (Pty) Ltd (Block A, Silverwood House, Silverwood Close, Steenberg Office Park, Cape Town 7945, South Africa; tel: +27 21 702 9100). It contributes to the Basic Assessment for the proposed 16 Mtpa railway developments and it will also inform the Environmental Management Plan for the project. The scope of work for this desktop study, as defined by ERM, is as follows:

> The Contractor's role involves generating a Paleontological Baseline Report and a Paleontological Assessment Report. The findings will be based on one extended field trip (10 days) covering both the Northern Cape and Eastern Cape.

1.3. Approach to the palaeontological heritage Basic Assessment study

The approach to this palaeontological heritage Basic Assessment study is briefly as follows. Fossil bearing rock units occurring within the broader study area are determined from geological maps and satellite images (Figs. 4 and 5). Known fossil heritage in each rock unit is inventoried from scientific literature, previous assessments of the broader study region, and the author's field experience and palaeontological database (Table 3). Based on this data as well as field examination of representative exposures of all major sedimentary rock units present, the impact significance of the proposed development is assessed with recommendations for any further studies or mitigation.

In preparing a palaeontological desktop study the potentially fossiliferous rock units (groups, formations *etc*) represented within the study area are determined from geological maps. The known fossil heritage within each rock unit is inventoried from the published scientific literature, previous palaeontological impact studies in the same region, and the author's field experience (Consultation with professional colleagues as well as examination of institutional fossil collections may play a role here, or later following field assessment during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development (Provisional tabulations of palaeontological sensitivity of all formations in the Western, Eastern and Northern Cape have already been compiled by J. Almond and colleagues; *e.g.* Almond *et al.* 2008). The likely impact of the proposed development on local fossil heritage is then determined on the basis of (1) the palaeontological sensitivity of the rock units concerned and (2) the nature and scale of the development itself, most significantly the extent of fresh bedrock excavation envisaged. When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a Phase 1 field assessment study by a professional palaeontologist is usually warranted to identify any palaeontological hotspots and make specific recommendations for any mitigation required before or during the construction phase of the development.

On the basis of the desktop and Phase 1 field assessment studies, the likely impact of the proposed development on local fossil heritage and any need for specialist mitigation are then determined. Adverse palaeontological impacts normally occur during the construction rather than the operational or decommissioning phase. Phase 2 mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) may be required (a) in the pre-construction phase where important fossils are already exposed at or near the land surface and / or (b) during the construction phase when fresh fossiliferous bedrock has been exposed by excavations. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority (*e.g.* ECPHRA, the Eastern Cape Provincial Heritage Resources Authority, for the Eastern Cape. Contact details: Mr Sello Mokhanya, 74 Alexander Road, King Williams Town 5600; smokhanya@ecphra.org.za). It should be emphasized that, *providing appropriate mitigation is carried out*, the majority of developments involving bedrock excavation can make a *positive* contribution to our understanding of local palaeontological heritage.

1.4. Assumptions & limitations

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

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

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

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

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

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

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

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

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

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

In the case of the Transnet 16 Mtpa study areas a major limitation for fossil heritage studies is the 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 Eastern Cape region as a whole.

1.5. Information sources

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

1. A short project outline provided by ERM;

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 broader Cradock – Kommadagga region of the Eastern Cape (*e.g.* Almond 2009, 2010b, 2011, 2013).

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

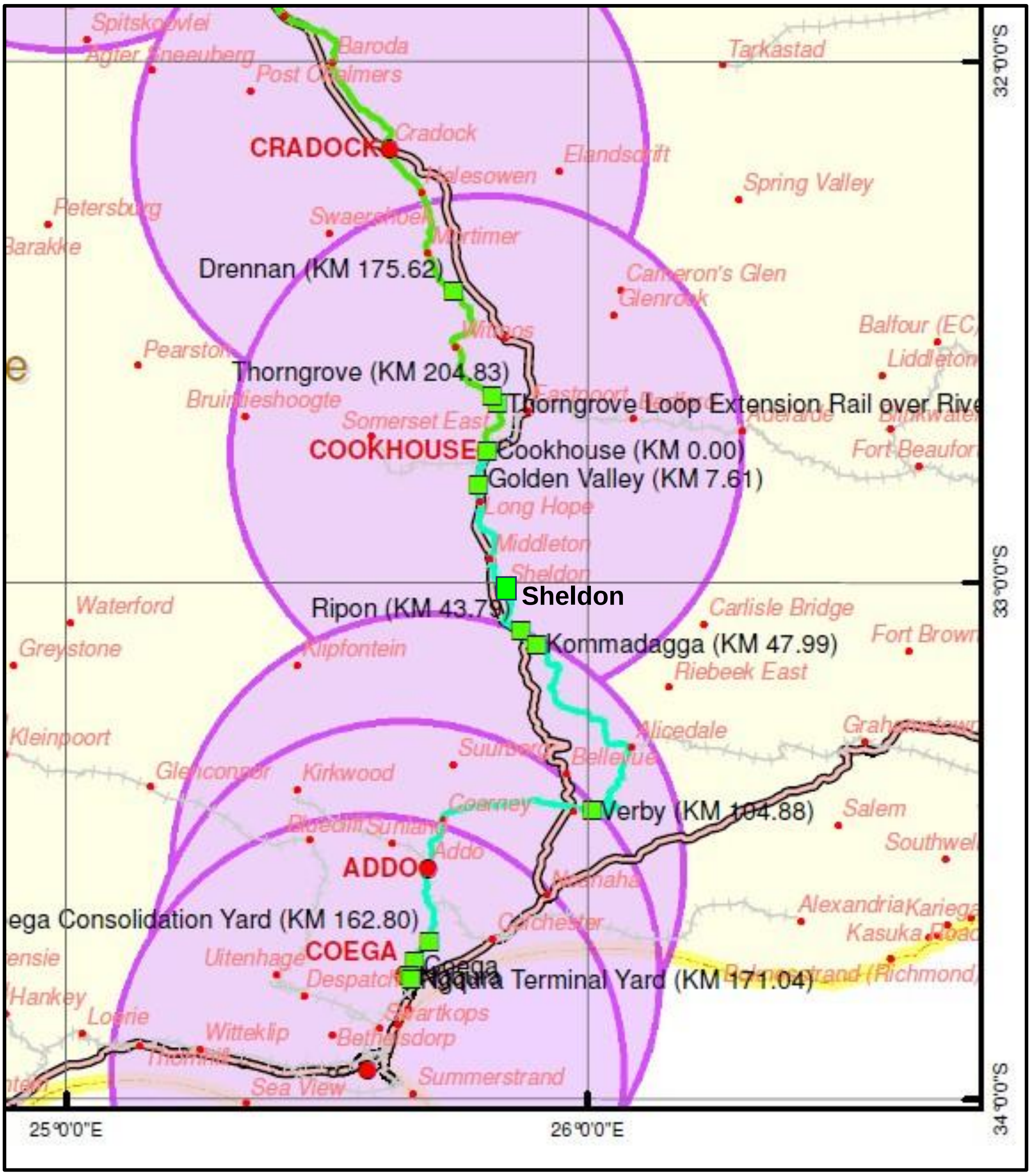

Fig. 1. Map of the Cradock to Coega sector of the Transnet manganese ore export railway line, Eastern Cape, showing the locations of the five railway loops covered by the present desktop Basic Assessment report as well as of the Coega IDZ Compilation Yard (green squares; see also Table 1) (Map modified from image kindly provided by ERM).

Table 2. Summary of geology and palaeontological sensitivity of the five railway loop study sites between Cradock and Kommadagga.

LOOP	LOCATION	PROJECT	GEOLOGY	PALAEONTOLOGICAL HERITAGE SENSITIVITY	RECOMMENDATION
1. DRENNAN (km 175.62)	c. 32º 26' 30.09" S c. 25º 44' 33.10" E	Loop extension	Balfour Formation (Lower Beaufort Group, possibly baked by nearby dolerite intrusion), river alluvium	HIGH	Brief field assessment of loop development footprints and representative bedrock exposures in the region to assess likely palaeontological impacts based on levels of bedrock exposure, degree of weathering and deformation, and presence of near-surface fossils.
2. THORNGROVE (km 204.83)	c. 32º 38' 49.57" S c. 25º 49' 15.70" E	Loop extension	Balfour Formation (Lower Beaufort Group, possibly baked by nearby dolerite intrusion), dolerite, river alluvium	HIGH	
3. COOKHOUSE – GOLDEN VALLEY (km 0 to km 7.61)	c. 32º 46' 28.28" S c. 25º 47' 45.72" E	Loop extension	Alluvium overlying Middleton Formation (Lower Beaufort Group)	LOW	
4. SHELDON	c. 33º 00' 30.22" S c. 25º 51' 53.53" E	Loop extension	Koonap Formation (Lower Beaufort Group) and overlying alluvium	MEDIUM	
5. RIPON – KOMMADAGGA (km 43.79 – km 47.99)	c. 33º 06' 08.2" S c. 25º 52' 32.14" E	Loop extension	Prince Albert, Whitehill, Collingham & Ripon Formations (Ecca Group), Dwyka Group, Kommadagga Subgroup (Witteberg Group)	HIGH	

