Appendix D2

Paleontological Specialist Study

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 1: Hotazel to Kimberley, Northern Cape

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September 2012

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 fourteen 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 ten railway loop developments along the manganese ore railway line between Hotazel and Kimberley in the Northern Cape.

The construction phase of the proposed new and extended railway loops along the Transnet Hotazel to Kimberley 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, while palaeontologically highly sensitive rock units along the route, such as the lower Ecca Group and the Vaal River Gravels, will not be directly affected by the loop construction programme. The operational and decommissioning phases of the 16 Mtpa railway line are unlikely to involve significant adverse impacts on palaeontological heritage.

The extended loop development at Gong Gong is underlain by unfossiliferous lavas of the Early Precambrian Allanridge Formation (Ventersdorp Group) and no palaeontological impacts are therefore anticipated here.

Four of the proposed loop developments (Glosam, Postmasburg, Tsantsabane and Trewil) are underlain by Early Precambrian (2.6-2.5 billion year old) marine carbonate rocks of the Campbell Rand Subgroup (Ghaap Group, Transvaal Supergroup) that are known for their prolific fossil record of stromatolites, *i.e.* laminated microbial reefs constructed by cyanobacteria, in some cases associated with well-preserved microfossils.

The proposed loop developments at Wincanton, Sishen and Ulco are underlain by Late Caenozoic (probably Plio-Pleistocene) calcretes or pedogenic limestones, at least some of which may be attributed to the Mokalanen Formation of the Kalahari Group. The proposed new loop at Witloop and the Fieldsview loop extension overlie Pleistocene aeolian (wind-blown) sands of the Gordonia Formation, Kalahari Group. While a wide spectrum of vertebrate remains, invertebrates, trace fossils, plant fossils and microfossils have been recorded from these Kalahari Group sediments, 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.

It is recommended that a brief palaeontological field assessment of the sedimentary rock units exposed along the Hotazel to Kimberley 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 fourteen 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.

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 Northern Cape loops listed here between Hotazel and Kimberley.

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
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 fourteen 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 ten of the fourteen additional loops, located between Hotazel and Kimberley in the Northern 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 Precambrian 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) are currently being developed by SAHRA. The latest version of the SAHRA draft guidelines was circulated for comment in November 2011.

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 ten proposed loop study areas within the Northern Cape between Hotazel and Kimberley (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 Asessment 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. 3 to 8). 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 & Pether 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.* SAHRA for the Northern Cape). 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 Northern Cape region as a whole.

1.5. Information sources

The information used in this desktop study was basd 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 Hotazel to Kimberley region by the author (*e.g.* Almond 2010a, 2010b, 2011a, 2011b, 2012a, 2012b, among others).

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).

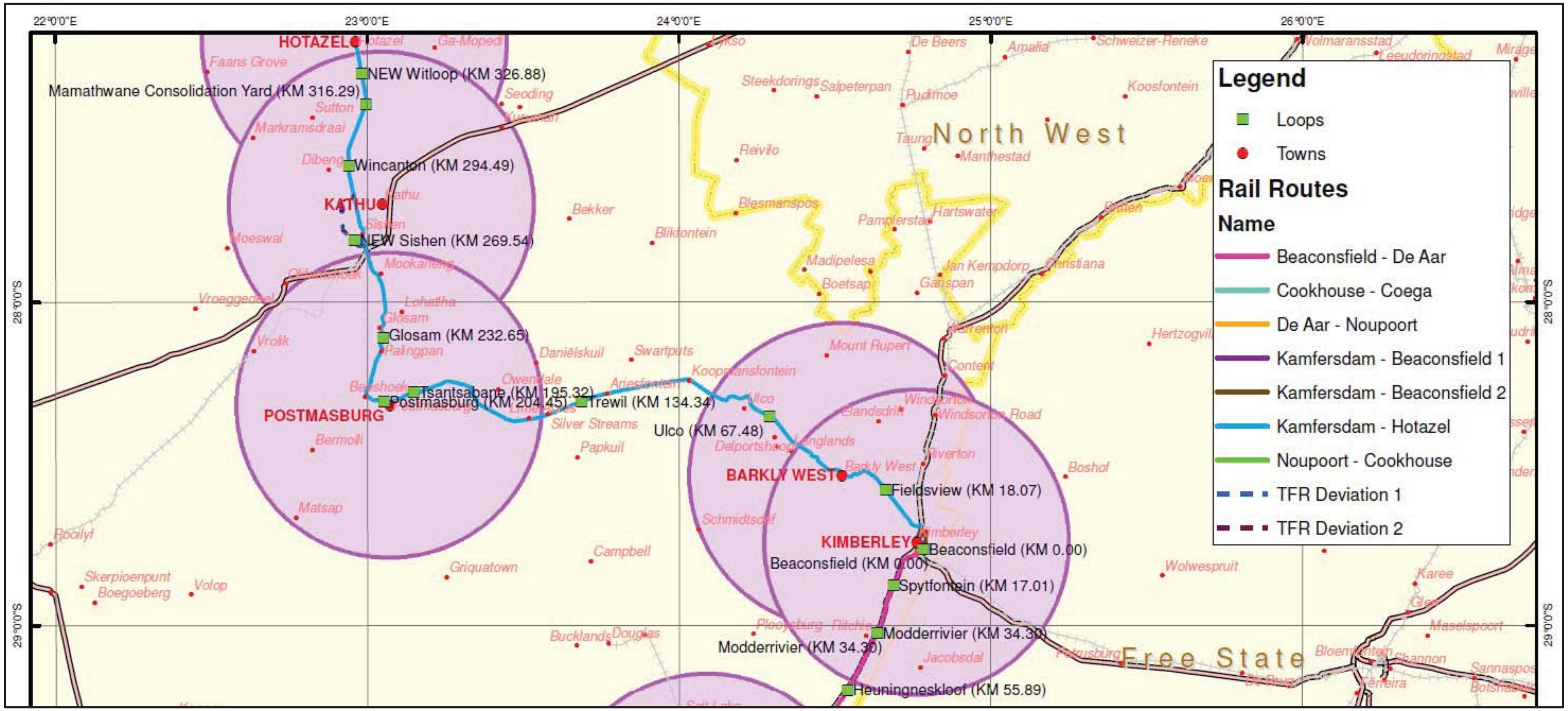

Fig. 1. **Map of the Hotazel to Kimberley sector of the Transnet manganese ore export railway line, Northern Cape, showing the ten railway loops covered by the present desktop Basic Assessment report as well as the location of the Mamathwane Compilation Yard (green squares) (Map modified from image kindly provided by ERM).**

Table 2. Summary of geology and palaeontological sensitivity of the 10 railway loop study sites between Hotazel and Kimberley

LOOP	LOCATION	PROJECT	GEOLOGY	PALAEONTOLOGICAL HERITAGE SENSITIVITY	RECOMMENDATION
1. WITLOOP (km 326.88)	27º 17' 54.4" S 23º 00' 59.05" E	New loop	Gordonia Formation (Kalahari Group)	LOW	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. WINCANTON (km 294.49)	27º 34' 48.1" S 22º 56' 27.02" E	Loop extension	Calcrete	LOW	
3. SISHEN (km 269.54)	27º 48' 31.52" S 22º 57' 26.9" E	Loop extension	Calcrete	LOW	
4. GLOSAM (km 232.65)	28º 06' 40.09" S 23º 02' 58.22" E	Loop extension	Campbell Rand Subgroup dolomites	MEDIUM	
5. POSTMASBURG (km 204.45)	28º 18' 26.63" S 23º 03' 08.92" E	Loop extension	Campbell Rand Subgroup dolomites	MEDIUM	
6. TSANTSABANE (km 195.32)	28º 16' 45.12" S 23º 08' 51.78" E	Loop extension	Campbell Rand Subgroup dolomites	MEDIUM	
7. TREWIL (km 134.34)	28º 18' 25.01" S 23º 41' 10.45" E	Loop extension	Campbell Rand Subgroup dolomites	MEDIUM	
8. ULCO (km 67.48)	28º 21' 15.12" S 24º 17' 20.11" E	Loop extension	Calcrete	LOW	
9. GONG GONG	c. 28º 28' 27.99" S c. 24º 25' 31.61" E	Loop extension	Allanridge Formation (Ventersdorp Group)	ZERO	
10. FIELDSVIEW (km 18.07)	28º 34' 48.76" S 24º 39' 40.98" E	Loop extension	Gordonia Formation (Kalahari Group)	LOW	

2. GEOLOGICAL OUTLINE OF THE STUDY AREA

The existing Transnet manganese ore export railway line between Hotazel and Kimberley, Northern Cape, crosses several different physiographic regions of the RSA (Visser *et al.* 1989, their Fig. 2.1.). The initial stretch between Hotazel southwards to Dingleton traverses flat-lying, sandy semi-desert terrain at *c*. 1100-1200 m amsl of the southern Kalahari Region lying between the Korannaberg in the west and the Kurumanheuwels in the East. This region is drained by the Ga-Mogara River (a southern tributary of the Kuruman River) and its tributaries, and bedrock exposure is extremely limited. Between Dingleton, Postmasburg and east to Lime Acres the line runs through the slightly higher-lying (1300-1400m amsl), more rocky terrain of the Griqua Fold Belt Region on the western side of the Ghaap Plateau. This region is characterised by north-south trending rocky ridges and megafolds of Precambrian bedrocks, including the Maremane Anticline in the west and the Asbesberge to the east. From Lime Acres (south of Daniëlskuil) east to Ulco the railway crosses the southern part of the extensive, flat-lying Ghaap Plateau Region (*c*. 1200-1400m amsl) that is underlain by great thicknesses of Precambrian carbonate sediments (limestones, dolomites). The railway line then descends from the eastern edge of the Ghaap Plateau into the western portion of the Upper Karoo Region drained by the Harts and Vaal Rivers. This lower-lying region (*c*. 1100-1200m amsl) includes the sector all the way to Barclay West and Kimberley, situated between the Vaal and Orange Rivers.

