Palaeontological specialist assessment: combined field-based and 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 3: Kimberley to De Aar, Northern Cape

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EXECUTIVE SUMMARY

Transnet SOC Limited is planning to expand the capacity of the existing manganese ore export railway line (*c.* 1100 km) between Hotazel (Northern Cape) and the Port of Ngqura (Coega IDZ, Eastern Cape) to 16 Mtpa. Refurbishment and electrification of the second rail is required between Kimberley and De Aar in the Northern Cape. The present combined desktop and field-based palaeontological report forms part of the Heritage Impact Assessment of developments related to doubling the electrified line service between Kimberley and De Aar in the Northern Cape. These developments include construction of a bypass line at Beaconsfield Station (Kimberley), reinstating and overhead electrification of an existing, but currently disused, line between Beaconsfield and De Aar with associated infrastructure, as well as the upgrading of three electrical substations (Kareeboschpan, Kalkbult, Behrshoek).

The construction phase of the proposed railway developments between Kimberley and De Aar would entail only minor excavations into the superficial sediment cover as well as locally into the underlying bedrock. These excavations might disturb, damage or destroy scientifically valuable fossil heritage exposed at the surface or buried below ground. Other infrastructure components (*e.g.* site construction offices) may seal-in buried fossil heritage, but this would be only temporary. 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.

Desktop and field-based surveys of the railway line between Kimberley and De Aar show that (1) only a limited range of rock units (formations *etc*) will be directly affected by the proposed development and (2) none of these units as exposed within the study area are of high palaeontological sensitivity near-surface. Well-preserved fossil remains may occur within fresher (unweathered) bedrocks at depths of many meters, but these are unlikely to be directly affected by the proposed railway developments. Igneous rocks such as Late Archaean (2.7 billion years old) lavas of the Ventersdorp

Supergroup and the Early Jurassic Karoo dolerites are entirely unfossiliferous. Permian marine to non-marine basinal mudrocks of the Lower Ecca Group (Prince Albert and Whitehill Formations) are palaeontologically sensitive in some areas of the Northern Cape (*e.g.* Kimberley, Douglas). However, their original fossil heritage has been seriously compromised along the Kimberley – De Aar railway line due to (1) baking by dolerite intrusions, (2) near-surface weathering as well as (3) extensive formation of calcrete (pedogenic limestone) in Quaternary times. The same applies to stratigraphically higher subunits of the Ecca Group such as the Middle Permian Tierberg and Waterford Formations whose original palaeontological sensitivity is ranked as medium. A very high proportion of the pre-Caenozoic bedrocks in the study area are covered with a thick (several meters or more) mantle of Late Caenozoic deposits, notably Quaternary calcrete hardpans, Kalahari sands (Gordonia Formation), surface gravels, alluvium and soils so that they are mainly exposed only in borrow pits, railway and road cuttings. These superficial deposits are generally of low palaeontological sensitivity.

Only very limited fossil to subfossil remains were observed within sedimentary rocks along the Kimberley to De Aar railway line during the present field study. Low diversity trace fossil assemblages occur within Lower Ecca mudrocks (probably Prince Albert Formation) at Graspan. Stromatolite-like structures within large (meter-scale) nodules of the Tierberg Formation (*e.g.* Kraankuil area) are pseudofossils, formed abiotically during late diagenetic carbonate precipitation. Calcretised rhizoliths (plant root casts), and occasional carbonaceous rootlets, occur within and at the base of calcrete hardpans, such as in the Heuningneskloof area. Small fragments of Middle Permian petrified wood are quite common among surface gravels overlying the Waterford Formation (erronerously mapped as Tierberg Formation) between Houtkraal and De Aar. Anthropogenically flaked hornfels clasts are a common component of surface gravels along much of the railway line and, apart from their obvious archaeological importance, are of geological interest in constraining the age of superficial sediment horizons (*e.g.* alluvial gravels, older consolidated soils) within which they are sometimes embedded.

Due to the low to very low palaeontological sensitivity of all rock units encountered along the Kimberley to De Aar sector of the manganese ore export railway line, the proposed railway developments are rated as having low palaeontological heritage significance (Table 1). It is concluded that they are unlikely to constitute a significant threat to fossil heritage within the study area. There are therefore no objections on palaeontological heritage grounds to the proposed developments and no further specialist studies are recommended here, pending potential discovery of significant new fossils during the construction phase.