2. GEOLOGICAL OUTLINE OF THE STUDY AREA

The sector of the Transnet manganese ore export railway line between Cradock and Kommadagga traverses the eastern part of the Great Karoo Region, extending into the northern edge of the Cape Fold Belt at its southern end (*cf* Visser *et al.* 1989, their Fig. 2.1.). For much of its length it follows the valley of the Great Fish River that flows within a deeply-incised, meandering valley flanked by mountainous terrain (*e.g.* Swaershoekberge, Winterberge ranges) between Cradock and Cookhouse. The railway lies at elevations of around 800-600m amsl within this portion of the study region and crosses the river at several points. At Cookhouse the railway line enters lower-lying (580-500m amsl), hilly terrain known as *Die Smal Deel* on either side of the Great Fish River. The river valley is much wider here and bedrock exposure here is very limited due to the thick development of alluvium. However, good exposures are present in cuttings along the N10 tar road and adjacent hillslopes, in railway cuttings as well as intermittently along the banks of the Great Fish River (Almond 2009, 2010b, 2011). Just north of Ripon the railway line crosses a gravel-capped pediment surface (*c*. 480-500m amsl) and the Little Fish River before cutting through a prominent west-east ridge of Dwyka Group rocks at the base of the Karoo Supergroup succession. The lowermost Karoo Supergroup and uppermost Cape Supergroup bedrocks here are highly folded and lie well within the margins of the Cape Fold Belt, as reflected by the ridge and valley terrain developed at the southern end of the study sector between Ripon and Kommadagga.

The geology of the study area between Cradock and Kommadagga is covered by two adjacent 1: 250 000 scale geological maps, sheets 3224 Graaff-Reinet (sheet explanation by Hill 1993) and 3324 Port Elizabeth (sheet explanation by Toerien & Hill 1989). Relevant extracts from these maps are provided in Figs. 4 to 5 below. 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.

All major rock units mapped along the railway line between Cradock and Kommadagga are listed in Table 3, together with a brief summary of their geology, age, known fossil heritage and inferred palaeontological sensitivity (largely based on Almond *et al.* 2008). The location of these rock units within the stratigraphic column for South Africa is shown in Fig. 2. They include a wide range of sedimentary and igneous rocks ranging in age from Early Carboniferous (*c*. 320 Ma) to Recent. The intrusive igneous rocks (*i.e.* dolerites) are entirely unfossiliferous while a high proportion of the sedimentary rocks are of moderate to high palaeontological sensitivity, notably the inland sea sediments of the lower Ecca Group and the continental sediments of the Lower Beaufort Group (Adelaide Subgroup), all of which are Early to Middle Permian in age.

For the purposes of the present Basic Assessment of the five proposed new loop extensions in the Eastern Cape sector of the manganese ore railway line only those rock units that are mapped within the development footprint (as shown on 1: 250 000 geological maps, Figs. 4 to 5) will be considered further here. As seen in Table 2, the Drennan and Thorngrove loop extensions are largely underlain by sediments of the Late Permian to Early Triassic **Balfour Formation** (**Adelaide Group / Lower Beaufort Group**) as well as Late Caenozoic **river alluvium** and / or Early Jurassic **Karoo dolerite**. Most of the long Cookhouse – Golden Valley loop extension study area is mantled with Late Caenozoic alluvium of the Great Fish River which here overlies Middle to Late Permian rocks of the Middleton Formation (**Adelaide Group / Lower Beaufort Group**). The loop extension at Sheldon overlies Middle Permian continental sediments of the **Koonap Formation** (**Adelaide Subgroup / Lower Beaufort Group**) that here are mantled with Caenozoic alluvium (with a seasonal watercourse crossing the northern part of study area). The loop extension between Ripon and Kommadagga traverses the outcrop areas of the uppermost shallow marine sediments of the **Witteberg Group** (**Kommadagga Subgroup**, for which this is the type area) as well as the basal formations of the Karoo Supergroup, namely the glacial **Elandsvlei Formation** of the **Dwyka Group** and the **Prince**

Albert, **Whitehill**, **Collingham** and **Ripon Formations** of the **Ecca Group** (See Fig. 3 for stratigraphic subdivision of the Karoo Supergroup).

A short review of the geology of these rock units is given below, while details of their known fossil heritage are given in Section 3.

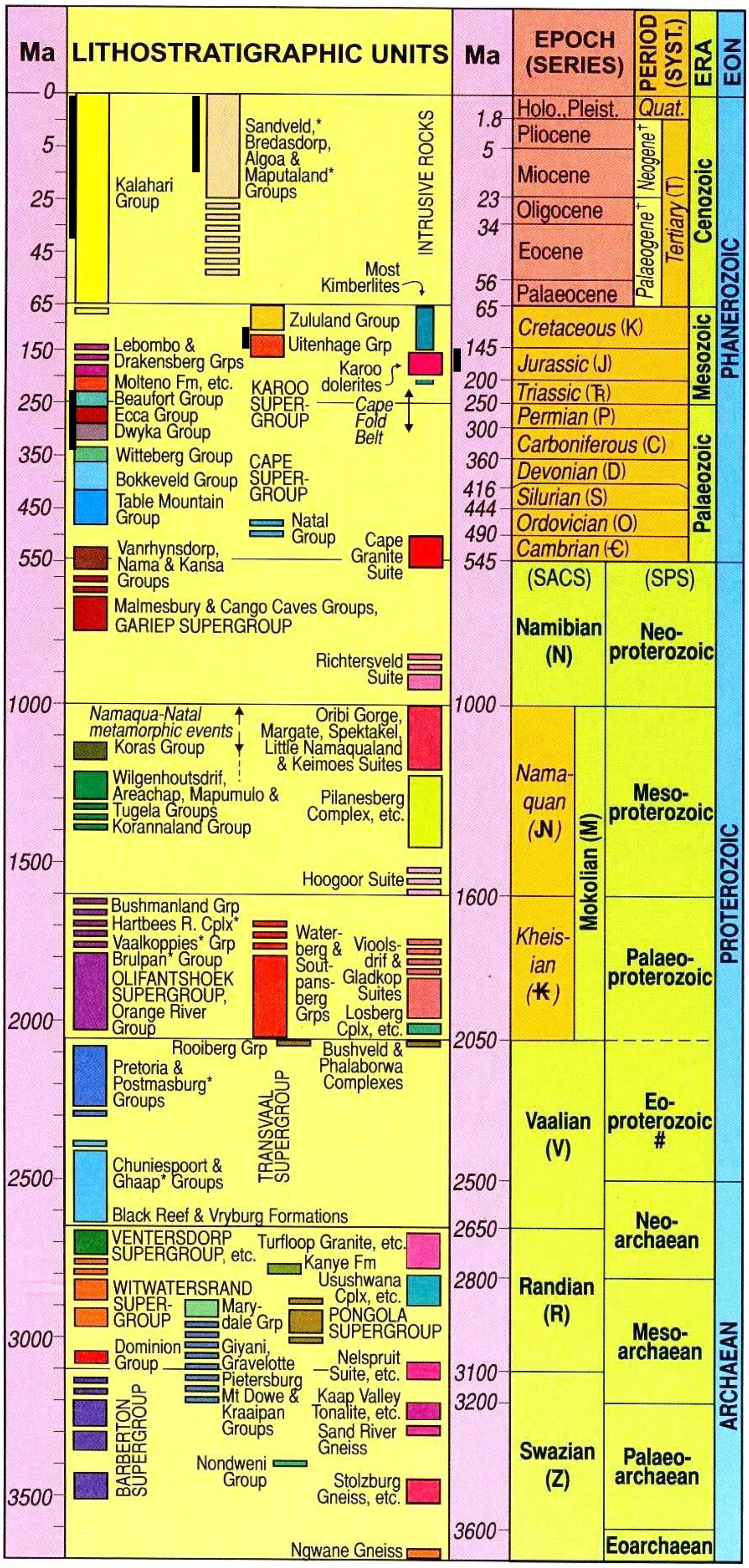

Fig. 2. Stratigraphic column for southern Africa showing the main Phanerozoic rock units represented along the manganese ore export line railway between Cradock and Coega, Eastern Cape (thick vertical black lines) (See also Table 3 for Karoo Supergroup rock units.