The geology of the study area between Hotazel and Kimberley is covered by three adjacent 1: 250 000 scale geological maps, 2722 Kuruman (brief sheet explanation printed on map), 2822 Postmasburg (brief sheet explanation printed on map) and 2824 Kimberley (sheet explanation by Bosch 1993). Relevant extracts from these sheets are provided in Figs. 3 to 8 below. A more regional geological map at 1: 1 000 000 scale is also available (sheet explanation by Visser 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).

All major rock units mapped along the railway line between Hotazel and Kimberley 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 & Pether 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 Late Archaean (2.7 Ga = billion years old) to Recent. The igneous rocks (*e.g.* lavas, dolerite intrusions) are entirely unfossiliferous and a high proportion of the sedimentary rocks are of low palaeontological sensitivity. The main exceptions are fossiliferous marine shelf carbonates of the Ghaap Group (Vryburg Formation, Campbell Rand Subgroup), interglacial to post-glacial sediments of the Dwyka and Ecca Groups (Karoo Supergroup) and Late Tertiary (Neogene) to Pleistocene alluvial gravels along the Vaal River.

For the purposes of the present Basic Assessment of the proposed new railway loops and loop extensions only those rock units that are mapped within the development footprint (as shown on 1: 250 000 geological maps, Figs. 3 to 8) will be considered further here. As seen in Table 2, the Gong Gong study area is underlain by Late Archaean lavas of the **Allanridge Formation** (**Ventersdorp Subgroup**), the Glosam, Postmasburg, Tsantsabane and Trewil sites by Late Archaean shelf carbonates of the **Campbell Rand Subgroup** (**Transvaal Supergroup**), the Wincanton, Sishen and Ulco sites by Late Caenozoic (probably Plio-Pleistocene) **calcretes** or pedogenic limestones, while the Witloop and Fieldsview sites overlie Pleistocene to Recent aeolian sands of the **Gordonia Formation** (**Kalahari Group**). 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.

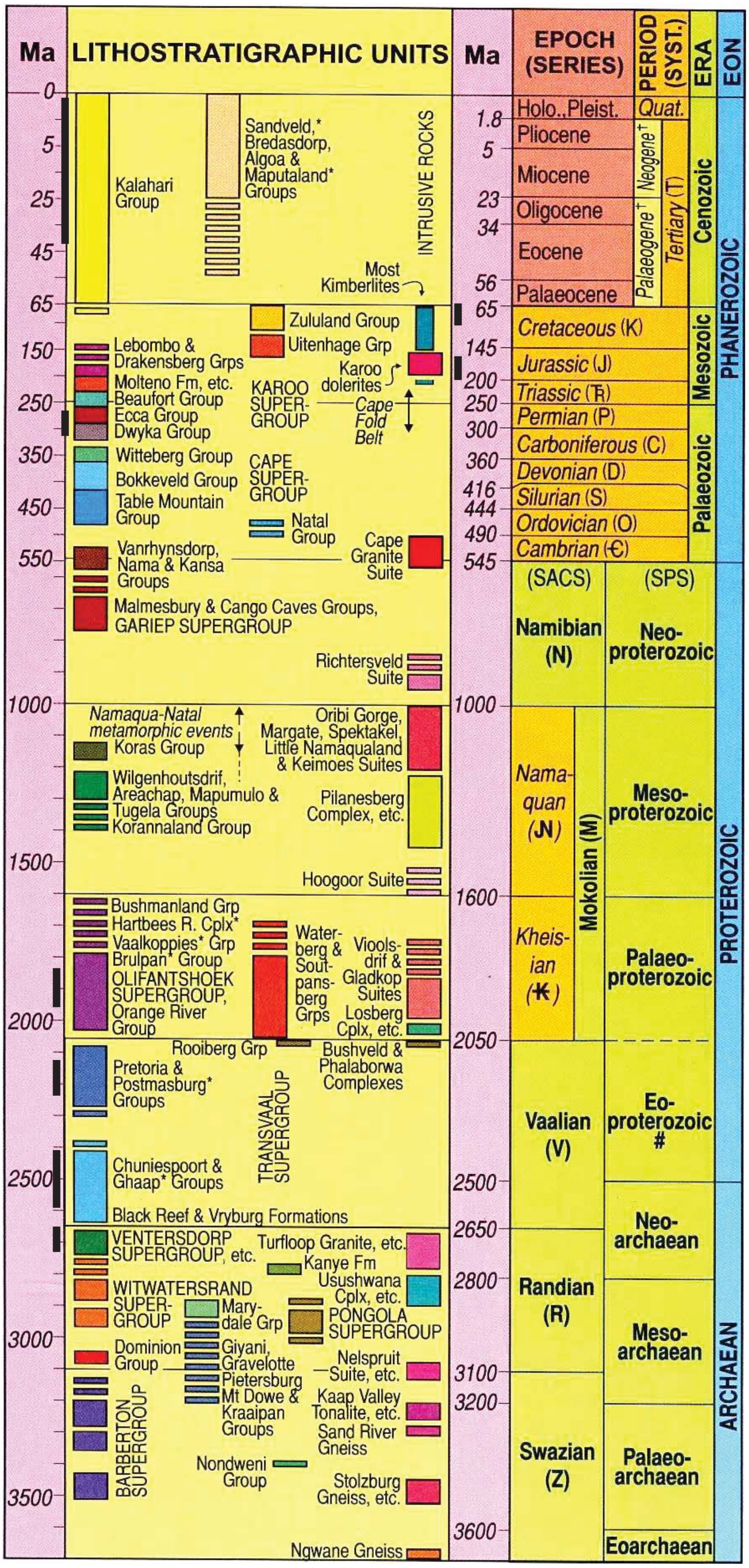

Fig. 2. Stratigraphic column for southern Africa showing the main rock units represented along the manganese ore export line railway between Hotazel and Kimberley, Northern Cape (thick vertical black lines) (See also Table 3).

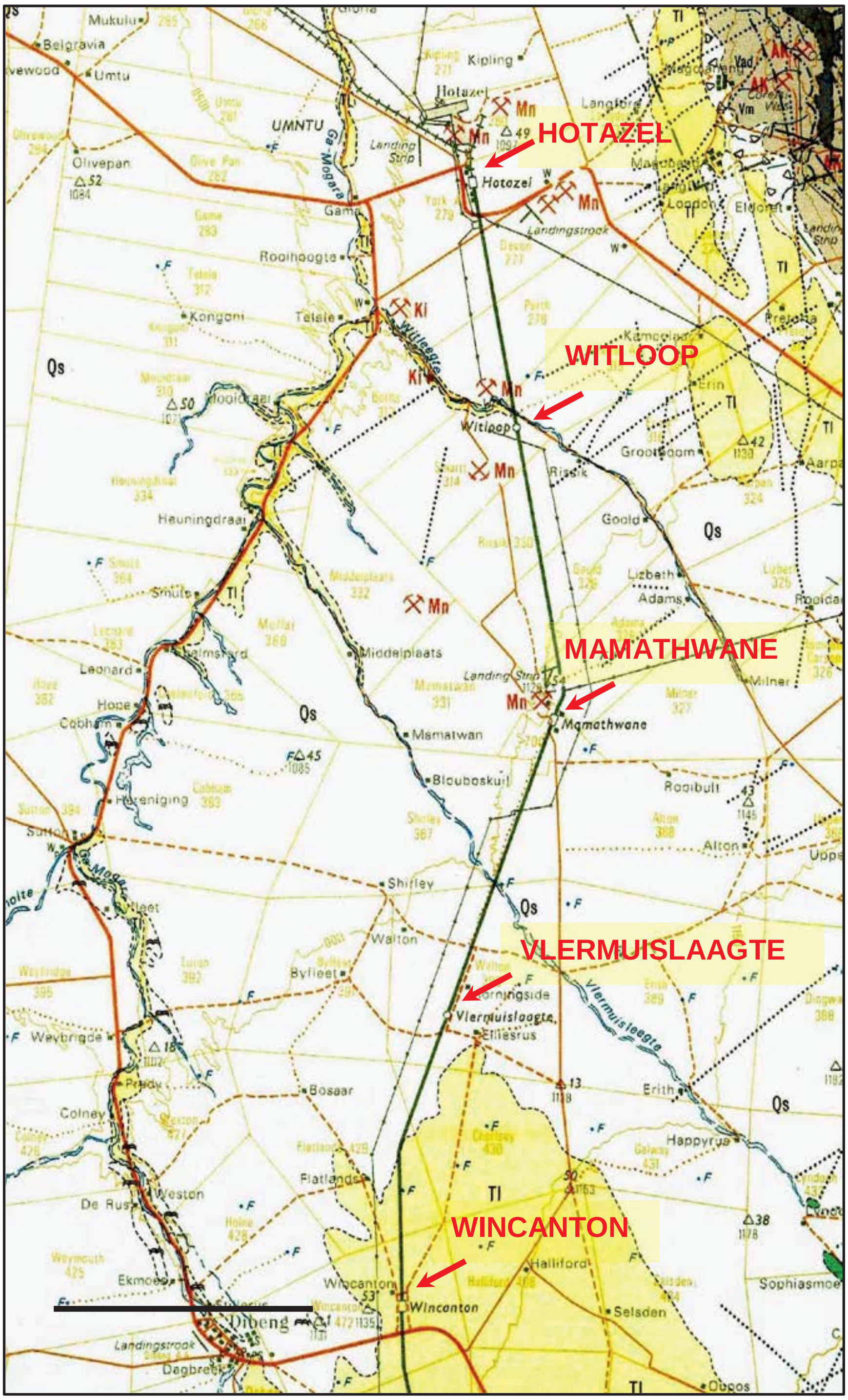

Fig. 3. Extract from 1: 250 000 geology map 2722 Kuruman (Council for Geoscience, Pretoria) showing location of the proposed new rail loop at Witloop (underlain by aeolian sands of the Gordonia Formation, Qs) and the loop extension at Wincanton (underlain by surface calcrete, Tl). Note also the position of the proposed new compilation yard at Mamathwane and Vlermuislaagte Substation that is due to be upgraded. Both these additional sites are also underlain by Gordinia Formation aeolian sands. See Table 3 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

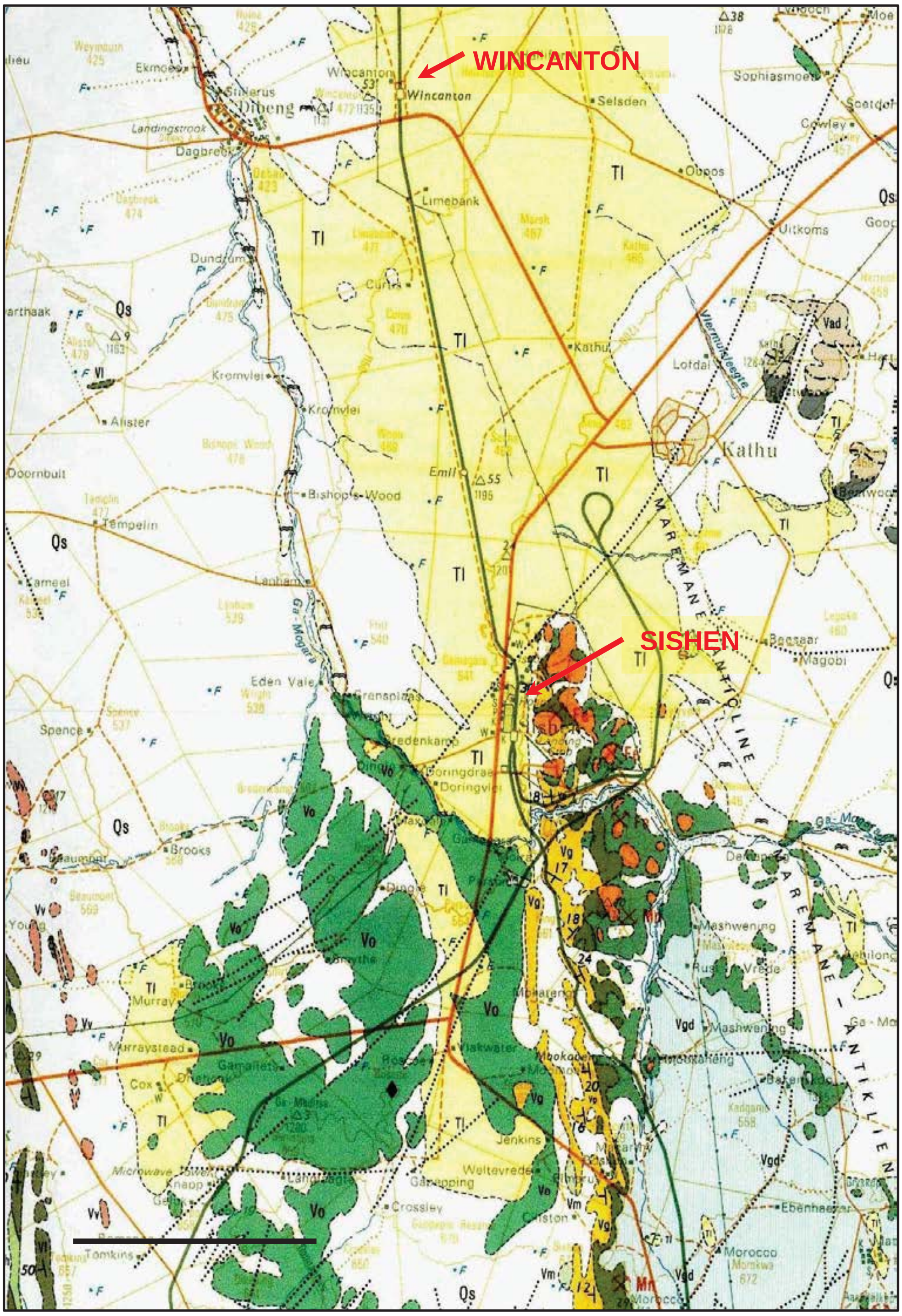

Fig. 4. Extract from 1: 250 000 geology map 2722 Kuruman (Council for Geoscience, Pretoria) showing location of the proposed new loop extensions at Wincanton and Sishen (both underlain by surface calcrete, Tl). See Table 3 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c.* 10 km.

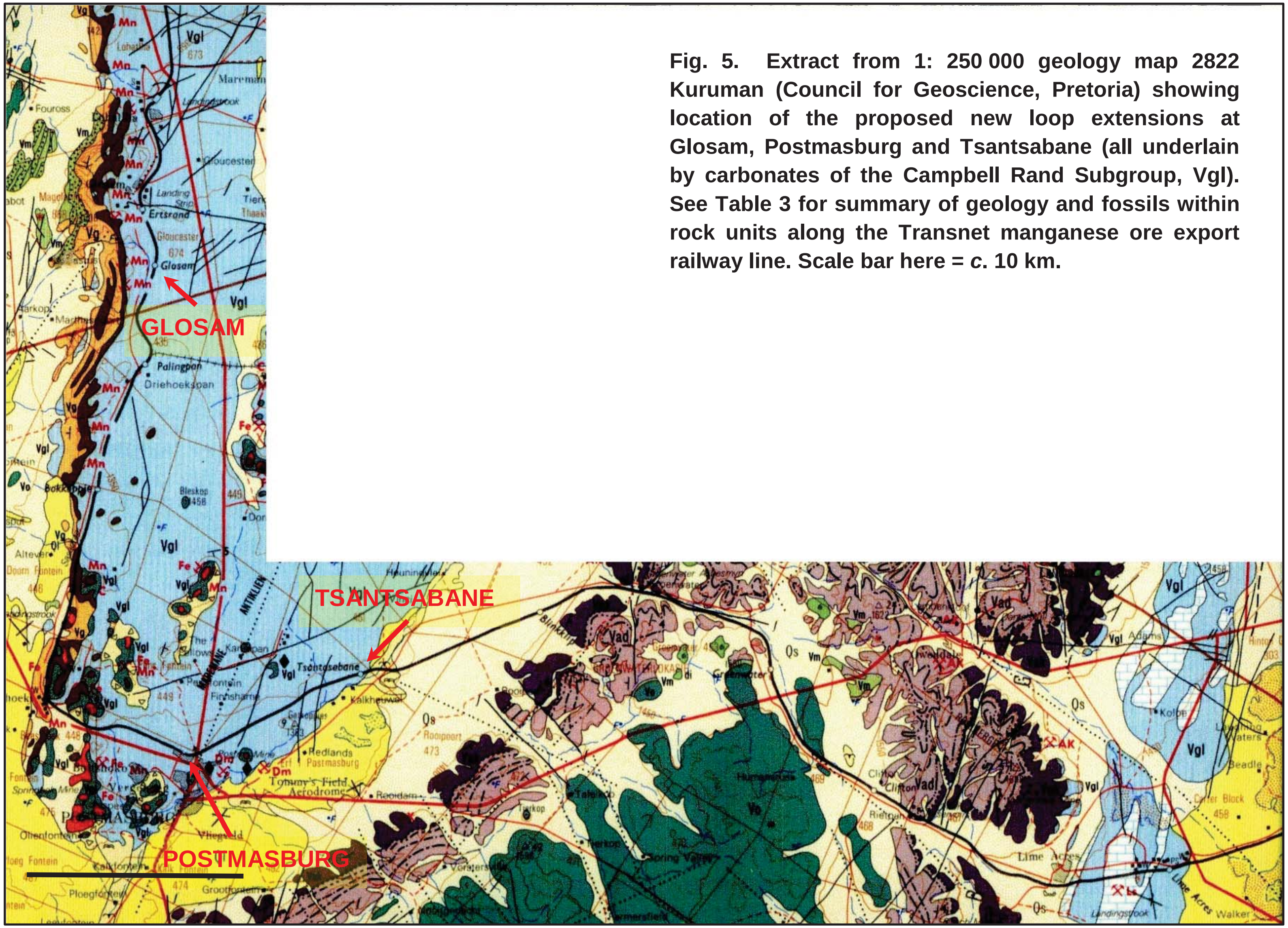

Fig. 5. Extract from 1: 250 000 geology map 2822 Kuruman (Council for Geoscience, Pretoria) showing location of the proposed new loop extensions at Glosam, Postmasburg and Tsantsabane (all underlain by carbonates of the Campbell Rand Subgroup, Vgl). See Table 3 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