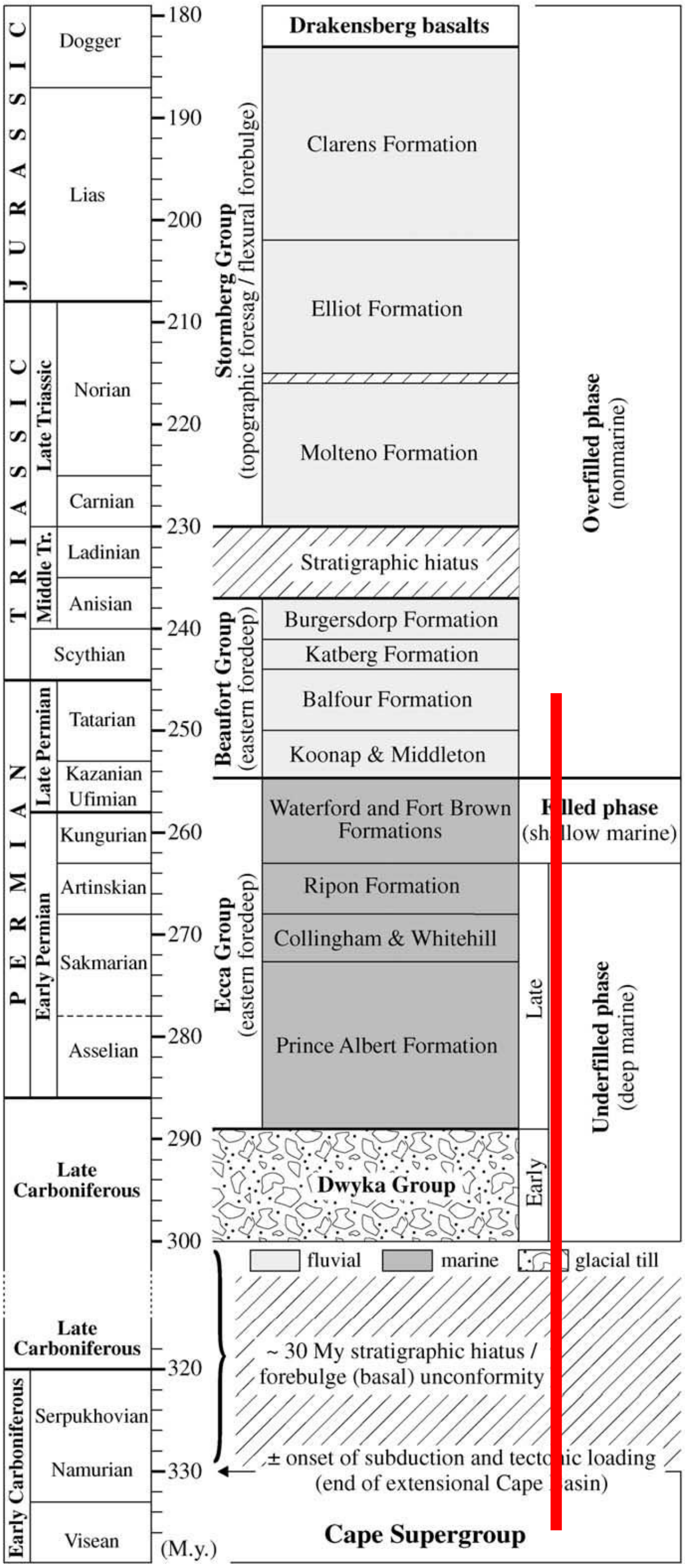

Figure 3. Stratigraphic subdivision of the *c*. 12km-thick Karoo Supergroup (From Catuneanu *et al.* 2005). The Early Carboniferous to Late Permian formations of the Witteberg, Dwyka, Ecca and Lower Beaufort Groups that are represented within the Transnet project area between Cradock and Kommadagga are emphasized by the thick red bar.

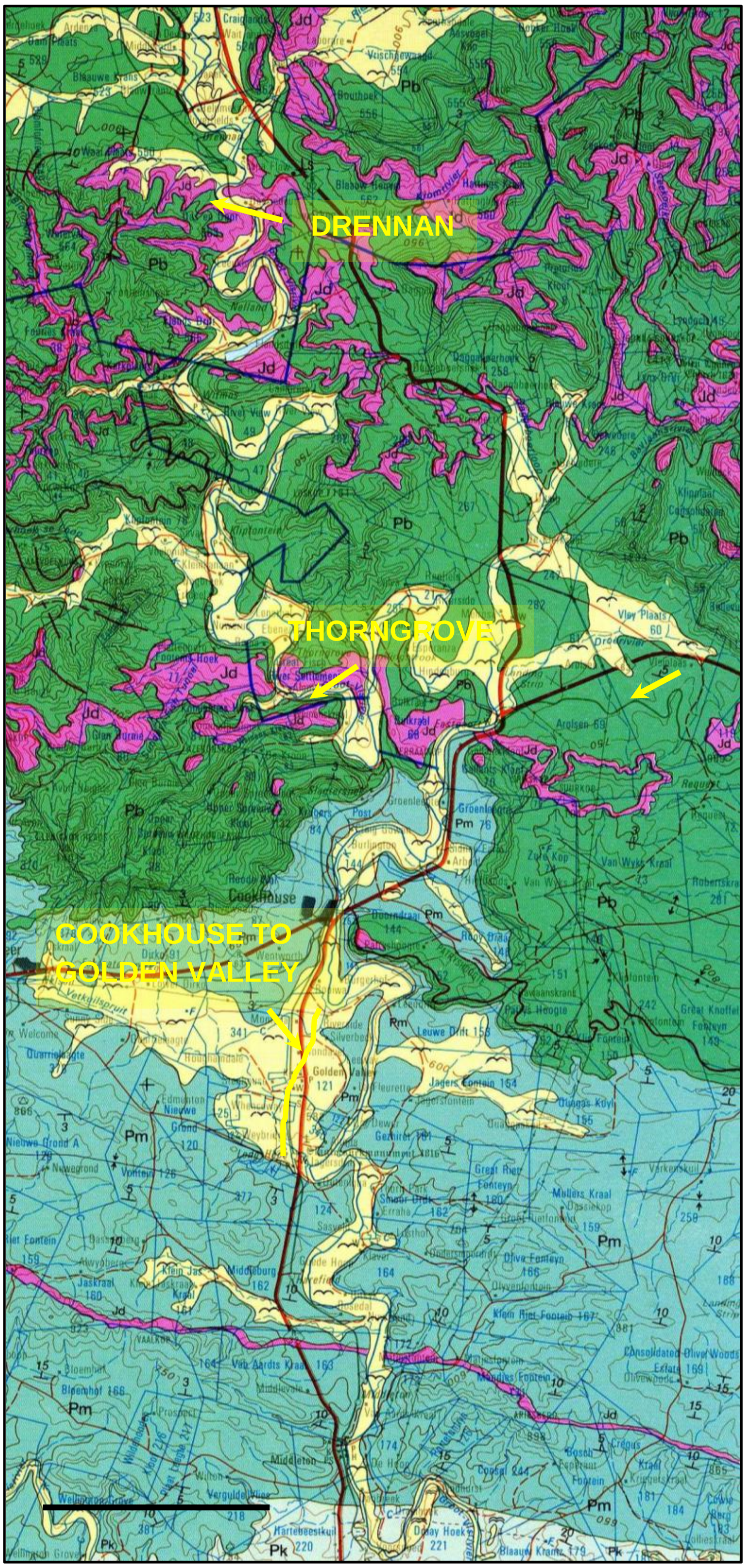

Fig. 4. Extract from 1: 250 000 geology map 3224 Graaff-Reinet (Council for Geoscience, Pretoria) showing location of the proposed loop extensions at Drennan, Thorngrove (both underlain by the Balfour Formation, Pb) and Cookhouse – Golden Valley (underlain by alluvium and the Middleton Formation). See Table 3 for summary of geology and fossils within rock units along this section of the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

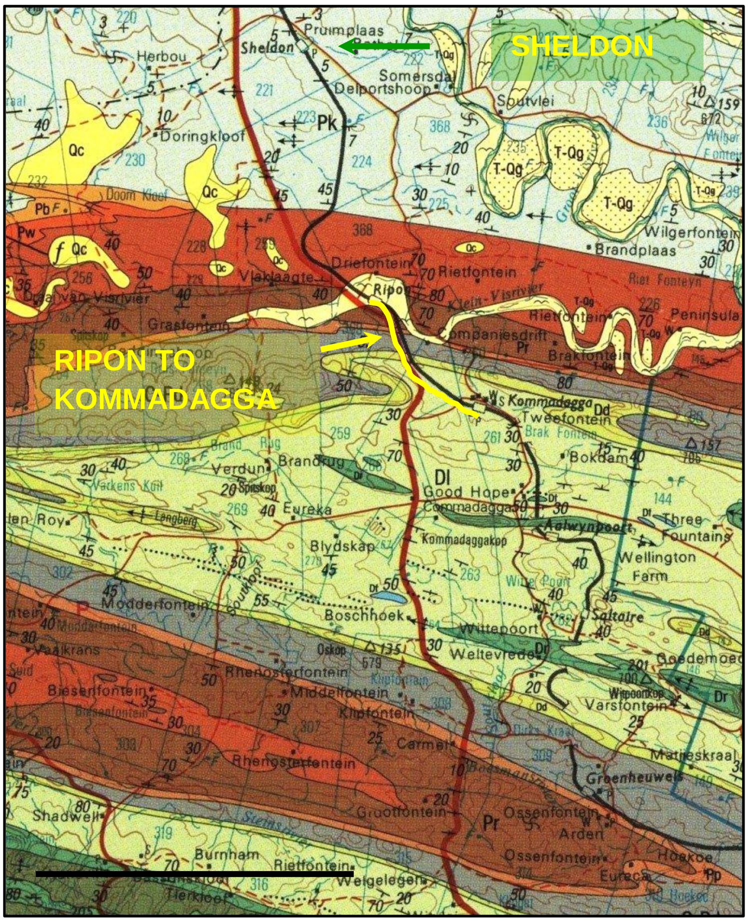

Fig. 5. Extract from 1: 250 000 geology map 3324 Port Elizabeth (Council for Geoscience, Pretoria) showing location of the proposed loop extensions at Sheldon, underlain by sediments of the Koonap Formation (Pk, Lower Beaufort Group), and at Ripon – Kommadagga, underlain by upper Witteberg Group (Dl, Dd), Dwyka Group (C-Pd) and Ecca Group (Pp, Pr) sediments. See Table 3 for summary of geology and fossils within rock units along this section of the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