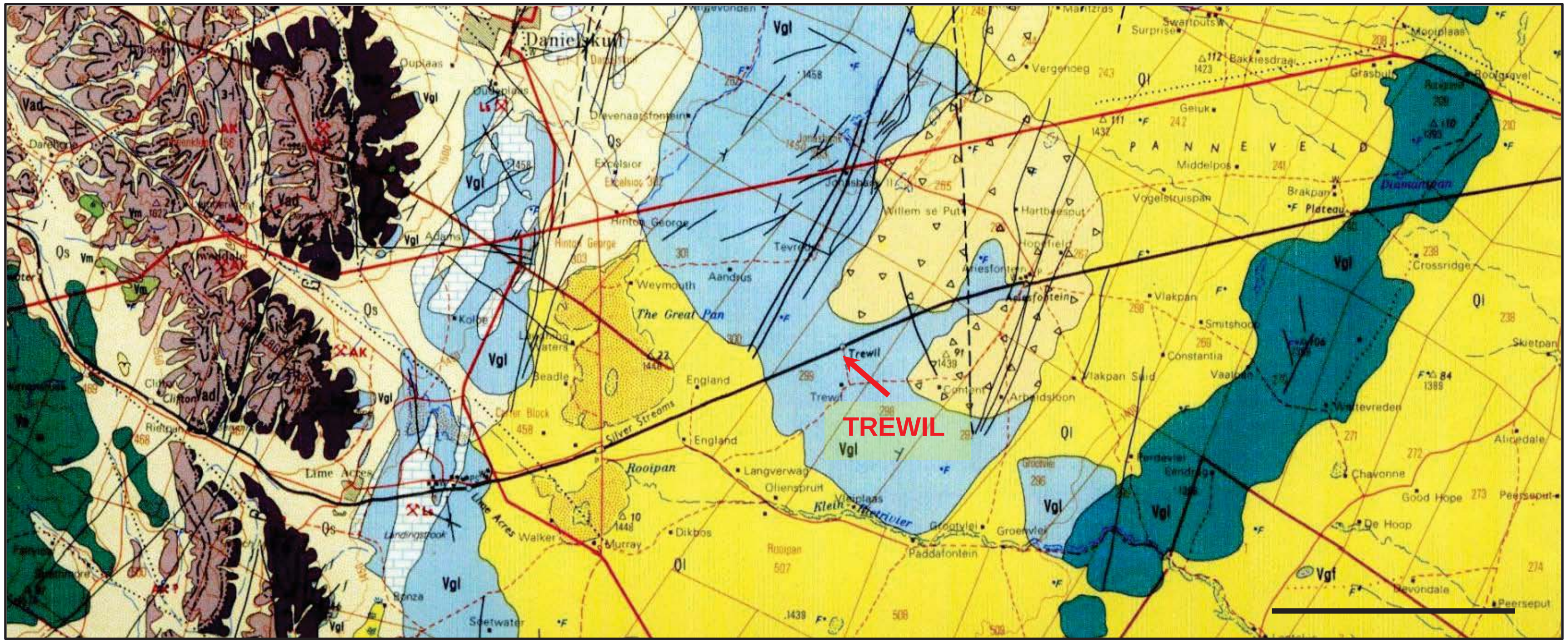

Fig. 6. Extract from 1: 250 000 geology map 2822 Kuruman (Council for Geoscience, Pretoria) showing location of the proposed new loop extension at Trewil (underlain by carbonates of the Campbell Rand Subgroup, Vgl). See Table 3 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

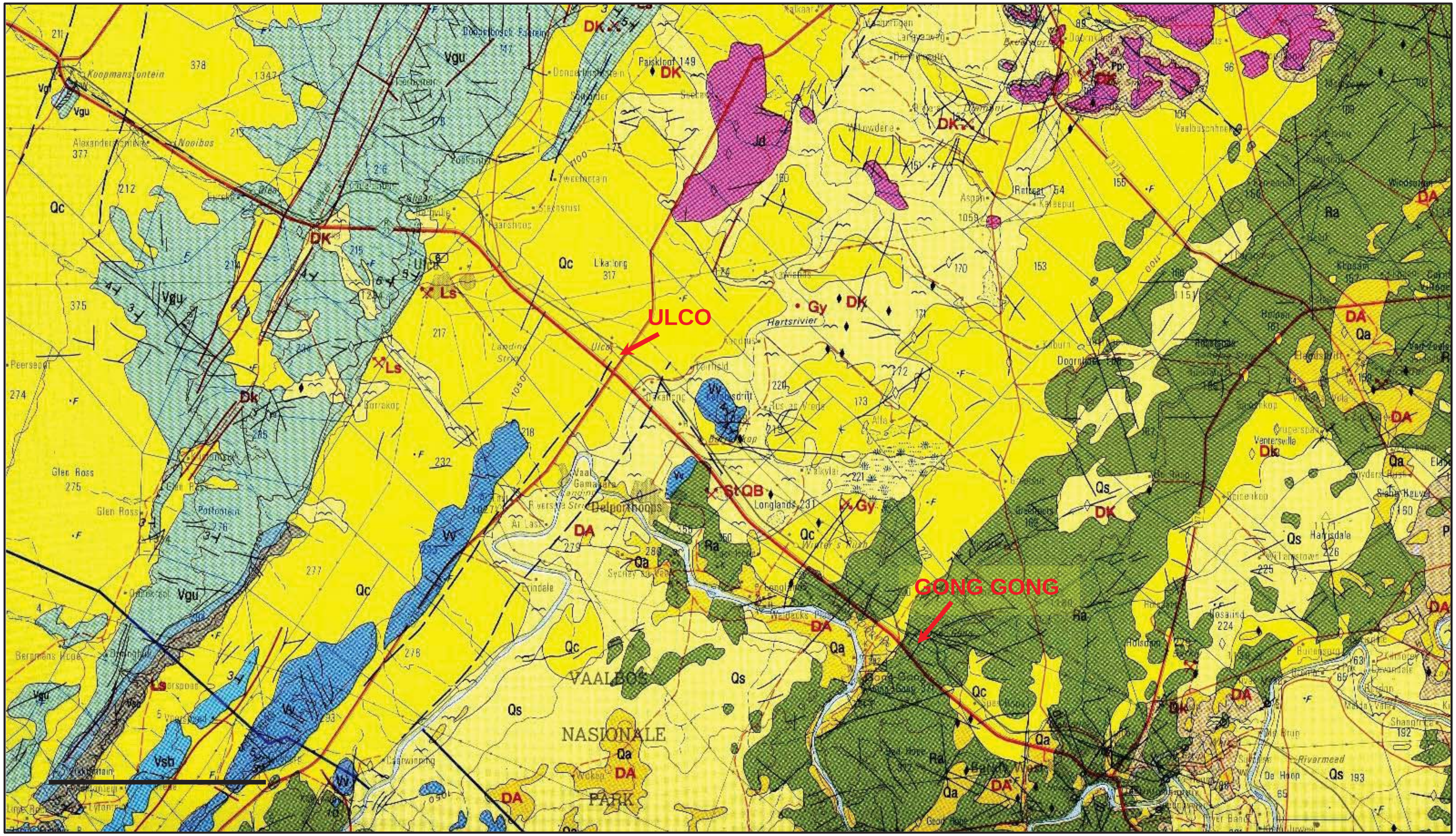

Fig. 7. **Extract from 1: 250 000 geology map 2824 Kimberley (Council for Geoscience, Pretoria) showing location of the proposed new loop extensions at Ulco (underlain by surface calcrete, Qc) and Gong Gong (underlain by Allanridge Formation lavas, Ra). See Table 3 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.**

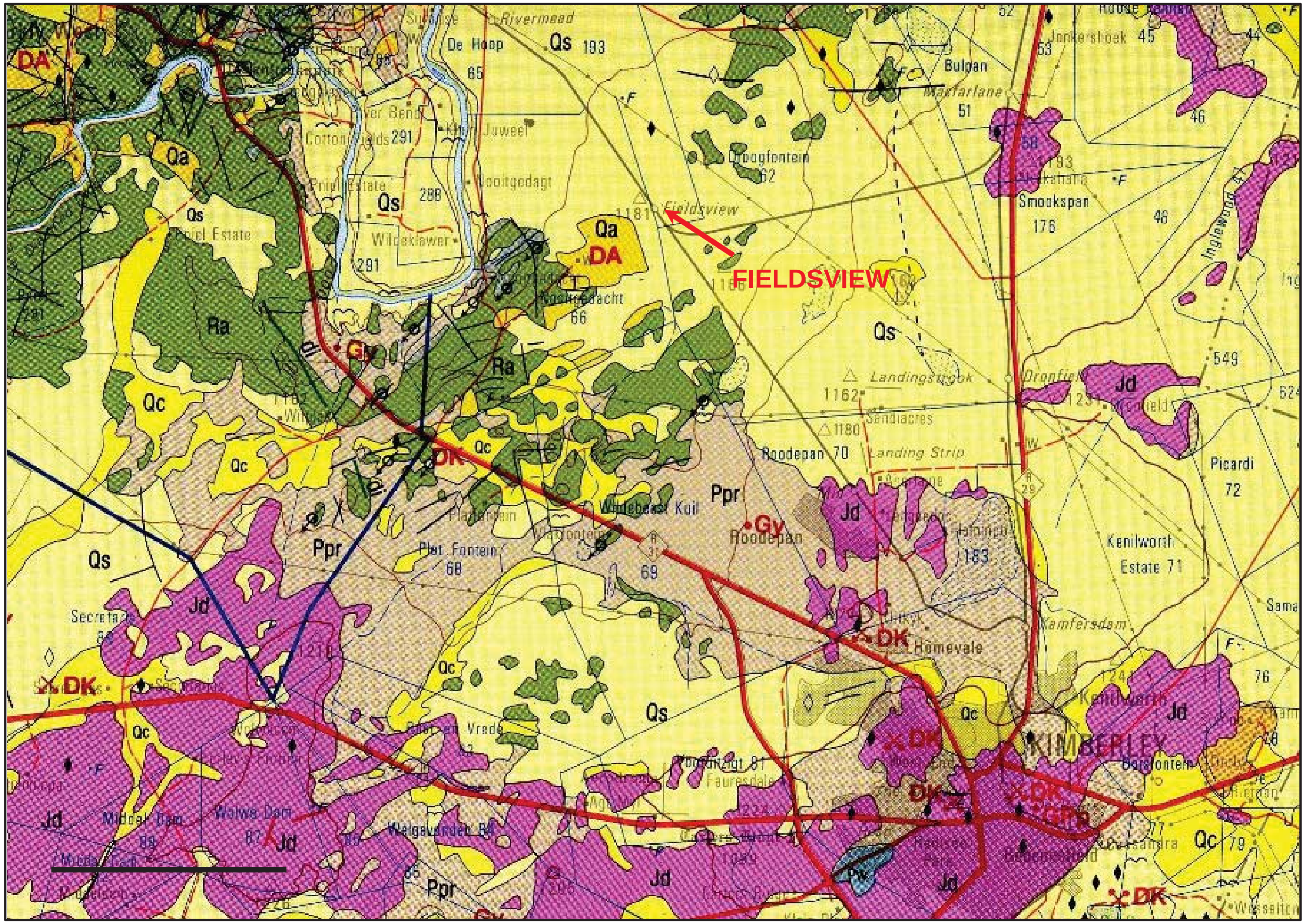

Fig. 8. Extract from 1: 250 000 geology map 2824 Kimberley (Council for Geoscience, Pretoria) showing location of the proposed new loop extension at Fieldsview (underlain by Gordonia Formation aeolian sands, Qs). See Table 3 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

2.1. Allanridge Formation (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, such as the porphyritic felsites and pyroclastic flows of the Makwassie Formation near Kimberley (Bosch 1993, Van der Westhuizen *et al.* 2006). These igneous rocks are associated with rift-related sediments, including colluvial, alluvial fan and lacustrine deposits, and 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 14m 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 broad NE-SW trending outcrop area of resistant-weathering Allanridge Formation lavas is mapped to the northwest of Kimberley, including the Gong Gong loop extension study area (Fig. 7). A rusty-brown to metallic (desert varnish) surface weathering patina has developed on many surface boulders; 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. Campbell Rand Subgroup (Ghaap Group, Transvaal Supergroup)

According to the 1: 250 000 geology maps (Figs. 5 to 7) the majority of the manganese ore railway line between Sishen to just east of Ulco is underlain by Early Precambrian (Late Archaean to Early Proterozoic) marine sediments of the **Transvaal Supergroup**, and in particular by the **Ghaap Group** of the Griqualand West Basin, Ghaap Plateau Subbasin. Useful reviews of the stratigraphy and sedimentology of these Transvaal Supergroup rocks have been given by Moore *et al.* (2001), Eriksson and Altermann (1998) as well as Eriksson *et al.* (1993, 1995, 2006). The Ghaap Group represents some 200 Ma of chemical sedimentation - notably iron and manganese ores, cherts and carbonates - within the Griqualand West Basin that was situated towards the western edge of the Kaapvaal Craton (See also fig. 4.19 in McCarthy & Rubidge 2005).

The **Campbell Rand Subgroup** (previously included within the Ghaapplato Formation) of the Ghaap Group is a very thick (1.6-2.5 km) carbonate platform succession of dolomites, dolomitic limestones and cherts with minor tuffs that was deposited on the shallow submerged shelf of the Kaapvaal Craton roughly 2.6 to 2.5 Ga (billion years ago; see the readable general account by McCarthy & Rubidge, pp. 112-118 and Fig. 4.10 therein). A range of shallow water facies, often forming depositional cycles reflecting sea level changes, are represented here, including stromatolitic limestones and dolomites, oolites, oncolites, laminated calcilutites, cherts and marls, with subordinate siliclastics (shales, siltstones) and minor tuffs (Eriksson *et al.* 2006). Due to their solubility and low resistence to weathering, exposure levels of these rocks are often very low. The outcrop area of chert-rich subunits is often largely covered in downwasted, siliceous rock rubble (*e.g.* Postmasburg sheet area).

Carbonates of the “Ghaapplato Formation” underlie the loop study areas at Glosam, Postmasburg, Tsantsabane and Trewil (Figs. 5 & 6). Note that since the 1: 250 000 geological maps were produced, the Campbell Rand succession has been subdivided into a series of formations, some of which were previously included within the older Schmidtsdrift Formation or Subgroup (Beukes 1980, 1986, Eriksson *et al.* 2006). It is unclear exactly which of these newer carbonate-dominated units are represented in the Transnet railway study areas. However, this level of stratigraphic resolution is not critical for the current baseline report.

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

Large sections of the Transnet manganese ore export railway line study area are mantled by a range 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, surface gravels of various origins, as well as spring and pan sediments. The colluvial and alluvial deposits may be extensively calcretised (*i.e.* cemented with pedogenic limestone), especially in the neighbourhood of dolerite intrusions.

Mappable exposures of **calcrete** or **surface limestone** (**Ql / Qc**) occur in the southern Kalahari Region (Wincanton and Sishen loop study areas), also to the east of Postmasburg, as well as covering large portions of the Ghaap Group carbonates of the Ghaap Plateau (Ulco loop study area). 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) and Bosch (1993). The surface limestones may reach thicknesses of over 20m, 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 carbonate rocks. 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). Thick deposits of calc-tufa ("*kranskalk*") occur along the margins of the Ghaap Plateau, as at Ulco, where lime-rich groundwaters reach the ground surface (Bosch 1993).

Large areas of unconsolidated, reddish-brown to grey aeolian (*i.e.* wind-blown) sands of the Quaternary **Gordonia Formation** (**Kalahari Group**; **Qs** in Figs. 3 to 8) are mapped in the Transnet manganese ore railway study region, including the Witloop and Fieldsview loop study 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.

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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 & Pether 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 intense tectonic deformation, while extensive dolerite intrusion has compromised fossil heritage in portions of the Karoo Supergroup sediments (*e.g.* Ecca Group) due to resulting thermal metamorphism. In addition, pervasive calcretisation and chemical weathering of many near-surface bedrocks in the Northern Cape has further compromised their original fossil heritage in many areas (*e.g.* Ecca Group outcrop). The fossil record of the rock units underlying the proposed railway loop developments between Hotazel and Kimberly are reviewed in more detail below.

3.3. Fossils within the Ventersdorp Supergroup

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 (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 Campbell Rand Subgroup

The shallow shelf and intertidal sediments of the carbonate-dominated lower part of the **Ghaap Group** (*i.e.* **Schmidtsdrif** and **Campbell Rand Subgroups**) are well known for their rich fossil biota of *stromatolites* or microbially-generated, finely-laminated sheets, mounds and branching structures. Some stromatolite occurrences on the Ghaap Plateau of the Northern Cape are spectacularly well-preserved (*e.g.* Boetsap locality northeast of Daniëlskuil figured by McCarthy & Rubidge 2005, Eriksson *et al.* 2006). Detailed studies of these 2.6-2.5 Ga carbonate sediments and their stromatolitic biotas have been presented by Young (1932), Beukes (1980, 1983), Eriksson & Truswell (1974), Eriksson & Altermann (1998), Eriksson *et al* (2006), Altermann and Herbig (1991), and Altermann and Wotherspoon (1995). Some of the oldest known (2.6 Ga) fossil microbial assemblages with filaments and coccoids have been recorded from stromatolitic cherty limestones of the Lime Acres Member, Kogelbeen Formation at Lime Acres (Altermann & Schopf 1995). The oldest, Archaean stromatolite occurrences from the Ghaap Group have been reviewed by Schopf (2006, with full references therein). The Tsineng Formation at the top of the Campbell Rand carbonate succession has yielded both stromatolites (previously assigned to the Tsineng Member of the Gamohaan Formation) as well as filamentous microfossils named *Siphonophycus* (Klein *et al.*1987, Altermann & Schopf 1995).

3.3. Fossils within the Kalahari Group

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 2008, 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.

Table 3. Fossil heritage of rock units cropping out along the Hotazel to Kimberley sector of the Transnet manganese ore export railway line

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
OTHER 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 (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 Scattered records, many poorly studied and of uncertain age	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) Miocene to Pleistocene	ancient alluvial gravels, locally diamondiferous and calcretised	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**
Prince Albert Formation **(Ppr; 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**
Gamagara Formation (Vga / Vg) **OLIFANTSHOEK SUPERGROUP**	**continental red beds (shales, sandstones, conglomerates), lateritic palaeosols** **EARLY PROTEROZOIC** **(1.9 Ga or older)**	**lateritic palaeosols reflect terrestrial biomass**	**LOW**	**none recommended**
Ongeluk Formation (Vo) **Makganyene Formation (Vm)** **POSTMASBURG GROUP**	**lavas** **glacial diamictites *plus* carbonates** **EARLY PROTEROZOIC** **(2.2-2.3 Ga)**	**none** **stromatolitic domes within carbonate facies**	**LOW TO MODERATE**	**recording & sampling of any newly exposed stromatolites by palaeontologist**
Daniëlskuil Formation (Vad) **Kuruman Formation (Vak)** **Asbestos Hills Subgroup (Va)** **GHAAP GROUP**	**BIF (banded iron formations) with cherty bands** **EARLY PROTEROZOIC** **(*c.* 2.5-2.4 Ga)**	**important early microfossil biotas**	**LOW**	**none recommended**

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Campbell Rand Subgroup (Vca / Vgl, Vgu, Vgd *etc*) GHAAP GROUP	shallow marine to intertidal limestones / dolomites, siliceous breccias ("Manganese Marker") LATE ARCHAEAN (*c*. 2.6-2.5 Ga)	rich stromatolite assemblages (stratiform, domical, columnar), important early microfossil biotas	MODERATE TO HIGH	recording & sampling of any newly exposed stromatolites in development footprint
Vryburg Formation (Vv) GHAAP GROUP	lavas, siliciclastics, carbonates LATE ARCHAEAN 2.64 Ga	stromatolites in carbonates	MODERATE	recording & sampling of any newly exposed stromatolites in development footprint
Allanridge Formation (Ra / Ral) VENTERSDORP SUPERGROUP	lavas and volcaniclastic sediments LATE ARCHAEAN 2.7 Ga	no fossils recorded	LOW	none recommended any substantial fossil finds to be reported by ECO to SAHRA

5. CONCLUSIONS AND RECOMMENDATIONS

The construction phase of the proposed new and extended railway loops along the Transnet Hotazel to Kimberley 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, while palaeontologically highly sensitive rock units along the route, such as the lower Ecca Group and the Vaal River Gravels, will not be directly affected by the loop construction programme. The operational and decommissioning phases of the 16 Mtpa railway line are unlikely to involve significant adverse impacts on palaeontological heritage.