2.1. Kommadagga Subgroup (Witteberg Group)

The Kommadagga Subgroup (Dl in part, Dd) is thin (430m to 250m), glacially-influenced succession of shallow marine siliclastic sediments of Early Carboniferous age that forms the uppermost part of the Witteberg Group in the Eastern Cape (Willowmore – Grahamstown region) (Loock 1967, Rossouw 1970, Johnson 1976, Swart 1982, Loock & Visser 1985, Toerien & Hill 1989, Johnson & Le Roux 1994, Theron 1994, Thamm & Johnson 2006). It is paraconformably or uncomformably overlain by the Dwyka Group. The four constituent formations of the Kommadagga Subgroup vary in thickness along strike and may be absent in some areas, in part due to pre-Dwyka erosion. The lenticular, sparsely pebbly, massive, dark grey, sandy diamictites of the basal **Miller Formation** (10-95m thick) may be of debris flow rather than direct glacial melt-out origin. The pebbles are mainly of quartz and black chert. This unit interfingers with pale, pebbly, laminated quartzites or siliceous sandstones of the **Swartwaterspoort Formation** (*c*. 6-10m or less) that are characterised by chaotic bedding, including convoluted intraformational folds. This deformation has been various linked to slumping or subglacial deformation. The horizontally-laminated pebbly sands may have been originally deposited in a beach setting with wave reworking of poorly-sorted glacial outwash or tillite. Thinly-laminated offshore mudrocks of the overlying **Soutkloof Formation** (45-165m) include rhythmitites towards the base - possibly glacially-related varves. They form the lower portion of a major shallowing-upwards cycle that grades up into the fine- to medium-grained, well-sorted, grey, feldspathic to lithofeldspathic sandstones of the **Dirkskraal Formation** (175m or less; Dd). A shallow shoreface or even beach setting for this last unit has been proposed (Johnson & Le Roux 1994). The Kommadagga Subgroup in its type area near Kommadagga is approximately 260m thick (Toerien & Hill 1989).

2.2. Elandsvlei Formation (Dwyka Group)

The Late Carboniferous to Early Permian sediments of the Elandsvlei Formation (Dwyka Group, C-Pd) were deposited as glacial tillites and interglacial mudrocks in a shallow epicontinental sea on the margins of Gondwana. The geology of the Dwyka Group has been summarized by Visser (1989, 2003), Visser *et al.* (1990) and Johnson *et al.* (2006), among others. A brief account of the Dwyka rocks in the southern part of the study region is given by Toerien and Hill (1989), largely based on Johnson (1976). The Dwyka succession here is *c*. 680m thick and consists of largely of massive, blue-grey to grey-green glacial diamictites with subordinate well-bedded sandstones and shales. There is evidence of several deglaciation cycles, as also recorded in the Western Cape (*e.g.* Visser 1997). Potentially fossiliferous interglacial mudrock successions, including dropstone laminites, are also present here between the massive diamictites but are often obscured by drift cover, including Quaternary alluvium as well as downwasted polymict gravels

2.3. Prince Albert Formation

The Dwyka Group is conformably overlain by post-glacial basinal mudrocks of the Prince Albert Formation (Ppr / Pp in part), the lowermost subunit of the Ecca Group. This thin-bedded to laminated mudrock-dominated succession of Early Permian (Asselian / Artinskian) age was previously known as "Upper Dwyka Shales". Key geological accounts of this formation are given by Visser (1992) and Cole (2005). The Prince Albert succession in the Port Elizabeth sheet area is *c.* 100m thick (Toerien & Hill 1989). It consists mainly of thin-, tabular-bedded mudrocks of blue-grey, olive-grey to reddish-brown colour with occasional thin (dm) buff sandstones and even thinner (few cm), soft-weathering layers of yellowish water-lain tuff (*i.e.* volcanic ash layers). Extensive diagenetic modification of these sediments has led to the formation of thin cherty beds, pearly-blue phosphatic nodules, rusty iron carbonate nodules, as well as beds and elongate ellipitical siliceous concretions impregnated with iron and manganese minerals.

2.4. Whitehill Formation

The Whitehill Formation (Pw / Pp in part) is a thin (*c*. 20 to 90m) 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 1973, Oelofsen 1981, 1987, Visser 1992, 1994, Cole & Basson 1991, MacRae 1999, McCarthy & Rubidge 2005, Johnson *et al*. 2006). Fresh Whitehill Formation 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. According to Almond (2013) the Whitehill Formation in the Kommadagga region is poorly exposed and deeply weathered near-surface.

2.5. Collingham Formation

The tabular-bedded Collingham Formation (*c*. 30m; Pc / Pp in part) is characterized by the regular "striped" alternation of thin, tabular-bedded, well-jointed, greyish siliceous mudrocks and soft-weathering pale yellow tuffs (*i.e.* volcanic ash layers) (Viljoen 1992, 1994). These tuffs have been radiometrically dated to 270-275 Ma or Early to Middle Permian (Tankard *et al.* 2009). Basinal mudrocks and tuffs deposited by suspension settling in the lower part of the Collingham succession give way higher up to thicker, tabular-bedded turbidite units deposited by sediment gravity flows.

2.6. Ripon Formation

The Ripon Formation (Pr) crops out along the southeastern margin of the Main Karoo Basin from Prince Albert eastwards. This is a thick, non-marine submarine fan succession comprising tabular-bedded greywackes, rhythmitites and dark mudrocks deposited by turbidity current and suspension settling processes (Johnson 1976, Kingsley 1977, Kingsley 1981, Johnson & Kingsley 1993, Catuneanu *et al.* 2005, Johnson *et al.* 2006). In the Graaff-Reinet sheet area it reaches thicknesses of 500 to 800m. Within the project area the Ripon Formation crops out along the banks of the Little Fish River as well as in road cuttings along the N10 near Ripon Station (Almond 2011). Gullied exposures of dark, thin-bedded to laminated Ripon mudrocks here are interbedded with thin, buff-coloured fine sandstone event beds. Small-scale sedimentary structures include flaser and lenticular lamination as well as ripple cross-lamination. Fine-scale grading within successive tabular beds results in rhythmitites which build higher order coarsening-upwards cycles. Rusty-brown nodules and lenticles of ferruginous carbonate are common. Weathering styles vary from hackly to well-developed pencil cleavage.

2.7. Lower Beaufort Group (Adelaide Subgroup)

As shown on the relevant 1: 250 000 geological maps (Figs. 4 and 5), the Cradock to Cookhouse study area is largely underlain by Middle to Late Permian continental sediments of the Lower Beaufort Group (Adelaide Subgroup, Karoo Supergroup). In particular the Karoo sediments belong to the **Koonap Formation** (**Pk**), the **Middleton Formation** (**Pm**) and the overlying **Balfour Formation** (**Pb**) (Hill 1993, Cole *et al*. 2004, Johnson *et al*., 2006). In the northern part of the study area, to the north of Cookhouse, the Balfour succession is extensively intruded by major, resistant-weathering intrusive sills of the **Karoo Dolerite Suite** (**Jd**) of Early Jurassic age (*c*. 183 Ma), in part accounting for the more mountainous terrain here. Dips of Beaufort Group sediments in the northern and central study region are generally shallow (< 5°), with small-scale E-W fold axes to the south and east of Cookhouse, so low levels of tectonic deformation and cleavage development are expected here. The lowermost Beaufort Group beds (Koonap Formation) in the south lie within the margins of the Cape Fold Belt, so higher dips and levels of deformation are seen here (seen, for example, along the banks of the Great Fish River), compromising fossil preservation.

2.7.1. Koonap Formation

The main characteristics of the Middle to Late Permian Koonap Formation (Pk), the basal subunit of the Lower Beaufort Group in the Eastern Cape study region with a thickness of up to one-and-a-half or two kilometers, have been briefly described by Hill (1993; see also Johnson 1976, Johnson *et al.* 2006 and refs. therein). This continental fluvial succession comprises grey-green and purple-brown overbank mudrocks with subordinate crevasse splay and lenticular channel sandstones. Palaeocurrents were mainly from the southeast. The basal Koonap succession consists largely of dark bluish-grey or grey-green, hackly-weathering mudrocks but purple-brown mudrocks are common at higher levels. Many of the sandstones display a characteristic coarse mottling. Horizons with abundant calcrete nodules (often ferruginous and rusty-brown in colour) represent ancient floodplain soils. Occasional cherty layers represent volcanic ash layers admixed with siliclastic sediment and should prove of considerable interest for radiometric dating studies in future (*cf* Blignault *et al.* 1948, Rubidge *et al.* 2010). According to recent fieldwork in the broader study region south of Middleton (Almond 2011) the Koonap Formation is only well-exposed here along the southern banks of the Great Fish River as well as on the slopes of a few isolated koppies to the south, apart from deep (and dangerous) railway cuttings and occasional road cuts along the N10. Several cliff sections along both banks of the deeply incised Great Fish River are too steep to be safely accessible. Good mudrock exposures with fossil potential are available close to the Sheldon Bridge on Farm 368.