The extended loop development at Gong Gong is underlain by unfossiliferous lavas of the Early Precambrian Allanridge Formation (Ventersdorp Group) and no palaeontological impacts are therefore anticipated here.

Four of the proposed loop developments (Glosam, Postmasburg, Tsantsabane and Trewil) are underlain by Early Precambrian (2.6-2.5 billion year old) marine carbonate rocks of the Campbell Rand Subgroup (Ghaap Group, Transvaal Supergroup) that are known for their prolific fossil record of stromatolites, *i.e.* laminated microbial reefs constructed by cyanobacteria, in some cases associated with well-preserved microfossils.

The proposed loop developments at Wincanton, Sishen and Ulco are underlain by Late Caenozoic (probably Plio-Pleistocene) calcretes or pedogenic limestones, at least some of which may be attributed to the Mokalanen Formation of the Kalahari Group. The proposed new loop at Witloop and the Fieldsview loop extension overlie Pleistocene aeolian (wind-blown) sands of the Gordonia Formation, Kalahari Group. While a wide spectrum of vertebrate remains, invertebrates, trace fossils, plant fossils and microfossils have been recorded from these Kalahari Group sediments, 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.

It is recommended that a brief palaeontological field assessment of the sedimentary rock units exposed along the Hotazel to Kimberley 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.

6. ACKNOWLEDGEMENTS

Mr Junaid Moosajee of ERM, Cape Town, is thanked for commissioning this study and providing the relevant background information. I am also grateful to Ms Elize Becker, Environmental Services Group, HATCH, Johannesburg for extensive discussions concerning heritage related issues relating to the Transnet 16 Mtpa project.

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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.

John E. Almond

Dr John E. Almond
Palaeontologist, *Natura Viva* cc

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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September 2012

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 fourteen 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 four 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 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 mesosaurud 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 fourteen 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 four 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 Eastern Cape loops 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
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 fourteen 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 four of the fourteen 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) are currently being developed by SAHRA. The latest version of the SAHRA draft guidelines was circulated for comment in November 2011.

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 four 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). 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).

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).

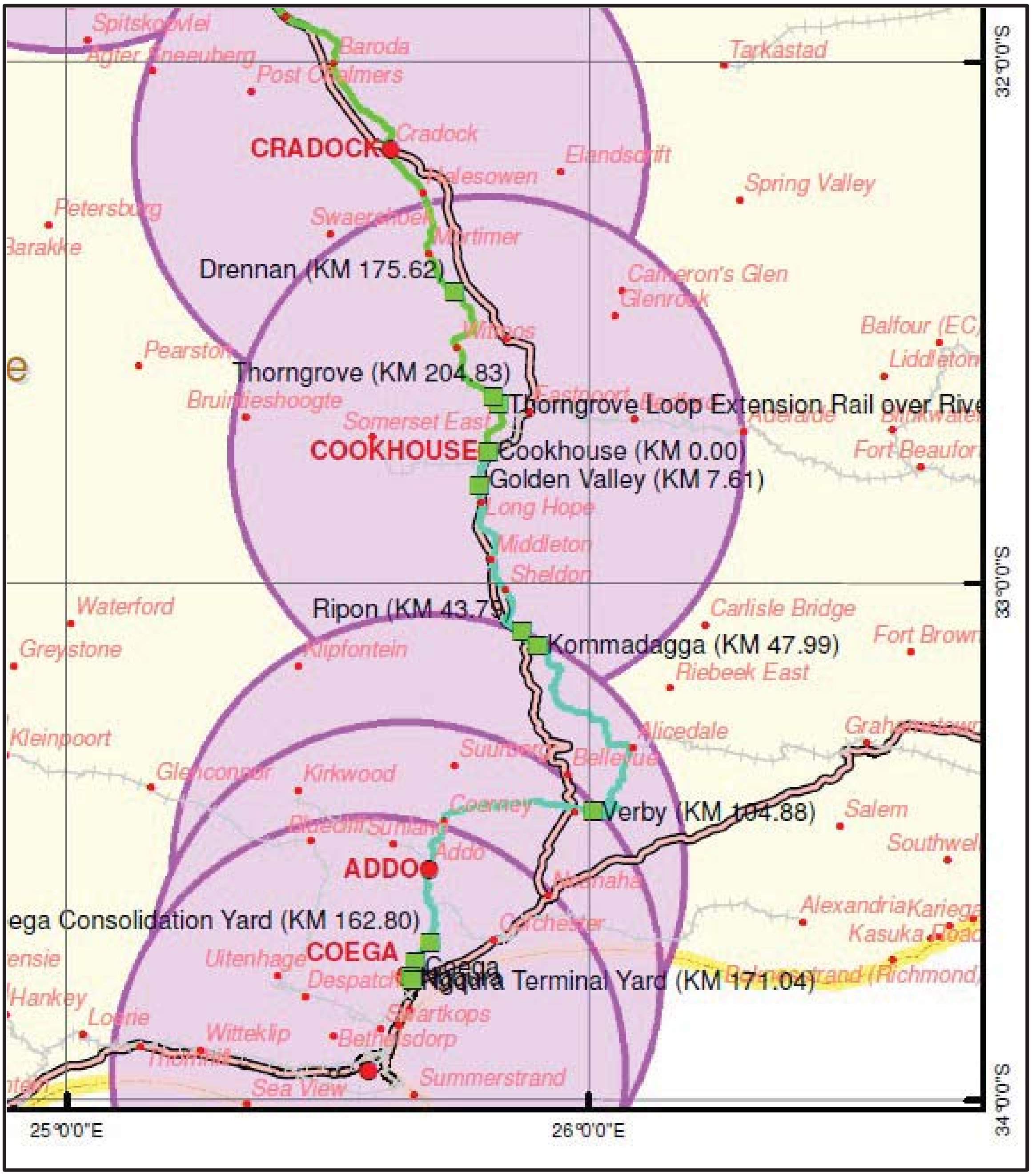

Fig. 1. Map of the Cradock to Coega sector of the Transnet manganese ore export railway line, Eastern Cape, showing the locations of the four railway loops covered by the present desktop Basic Assessment report as well as of the Coega IDZ Compilation Yard (green squares; see also Table 1) (Map modified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

Table 2. Summary of geology and palaeontological sensitivity of the four 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. 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 four 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 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

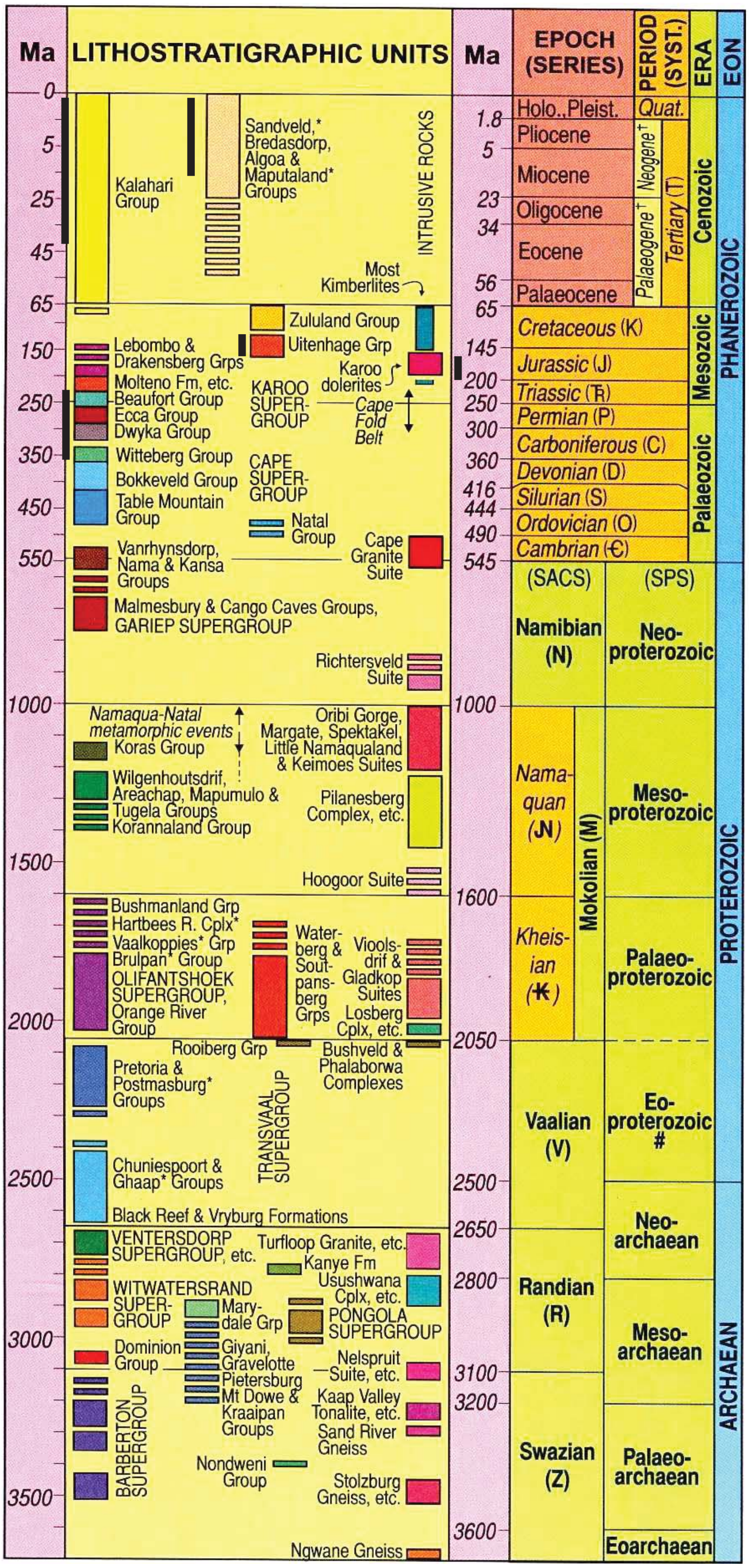

Fig. 2. Stratigraphic column for southern Africa showing the main Phanerozoic rock units represented along the manganese ore export line railway between Cradock and Coega, Eastern Cape (thick vertical black lines) (See also Table 3 for Karoo Supergroup rock units)