2.7.2. Middleton Formation

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

2.7.3. Balfour Formation

The fluvial Balfour Formation comprises recessive weathering, grey to greenish-grey overbank mudrocks with subordinate resistant-weathering, grey, fine-grained channel sandstones deposited by large meandering river systems in the Late Permian Period (Hill 1993). Thin wave-rippled sandstones were laid down in transient playa lakes on the flood plain. Reddish mudrocks are comparatively rare, but increase in abundance towards the top of the Adelaide Subgroup succession near the upper contact with the Katberg Formation. The base of the Balfour succession is defined by a sandstone-rich zone, some 50m thick, known as the **Oudeberg Member**. The Oudeberg sandstones and interbedded mudrocks crop out along the edge of the low escarpment that lies at the latitude of Cookhouse. Dark grey mudrocks with thin, tabular sandstones and wave ripples (formed in shallow lakes) within the overlying mudrock-dominated **Daggaboersnek Member** are well-exposed at higher elevations in Daggaboersnek itself along the main road between Cookhouse and Cradock (Hill 1993).

2.8. Karoo Dolerite Suite

Igneous intrusions intruding the Lower Beaufort Group north of Cookhouse are referred to the Karoo Dolerite Suite of Early Jurassic age (*c*. 182 Ma; Duncan & Marsh 2006). According to Hill (1993) the southernmost dolerites in the Graaff-Reinet sheet area take the form of “crescentic dykes and transgressive sheets with easterly strikes and dipping towards the north” (See extensive WNW-ESE trending dyke near Middleton in Fig. 4). Normally, extensive areas of Beaufort Group outcrop to either side of the larger dolerite intrusions are mantled in rubbly doleritic colluvium (scree deposits) that is often cemented with calcrete to form a resistant, concrete-like near-surface pan. These dolerite scree-mantled slopes are clearly seen as rusty areas on satellite images.

2.9. Caenozoic superficial deposits

Various types of superficial deposits or “drift” of Late Caenozoic (Miocene / Pliocene to Recent) age occur widely throughout the Great Karoo study region. They include pedocretes (*e.g*. calcretes), slope deposits (scree *etc*), river alluvium, as well as spring and pan sediments (*cf* Partridge *et al*. 2006). As a result, surface exposure of fresh Beaufort Group rocks within the development footprint itself is generally poor, apart from stream beds, dongas and steeper hillslopes and artificial exposures in road and railway cuttings. The hill slopes are typically mantled with a thin layer of **colluvium** or slope deposits (*e.g.* sandstone and dolerite scree). Thicker accumulations of sandy, gravelly and bouldery **alluvium** of Late Caenozoic age (< 5Ma) are found in stream and river beds, for example adjacent to the Great Fish River. These colluvial and alluvial deposits may be extensively calcretised (*i.e.* cemented with soil limestone or calcrete), especially in the neighbourhood of dolerite intrusions.

Thick, silty alluvium of the ancient Fish River drainage system overlies riverside cliffs and banks in the southern part of the study area, even where the river is incised quite deeply into Beaufort Group bedrock (Almond 2010b, 2011). Good exposures of silty alluvium are seen in the neighbourhood of Cookhouse and extensive portions of the area along the Fish River (mainly agricultural lands) are mantled with fertile alluvium (yellow areas on geological maps, Figs. 4 and 5). The Fish River was probably a major drainage conduit in Tertiary times, cutting a wide meandering valley. Subsequent regional uplift and aridification in Late Tertiary (Miocene /Pliocene) times has reduced its flow and caused the river to cut a narrower course down though its older alluvium and into the underlying bedrock, while headwards erosion has driven its tributaries to cut well back into the Great Karoo interior as far as Cradock (De Wit *et al*., 2000).

3. PALAEONTOLOGICAL HERITAGE WITHIN THE STUDY AREA

Fossil biotas recorded from each of the main rock units mapped along the Transnet manganese ore export railway line are briefly reviewed in Table 3 (Based largely on Almond *et al.* 2008 and references therein), where an indication of the palaeontological sensitivity of each rock unit is also given. The quality of fossil preservation may compromised in some areas due to weathering and tectonic deformation, while extensive dolerite intrusion has compromised fossil heritage in portions of the Karoo Supergroup sediments (*e.g.* Lower Beaufort Group) due to resulting thermal metamorphism. The fossil record of the rock units underlying the proposed railway loop developments between Cradock and Kommadagga are reviewed in more detail below.

3.1. Fossils in the Kommadagga Subgroup

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

3.2. Fossils in 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 (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).

3.3. Fossils in the Prince Albert Formation

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 Cape has recently been reviewed by Almond (2008a, b). The fossil biota of the postglacial mudrocks of the Prince Albert Formation has been summarized by Cole (2005). Epichnial (bedding plane) trace fossil assemblages of the non-marine *Mermia* Ichnofacies, dominated by the ichnogenera *Umfolozia* (arthropod trackways) and *Undichna* (fish swimming trails), are commonly found in basinal mudrock facies of the Prince Albert Formation throughout the Ecca Basin. These assemblages have been described by Anderson (1974, 1975, 1976, 1981) and briefly reviewed by Almond (2008a, b). The presence of more diverse, but incompletely recorded, benthic invertebrate fauna in the Early Permian Ecca Sea is suggested by the recent discovery of complex arthropod trails with paired drag marks in the Prince Albert Formation near Matjiesfontein in the southwestern Great Karoo. These trackways might have been generated by small predatory eurypterids (water scorpions), but this requires further confirmation.

Diagenetic nodules containing the remains of palaeoniscoids (primitive bony fish), sharks, spiral bromalites (coprolites, spiral gut infills *etc* attributable to sharks or temnospondyl amphibians) and petrified wood have been found in the Ceres Karoo (Almond 2008b and refs. therein). Rare shark remains (*Dwykaselachus*) are recorded near Prince Albert on the southern margin of the Great Karoo (Oelofsen 1986). Microfossil groups recorded in this formation include sponge spicules, foraminiferal and radiolarian protozoans, acritarchs and miospores.

3.4. Fossils in the Whitehill Formation

In palaeontological terms the Whitehill Formation is one of the richest and most interesting stratigraphic units within the Ecca Group (McLachlan & Anderson 1973, Anderson & McLachlan 1976, Oelofsen 1981, 1987, Visser 1992, 1994, Cole & Basson 1991, Evans & Bender 1999, Evans 2005, Johnson *et al.* 2006, Almond 2008a and refs. therein). Very briefly, the main groups of Early Permian fossils found within the Whitehill Formation include:

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

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

3.5. Fossils in the Collingham Formation

The palaeontology of the Collingham Formation has been reviewed by Viljoen (1992, 1994) and Almond (2008a). Transported, water-logged plant debris and tool marks generated by logs are often associated with thicker turbidite beds, especially within the upper part of the Collingham Formation. Substantial blocks of silicified wood are known from the Laingsburg and Prince Albert areas. The heterolithic character of this succession favours trace fossil preservation, with very high levels of bioturbation recorded locally. The abundance of fossil burrows indicates that oxygenation of bottom waters and the sea bed had improved substantially since Whitehill times. Abundant, moderately diverse trace fossil assemblages have been recorded from the Collingham Formation in the Tanqua Karoo and Laingsburg regions (Anderson 1974) as well as from the Kommadagga regon (Almond 2013). They include horizontal, 2cm-wide epichnial grooves with obscurely segmented levees ("*Scolicia*", possibly generated by gastropods), narrow, bilobate arthropod furrows ("*Isopodichnus*"), reticulate horizontal burrows (perhaps washed out *Megagrapton*-like systems), densely packed horizontal burrows with a rope-like surface texture covering selected bedding planes (*cf Palaeophycus*), narrow branching burrows, rare arthropod trackways (*Umfolozia*) and fish swimming trails (*Undichna*). The trackway of a giant sweep-feeding eurypterid has been identified from the upper Collingham Formation near Laingsburg, and fragmentary body fossils of similar animals are known from coeval sediments in South America (Almond 2002). At over two metres long, these bottom-feeding arthropod predators are the largest animal so far known from the Ecca Sea.

3.6. Fossils in the Ripon Formation

The fossil record within the Ripon Formation is rather sparse and has not received much attention from palaeontologists. Fragmentary, compressed plant remains (*e.g.* stems, leaves) of the *Glossopteris* Flora, mostly unidentified, occur sporadically throughout the Ripon succession, especially within the lowermost part (Johnson 1976). They include flattened silicified logs ("*Dadoxylon*") with well-developed seasonal growth rings (Johnson & Kingsley 1993). Reworked plant debris and a possible large lycopod stem cast were recorded from the region east of Kommadagga by Almond (2013). Fossil plant and wood material from the Ripon Formation was not included in the key reviews by Anderson and Anderson (1985) and Bamford (1999, 2004), however. A range of, mostly unidentified, deep water trace fossils are mentioned in the literature (Anderson 1974, Kingsley 1977, Kingsley 1981, Johnson and Kingsley 1993, Johnson *et al.* 2006). They include sporadic to locally abundant arthropod tracks, trails as well as horizontal and (possible) vertical burrows. *Umfolozia* and *Maculichna* arthropod trackways, probable *Quadrispinichna* resting traces ("small vertebrate footprint"), sinuous *Undichna* fish swimming trails and narrow meandering burrows are recorded from Ripon submarine fan facies in the Grahamstown area (Ecca Pass and Great Fish River; Haughton 1928, Mountain 1946, Anderson 1974, 1976, 1981, Kingsley 1981). It is likely that a wide spectrum of *Mermia* ichnofacies ichnofossils, as well as various organic-walled microfossils, are represented within this formation, similar to those seen in contemporary turbidite fans in the better-sampled southwestern part of the Ecca Basin (Almond 2008a, 2008b).