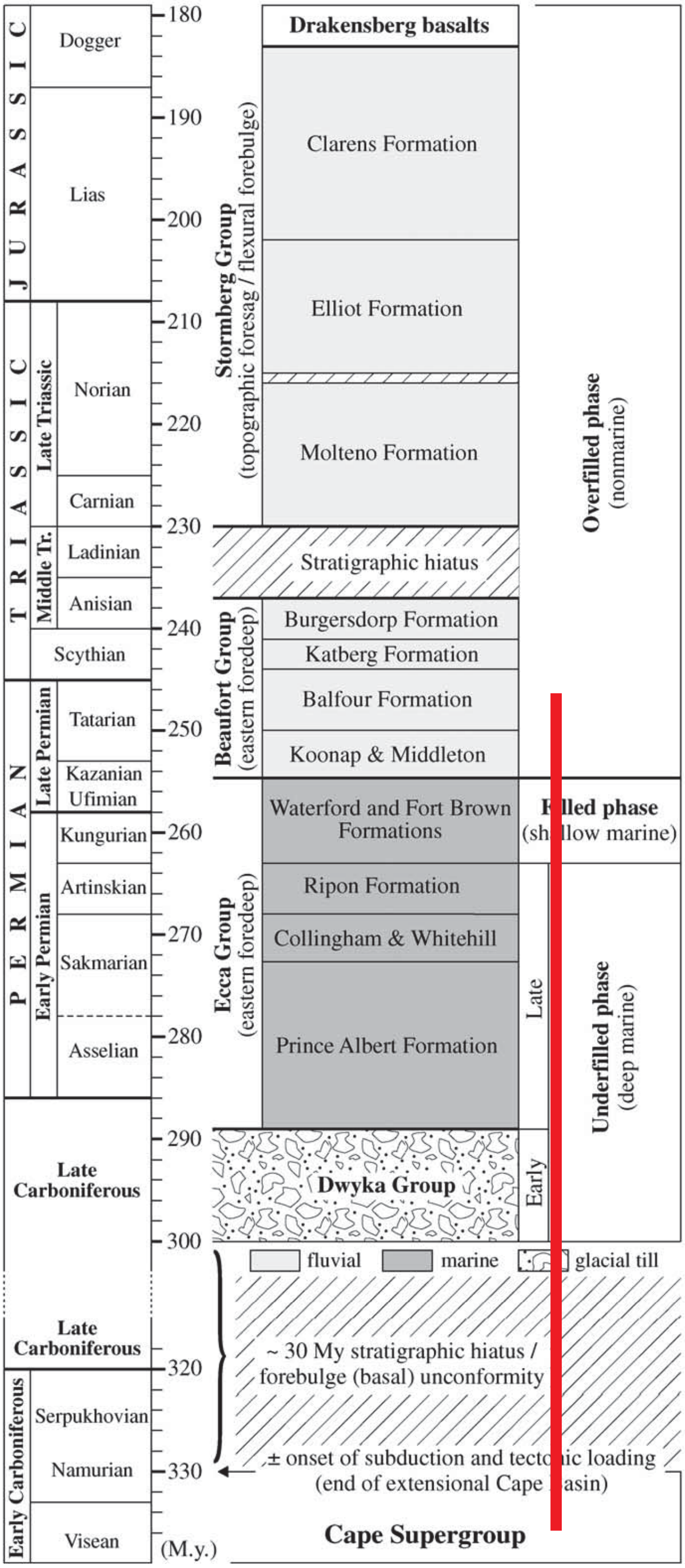

Figure 3. Stratigraphic subdivision of the *c*. 12km-thick Karoo Supergroup (From Catuneanu *et al.* 2005). The Early Carboniferous to Late Permian formations of the Witteberg, Dwyka, Ecca and Lower Beaufort Groups that are represented within the Transnet project area between Cradock and Kommadagga are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

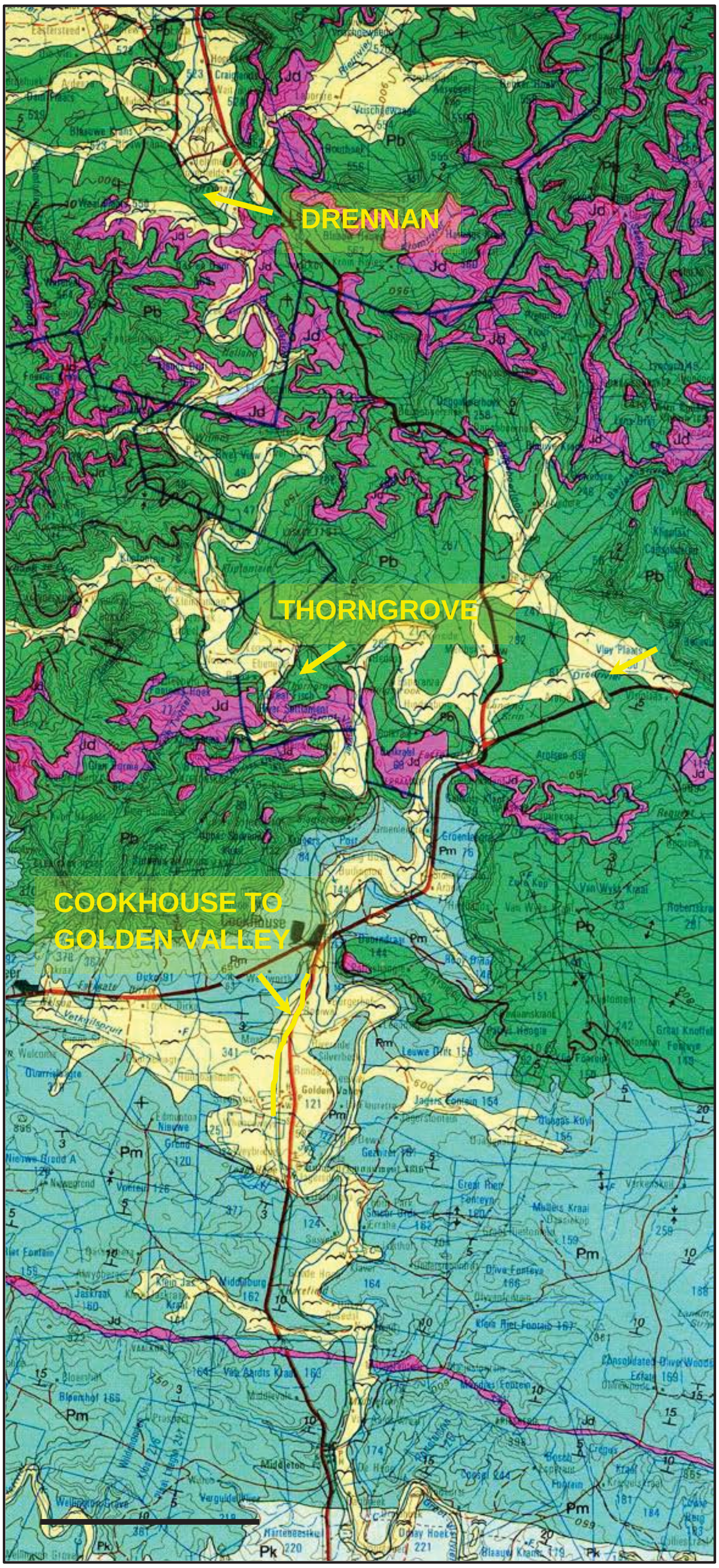

Fig. 4. Extract from 1: 250 000 geology map 3224 Graaff-Reinet (Council for Geoscience, Pretoria) showing location of the proposed loop extensions at Drennan, Thorngrove (both underlain by the Balfour Formation, Pb) and Cookhouse – Golden Valley (underlain by alluvium and the Middleton Formation). See 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.

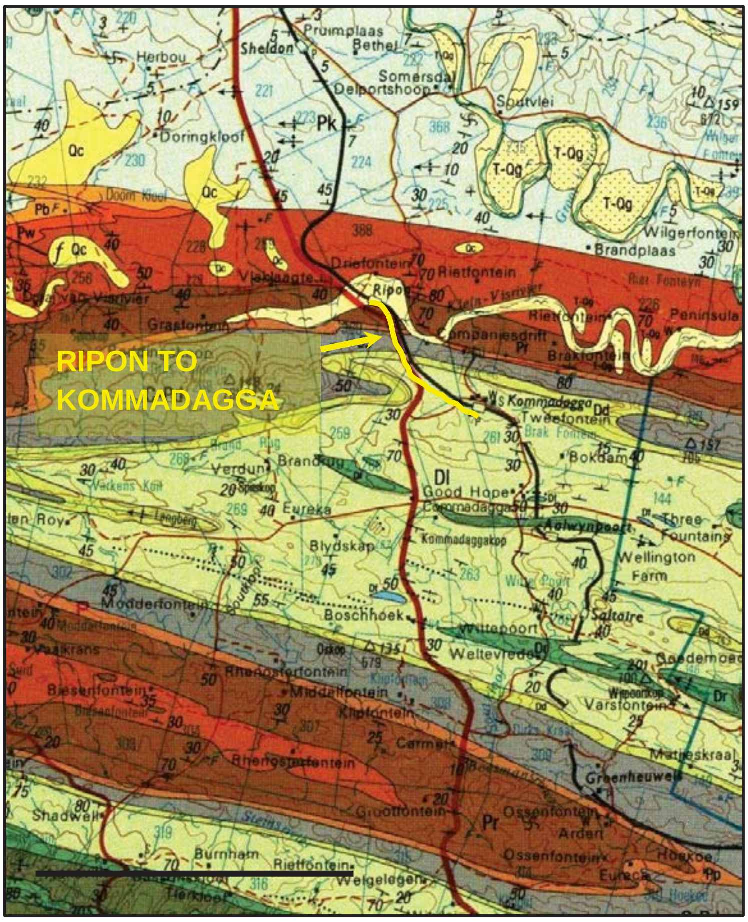

Fig. 5. Extract from 1: 250 000 geology map 3324 Port Elizabeth (Council for Geoscience, Pretoria) showing location of the proposed loop extension at Ripon – Kommadagga, underlain by upper Witteberg Group (Dl, Dd), Dwyka Group (C-Pd) and Ecca Group (Pp, Pr) sediments. See Table 3 for summary of geology 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.

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, compromising fossil preservation.

2.7.1. Middleton Formation

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

2.7.2. Balfour Formation

The fluvial Balfour Formation comprises recessive weathering, grey to greenish-grey overbank mudrocks with subordinate resistant-weathering, grey, fine-grained channel sandstones deposited by large meandering river systems in the Late Permian 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.

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, for example along the banks of the Doring River at Leeunershof (Anderson 1974). 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). 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).

3.7.1. 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. 6);

- 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).

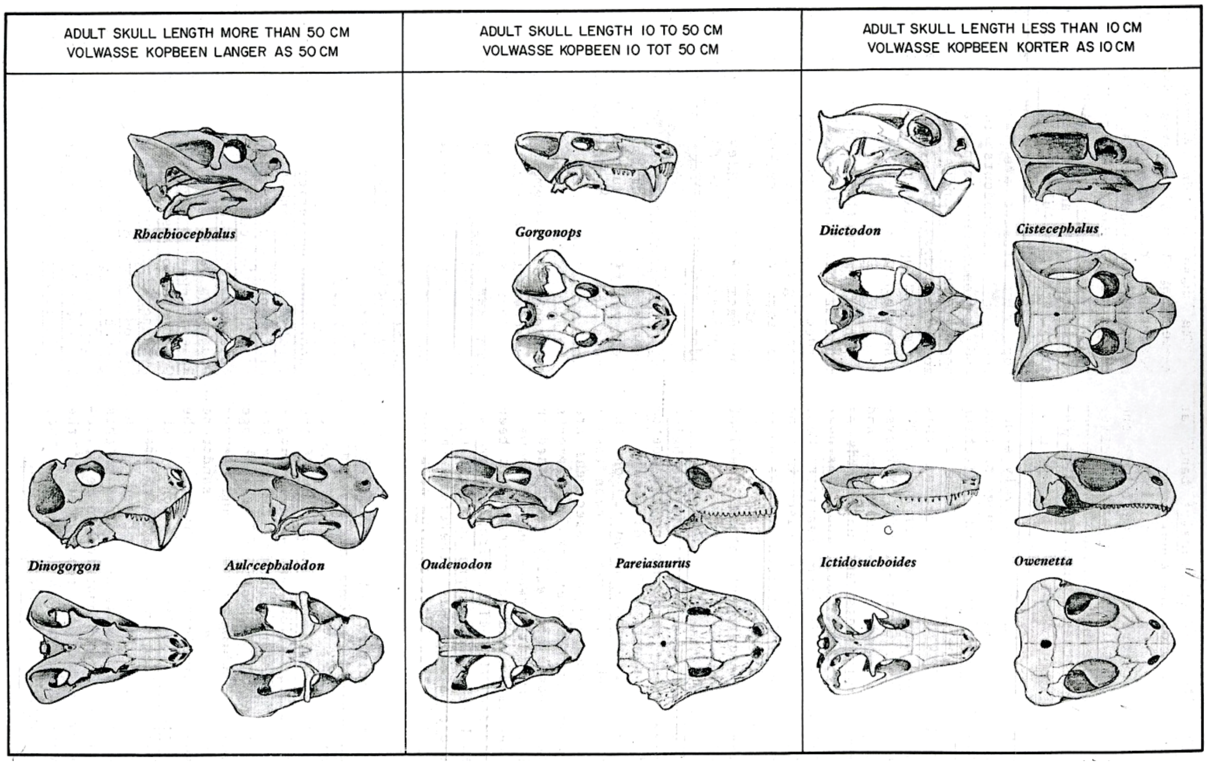

Fig. 6. Skulls of characteristic fossil vertebrates from the *Cistecephalus* Assemblage Zone (From Keyser & Smith 1979). *Pareiasaurus* a large herbivore, and *Owenetta*, a small insectivore, are true reptiles. The remainder are therapsids or "mammal-like reptiles". Of these, *Gorgonops* and *Dinogorgon* are large flesh-eating gorgonopsians, *Ictidosuchoides* is an insectivorous therocephalian, while the remainder are small – to large-bodied herbivorous dicynodonts.

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.

3.7.2. 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).

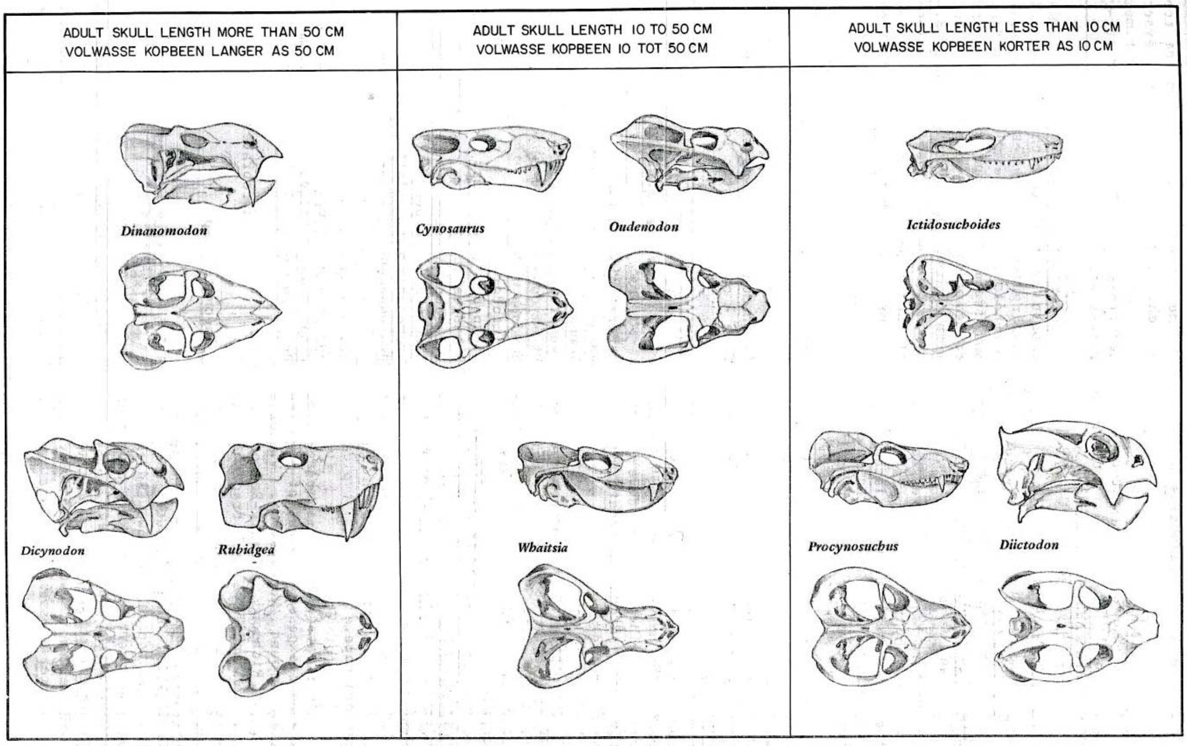

Fig. 7. Skulls of characteristic fossil vertebrates – all therapsids - from the *Dicynodon* Assemblage Zone (From Keyser & Smith 1979). Among the dominant therapsids ("mammal-like reptiles"), *Rubidgea* and *Cynosaurus* are carnivorous gorgonopsians *Whaitsia* (now *Theriognathus*) is a predatory therocephalian 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. 7 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 (*eg* 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 75km 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 extended railway loops 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 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 mesosaurud 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.

6. ACKNOWLEDGEMENTS

Mr Junaid Moosajee of ERM, Cape Town, is thanked for commissioning this study and providing the relevant background information. I am also grateful to Ms Elize Becker, Environmental Services Group, HATCH, Johannesburg for extensive discussions concerning heritage related issues relating to the Transnet 16 Mtpa project.

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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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