3.7. Fossils in the Lower Beaufort Group (Adelaide Subgroup)

The overall palaeontological sensitivity of the Lower Beaufort Group sediments is high (Rubidge 1995, Almond *et al*. 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. A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Keyser and Smith (1977-78) and Rubidge (1995), and for the Graaff-Reinet sheet area they are available in Hill (1993). An updated version based on a comprehensive GIS fossil database is currently in press (Van der Walt *et al.* 2010). The fossil record of the Lower Beaufort Group in the Cookhouse – Middleton region has been addressed in recent desktop and field-based palaeontological heritage assessments by Almond (2009, 2010b, 2011).

3.7.1. Fossils in the Koonap Formation

The Koonap Formation is generally considered to be the eastern stratigraphic equivalent of the much better-studied, and far better-exposed, Abrahamskraal Formation of the western outcrop area of the Lower Beaufort Group (Johnson 1976, Johnson *et al.* 2006). While the latter is for the most part characterized by a rich fauna of Middle Permian vertebrates assigned to the *Tapinocephalus* Assemblage Zone (Smith & Keyser 1995), useful vertebrate fossils are notoriously difficult to find in the Koonap beds. Indeed, the last authors even describe the Koonap Formation as "unfossiliferous" (ibid., p. 11). Fossil locality maps compiled by Kitching (1977), Keyser and Smith (1977-1978) as well as more recently by Nicolas (2007) show a virtual absence of recorded fossil sites within the lowermost Beaufort Group beds of the Eastern Cape.

Recent sedimentological and palaeontological studies across the Ecca / Beaufort boundary in the southern Karoo have been published by Rubidge *et al.* (2000) and Modesto *et al.* (2001). The second work refers to several new fossil localities in the south-eastern Karoo near Jansenville and Fort Beaufort, respectively 100 km to the west and 55 km to the ESE of the Middleton area (Fig. 6). The mainly sparse, and often poorly preserved, therapsid biotas recorded by these authors from the Koonap Formation include anteosaurid and tapinocephalid dinocephalians as well as a scylacosaurid therocephalian but, interestingly, no dicynodonts. This suggests a biostratigraphic equivalence with the lower, dinocephalian-dominated part of the *Tapinocephalus* Assemblage Zone. It is concluded that the older *Eodicynodon* Assemblage Zone is not represented this far to the east within the basin.

The results of Modesto *et al.* (2001) suggest that rare tetrapod remains may be preserved in the Koonap Formation beds in the project area. However, no fossil remains were recorded in the recent field assessment of Koonap exposures in the Great Fish River region to the southeast of Middleton by Almond (2011) apart from centimetre-wide vertical burrows preserved at a mudrock / sandstone interface found near Sheldon Bridge. Extensive, deep railway cuttings in the area were not investigated during this study for safety reasons, however, and might yield fossil remains.

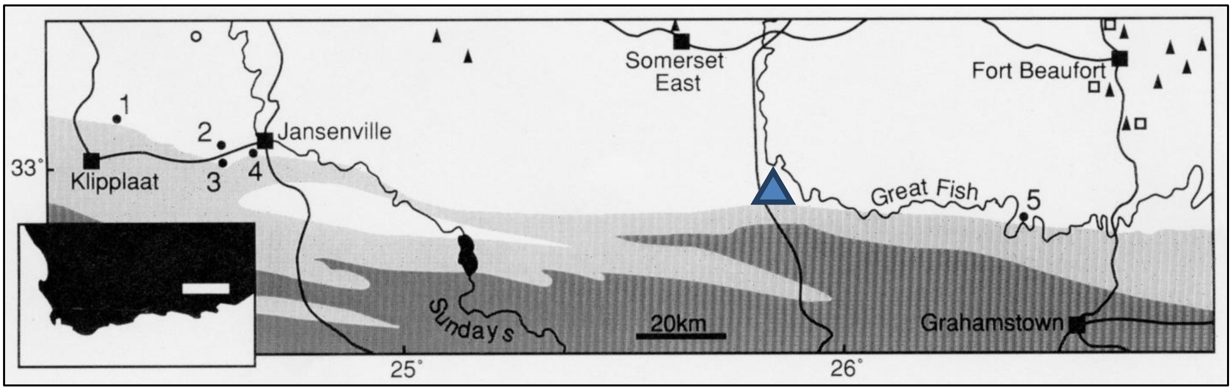

Fig. 6. Vertebrate fossil records from the Ecca / Beaufort contact zone in the Eastern Cape (from Modesto *et al.* 2001). Locality 5 indicated here is situated *c*. 55 km ESE of the Sheldon study area (indicated by the blue triangle).

3.7.2. Fossils in the Middleton Formation

The Middleton Formation comprises portions of three successive Beaufort Group fossil assemblage zones (AZ) that are largely based on the occurrence of specific genera and species of fossil therapsids. These are, in order of decreasing age, the *Pristerognathus*, *Tropidostoma* and *Cistecephalus* Assemblage Zones (Rubidge 1995). The three biozones have been assigned to the

Wuchiapingian Stage of the Late Permian Period, with an approximate age range of 260-254 million years (Rubidge 2005). According to published maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin (Keyser & Smith 1979, Hill 1993, Rubidge 1995), the upper Middleton Formation succession near Cookhouse lies within the ***Cistecephalus* Assemblage Zone** (= upper *Cistecephalus* Biozone or *Aulacephalodon-Cistephalus* Assemblage Zone of earlier authors; see table 2.2 in Hill 1993).

The following major categories of fossils might be expected within *Cistecephalus* AZ sediments in the study area (Keyser & Smith 1979, Anderson & Anderson 1985, Hill 1993, Smith & Keyser *in* Rubidge 1995, MacRae 1999, Cole *et al*., 2004, Almond *et al*. 2008):

- isolated petrified bones as well as rare articulated skeletons of **terrestrial vertebrates** such as true **reptiles** (notably large herbivorous pareiasaurs, small insectivorous owenettids and turtle-like eunotosaurs) and **therapsids** or "mammal-like reptiles" (*e.g.* diverse herbivorous dicynodonts, flesh-eating gorgonopsians, and insectivorous therocephalians) (Fig. 7);

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

- freshwater **bivalves** (*Palaeomutela*);

- **trace fossils** such as worm, arthropod and tetrapod burrows and trackways, coprolites (fossil droppings);

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

As far as the biostratigraphically important tetrapod remains are concerned, the best fossil material is generally found within overbank mudrocks, whereas fossils preserved within channel sandstones tend to be fragmentary and water-worn (Rubidge 1995, Smith 1993b). Many fossils are found in association with ancient soils (palaeosol horizons) that can usually be recognised by bedding-parallel concentrations of calcrete nodules.

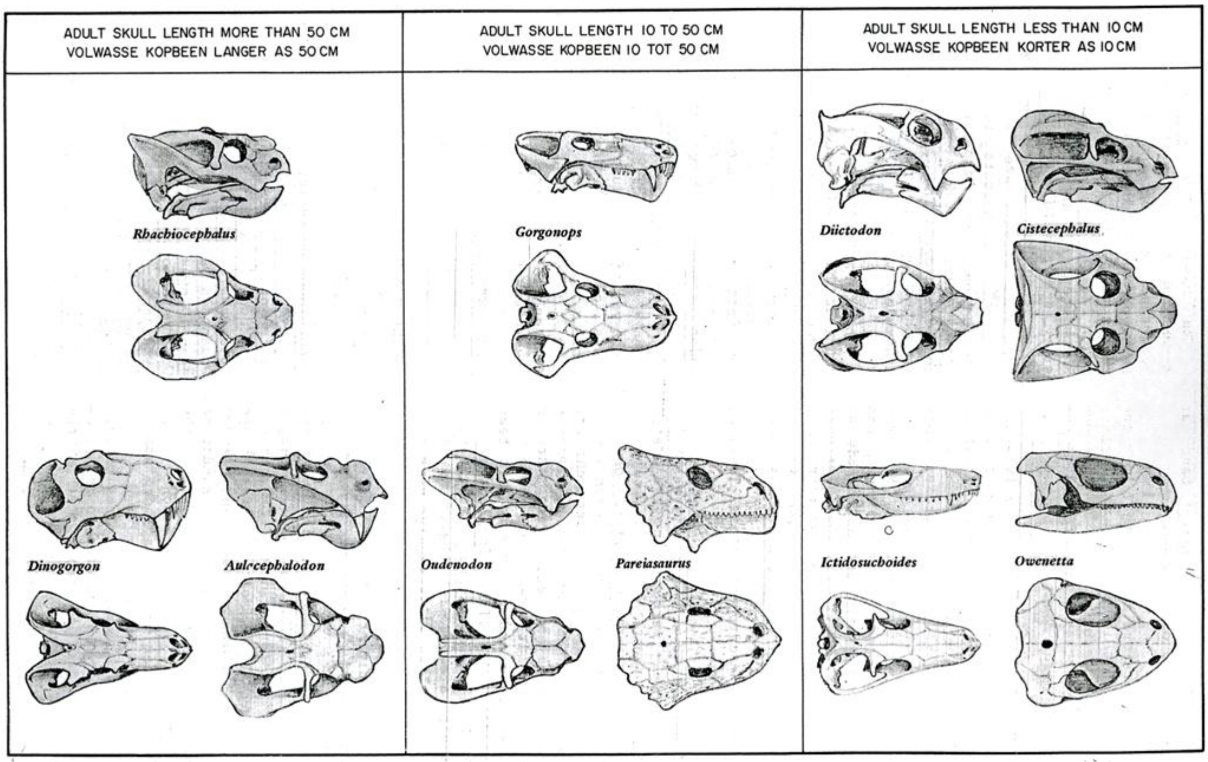

Fig. 7. Skulls of characteristic fossil vertebrates from the *Cistecephalus* Assemblage Zone (From Keyser & Smith 1979). *Pareiasaurus* a large herbivore, and *Owenetta*, a small insectivore, are true reptiles. The remainder are therapsids or "mammal-like reptiles". Of these, *Gorgonops* and *Dinogorgon* are large flesh-eating gorgonopsians, *Ictidosuchoides* is an insectivorous therocephalian, while the remainder are small – to large-bodied herbivorous dicynodonts.

3.7.3. Fossils in the Balfour Formation

The sandstone-dominated Oudeberg Member at the base of the Balfour Formation is also assigned to the *Cistecephalus* Assemblage Zone (Rubidge 1995) whose fossil biota has been treated above. The Assemblage Zone to which the overlying Daggaboersnek Member should be assigned is less clear (Cole *et al*., 2004). Le Roux and Keyser (1988) report *Cistecephalus* AZ fossils from this member in the Victoria West sheet area, whereas the Daggaboersnek Member in the Middelburg sheet area is assigned to the ***Dicynodon* Assemblage Zone** and this certainly applies to the greater part of the Balfour Formation (Rubidge 1995, Cole *et al*., 2004 p. 21). This younger biozone has been assigned to the Changhsingian Stage (= Late Tartarian), right at the end of the Permian Period, with an approximate age range of 253.8-251.4 million years (Rubidge 1995, 2005).

Good accounts, with detailed faunal lists, of the rich Late Permian fossil biotas of the *Dicynodon* Assemblage Zone have been given by Kitching (*in* Rubidge 1995) and by Cole *et al*. (2004). See also the reviews by Cluver (1978), MacRae (1999), McCarthy & Rubidge (2005) and Almond *et al*. (2008).

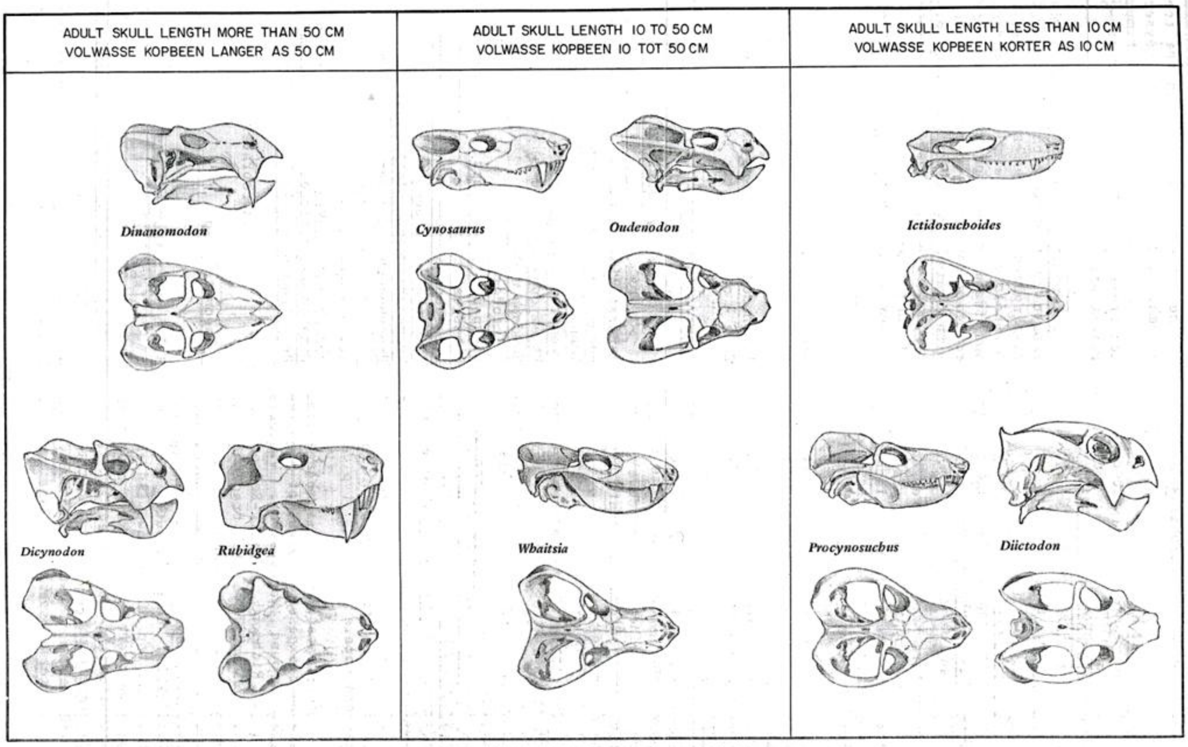

Fig. 8. Skulls of characteristic fossil vertebrates – all therapsids - from the *Dicynodon* Assemblage Zone (From Keyser & Smith 1979). Among the dominant therapsids ("mammal-like reptiles"), *Rubidgea* and *Cynosaurus* are carnivorous gorgonopsians *Whaitsia* (now *Theriognathus*) is a predatory therocephalian while *Ictidosuchoides* is a small insectivorous member of the same group, *Procynosuchus* is a promitive cynodont, and the remainder are large- to small-bodied dicynodont herbivores.

In general, the following broad categories of fossils might be expected within the Balfour Formation in the Cradock - Cookhouse area:

- isolated petrified bones as well as articulated skeletons of terrestrial vertebrates such as true **reptiles** (notably large herbivorous pareiasaurs, small lizard-like millerettids and younginids) and **therapsids** (diverse dicynodonts such as *Dicynodon* and the much smaller *Diictodon*, carnivorous gorgonopsians, therocephalians such as *Theriognathus* (= *Whaitsia*), primitive cynodonts like *Procynosuchus*, and biarmosuchians) (See Fig. 8 herein);

- aquatic vertebrates such as large, crocodile-like temnospondyl **amphibians** like *Rhinesuchus* (usually disarticulated), and palaeoniscoid **bony fish** (*Atherstonia*, *Namaichthys*);

- freshwater **bivalves** (*Palaeomutela*);

- **trace fossils** such as worm, arthropod and tetrapod burrows and trackways, coprolites (fossil droppings);

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

Several key fossil vertebrate sites of the Dicynodon Assemblage Zone are recorded along Great Fish River Valley area between Cradock and Cookhouse (See maps in Kitching 1977, Keyser & Smith 1979). The abundance and variety of fossils within the *Dicynodon* Assemblage Zone decreases towards the top of the succession (Cole *et al*., 2004). From a palaeontological viewpoint, these diverse *Dicynodon* AZ biotas are of extraordinary interest in that they provide some of the best available evidence for the last flowering of ecologically-complex terrestrial ecosystems immediately preceding the catastrophic end-Permian mass extinction (*e.g.* Smith & Ward, 2001, Rubidge 2005, Retallack *et al*., 2006).

Fossil vertebrate remains appear to be surprisingly rare in the Lower Beaufort Group outcrop area near Cookhouse compared to similar-aged deposits further west within the Great Karoo (Almond 2010). The important compendium of Karoo fossil faunas by Kitching (1977) lists numerous finds from the *Cistecephalus* Assemblage Zone near Pearston, some 75 km to the WNW of the study area. A few therapsid genera - the dicynodonts *Emydops* and *Cistecephalus plus* the therocephalian *Ictidosuchoides* – are reported from Bruintjieshoogte, between Pearston and Somerset East, although fossils are recorded as rare even here, despite the excellent level of exposure. Sparse dicynodonts are also mentioned from Bedford, *c*. 30km to the east of Cookhouse. Fossils of the long-ranging, small, communal burrowing dicynodont *Diictodon* are recorded from Slaghtersnek to the south of Cookhouse (precise location not provided, Kitching 1977, p. 66). A limited number of well-preserved dicynodont skulls (probably *Oudenodon, Diictodon*) as well as scattered postcranial therapsid remains, sphenophytes (horsetail ferns), locally abundant silicified wood (some showing insect borings), and low diversity assemblages of horizontal burrows (including *Scoyenia* arthropod scratch burrows) were recorded from the Middleton Formation in the Cookhouse – Middleton area during recent palaeontological field studies by the author (Almond 2010b, 2011). A couple of poorly-preserved therapsid tracks are also recorded from this succession near Middleton (Prof. Bruce Rubidge, pers. comm., and Almond 2011.). The recent discovery of a specimen of the rare, turtle-like parareptile *Eunotosaurus* in the same area supports the assignation of the lower Middleton Formation succession to the *Pristerognathus* Assemblage Zone, correlated with the Poortjie Member of the Teekloof Formation of the western Main Karoo Basin (Mike Day *et al*., in press 2012).

3.8. Fossils in the Karoo Dolerite Suite

The dolerite outcrops in the northern part of the study area are in themselves of no palaeontological significance since these are high temperature igneous rocks emplaced at depth within the Earth's crust. However, as a consequence of their proximity to large dolerite intrusions, the Beaufort Group sediments between Cradock and Cookhouse may well have been thermally metamorphosed or "baked" (*ie*. 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, p. 23 *in* Rubidge 1995). Thermal metamorphism by dolerite intrusions therefore tends to reduce the palaeontological heritage potential of Beaufort Group sediments.

3.9. Fossils in Late Caenozoic superficial deposits

Karoo "drift" deposits, including river alluvium, have been comparatively neglected in palaeontological terms for the most part. However, they may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals (*e.g.* Skead 1980, Klein 1984, MacRae 1999, Partridge & Scott 2000). Other late Caenozoic fossil biotas from these superficial deposits include non-marine molluscs (unionid bivalves, gastropods, rhizoliths), ostrich egg shells, trace fossils (*e.g.* calcretised termitaria, coprolites), and plant remains such as peats or palynomorphs (pollens) in organic-rich alluvial horizons. Angular to subrounded blocks of resilient silicified wood that have been reworked from the Lower Beaufort Group are locally abundant within ferruginous basal gravels and, to a lesser extent, younger alluvial deposits in the Middleton area (Almond 2011). Stone artefacts, an anthropogenic subcategory of trace fossils, occur widely in association with alluvial gravels and High Level Gravels where an abundant supply of suitable raw materials is present.

Table 3. Fossil heritage of rock units cropping out along the Cradock to Kommadagga sector of the Transnet manganese ore export railway line (Eastern Cape)

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
LATE CAENOZOIC TERRESTRIAL DEPOSITS OF THE INTERIOR (Most too small to be indicated on 1: 250 000 geological maps)	Fluvial, pan, lake and terrestrial sediments, including diatomite (diatom deposits), pedocretes, spring tufa / travertine, cave deposits, peats, colluvium, soils, surface gravels including downwasted rubble MOSTLY QUATERNARY TO HOLOCENE	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.	LOW (but locally high) Scattered records, many poorly studied and of uncertain age	Pre-construction field assessment by professional palaeontologist
KAROO DOLERITE SUITE (Jd)	Intrusive dolerites (dykes, sills), associated diatremes EARLY JURASSIC (182-183 Ma)	No fossils recorded	ZERO (also baking of adjacent fossiliferous sediments)	None
Balfour Formation (Pb) ADELAIDE SUBGROUP (LOWER BEAUFORT GROUP)	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	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
Middleton Formation (Pm) ADELAIDE SUBGROUP (LOWER BEAUFORT GROUP)				
Koonap Formation (Pk) ADELAIDE SUBGROUP (LOWER BEAUFORT GROUP)				

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Fort Brown Formation (Pf)	Prodeltaic mudrocks and sandstones, including rhythmites. MIDDLE PERMIAN	Low diversity trace fossil assemblages, transported plant material, rare fish remains & tetrapod bone fragments.	LOW	Pre-construction field assessment by professional palaeontologist
Ripon Formation (Pr) ECCA GROUP	Non-marine / lacustrine sediments (basin plain, turbidite fan, prodelta), minor tuffs (volcanic ashes). MIDDLE PERMIAN	Low diversity trace fossil assemblages, petrified wood & other plant remains	LOW	Pre-construction field assessment by professional palaeontologist
Collingham Formation (Pp in part) ECCA GROUP	Offshore non-marine mudrocks with numerous volcanic ashes, subordinate turbidites EARLY PERMIAN	Low diversiy but locally abundant ichnofaunas (horizontal “worm” burrows, arthropod trackways including giant eurypterids), vascular plant remains (petrified and compressed wood, twigs, leaves *etc*).	MODERATE	Pre-construction field assessment by professional palaeontologist
Whitehill Formation (Pp in part) ECCA GROUP	Carbonaceous offshore non-marine mudrocks within minor volcanic ashes, dolomite nodules EARLY PERMIAN	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 (Pp in part) ECCA GROUP	Marine to hyposaline basin plain mudrocks, minor volcanic ashes, phosphates and ironstones, post-glacial mudrocks at base EARLY PERMIAN	Marine invertebrates (esp. molluscs, brachiopods), coprolites, palaeoniscoid fish & sharks, trace fossils, various microfossils, petrified wood	MODERATE	Pre-construction field assessment by professional palaeontologist

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Elandsvlei Formation (C-Pd) **DWYKA GROUP**	**Predominantly massive to bedded tillites, with interglacial mudrocks at intervals** **LATE CARBONIFEROUS TO EARLY PERMIAN**	**Interglacial mudrocks occasionally with low diversity marine fauna of invertebrates (molluscs, starfish, brachiopods, coprolites *etc*), palaeoniscoid fish, petrified wood, leaves (rare) and palynomorphs of *Glossopteris* Flora. Well-preserved non-marine ichnofauna (traces of fish, arthropods) in laminated mudrocks. Possible stromatolites, oolites at top of succession.** **Occasional limestone erratics with shelly invertebrates (trilobites, archaeocyathid sponges).**	**LOW**	**Pre-construction field assessment by professional palaeontologist**
Kommadagga Subgroup **(Dl, Dd)** **WITTEBERG GROUP**	**Glacial and shallow marine siliciclastics** **EARLY / MID CARBONIFEROUS**	**Sparse vascular plants (leaves, wood), low diversity trace fossils, palynomorphs**	**MEDIUM**	**Pre-construction field assessment by professional palaeontologist**

5. CONCLUSIONS AND RECOMMENDATIONS

The construction phase of the proposed railway loop extensions along the Transnet Cradock to Kommadagga manganese ore railway may entail several substantial excavations into the superficial sediment cover as well as locally into the underlying bedrock. These excavations may disturb, damage or destroy scientifically valuable fossil heritage exposed at the surface or buried below ground. Other infrastructure components (*e.g.* laydown areas) may seal-in buried fossil heritage. However, most of the direct impacts will occur within the existing railway reserve, which is already highly disturbed. The operational and decommissioning phases of the 16 Mtpa railway line are unlikely to involve significant adverse impacts on palaeontological heritage.

The proposed railway loop extensions at Drennan and Thorngrove are underlain by Late Permian sediments of the Balfour Formation (Lower Beaufort Group) that are known for their fossil remains of therapsids (mammal-like reptiles) and other terrestrial vertebrates as well as plants and trace fossils. The Beaufort sediments at both localities may well have been baked by nearby intrusions of the Early Jurassic Karoo Dolerite Suite and are in part mantled with alluvial sediments of the Great Fish River that are of low palaeontological sensitivity.

The extended railway loop between Cookhouse and Golden Valley is largely underlain by alluvium but near-surface rocks of the Late Permian Middleton Formation (Lower Beaufort Group) might be impacted in the northern part of the study area near Cookhouse. Comparatively few, but scientifically important, vertebrate remains (*e.g.* various dicynodonts) have been recorded from the Lower Beaufort rocks in the Cookhouse area during recent palaeontological impact assessments. A wide range of vertebrate remains, invertebrates, trace fossils, plant fossils and microfossils have been recorded from Late Caenozoic alluvial sediments in the Great Karoo region, but in general they are of low palaeontological sensitivity and of considerable lateral extent so impacts on fossil heritage here are likely to be of low significance.

The proposed railway loop at Sheldon, just south of the Great Fish River, is underlain by Middle Permian continental sediments of the Koonap Formation (Lower Beaufort Group). These rocks have yielded scientifically important vertebrates (*e.g.* dinocephalians, therocephalians) to the west and east of the study area but these fossils are generally very sparse and bedrock exposure levels are low. Fossil invertebrate burrows are recorded from Sheldon Bridge. The overlying superficial sediments (fluvial gravels, calcretes, soils) are of low palaeontological sensitivity.

The proposed loop extension between Ripon and Kommadagga traverses a range of Carboniferous to Middle Permian sedimentary rock units including the Kommadagga Subgroup (Witteberg Group), Elandsvlei Formation (Dwyka Group), as well as the Prince Albert, Whitehill, Collingham and Ripon Formations of the Ecca Group. All of these units, especially the Whitehill Formation that is known for its well-preserved fossil fish, insects, crustaceans and aquatic mesosaurid reptiles, are potentially fossiliferous.

It is recommended that a brief palaeontological field assessment of the sedimentary rock units exposed along the Cradock to Kommadagga sector of the Transnet manganese ore export railway be undertaken before construction commences to assess impacts of the proposed loop developments on local fossil heritage and to make recommendations for any further specialist palaeontological studies or mitigation that should take place before or during the construction phase. These recommendations should also be incorporated into the Environmental Management Plan for the proposed railway developments.

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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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