It is recommended that:

- The Environmental Officer (EO) responsible at the railway developments should be aware of the possibility of important fossils (*e.g.* mammalian bones, teeth) being present or unearthed on site and should regularly monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;

- In the case of any significant fossil finds (*e.g.* vertebrate teeth, bones, burrows, petrified wood) made during construction, these should be safeguarded - preferably *in situ* - and reported by the EO as soon as possible to the relevant heritage management authority (South African Heritage Resources Agency. Contact details: SAHRA, 111 Harrington Street, Cape Town. PO Box 4637, Cape Town 8000,South Africa. Phone : +27 (0)21 462 4502. Fax : +27 (0)21 462 4509. Web : www.sahra.org.za) so that appropriate mitigation (*i.e.* recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer's expense; and

- These recommendations should be incorporated into the Environmental Management Plan (EMP) for the manganese ore export railway line project.

The palaeontologist concerned with mitigation work will need a valid collection permit from SAHRA. All work would have to conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording fossil collection and curation, final report) should adhere to the minimum standards for Phase 2 palaeontological studies recently published by SAHRA (2013).

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) to 16 Mtpa.

The present combined desktop and field-based palaeontological report forms part of the Heritage Impact Assessment of developments related to doubling the electrified line service between Kimberley and De Aar in the Northern Cape. These developments include construction of a bypass line at Beaconsfield Station (Kimberley), reinstating and overhead electrification of an existing, but currently disused, line between Beaconsfield and De Aar with associated infrastructure, as well as the upgrading of three electrical substations (Kareeboschpan, Kalkbult, Behrshoek).

The following brief outline of the proposed developments in the Kimberley to De Aar sector of the manganese railway line has kindly been provided by Hatch Africa (Pty) Ltd:

- The section from Beaconsfield to De Aar has an existing un-electrified line which has not been used since the current operating line was electrified. The intention is to bring this160 km section into operation. This will include doubling of the line service over this section that carries a heavy rail traffic load.
- A bypass line will be constructed at Beaconsfield and an associated AC/DC System Separation System.
- To be able to bring the disused Beaconsfield to De Aar line back in operation, the following portions must be reinstated:
- Beaconsfield to Heuningneskloof;
- Graspan to Kraankuil;
- Poupan to Houtkraal.

The refurbishment of this section of the line will include overhead electrification, signalling, replacing superstructure material with new material as well as minor localised earthworks. Additional works are inclusive of reinstatement of drainage, fencing and level crossing infrastructure.

Three electrical substations will be upgraded to support the rail wagons and they are:

- Kareeboschpan;
- Kalkbult;
- Behrshoek.

This work will take place within the footprint of the existing substations and will entail at most very limited earthworks.

The general works to be completed are the following:

- Establishment of a general site construction office at the construction areas;
- Ancillary works;
- Culverts will be upgraded as part of the maintenance process.

1.1. Legislative context for palaeontological assessment studies

Hatch Africa (Pty) Ltd (Building 14, Harrowdene Office Park, Eastern Service Road, Woodmead. Contact: Ms Elize Becker. Tel: +27 (0)11 239 5659; Fax: +27 (0)11 239 5790; email: EBecker@hatch.co.za) has commissioned a comprehensive Heritage Impact Assessment of the proposed railway developments between Kimberley and De Aar.

The present combined desktop and field-based study forms part of the Heritage Assessment of the proposed railway developments between Kimberley and De Aar in the Northern Cape. 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 Permian and younger, Late Tertiary or Quaternary age (Sections 2 and 3). The construction phase of the developments may entail excavations into the superficial sediment cover as well as locally into the underlying bedrock. In addition, 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.

The various categories of heritage resources recognised as part of the National Estate in Section 3 of the National Heritage Resources Act include, among others:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Minimum standards for the palaeontological component of heritage impact assessment reports (PIAs) have recently been published by SAHRA (2013).

1.2. Scope and brief for the desktop study

This desktop palaeontological specialist report provides a combined desktop and field-based assessment of the observed or inferred palaeontological heritage along the existing railway line between Kimberley and De Aar, Northern Cape (Fig. 1, Table 1), with recommendations for further specialist palaeontological studies and / or mitigation where this is considered necessary.

The report has been commissioned by Hatch Africa (Pty) Ltd (Building 14, Harrowdene Office Park, Eastern Service Road, Woodmead. Contact: Ms Elize Becker. Tel: +27 (0)11 239 5659; Fax: +27 (0)11 239 5790; email: EBecker@hatch.co.za).

The report contributes to the Heritage Impact Assessment for the proposed 16 Mtpa manganese ore railway developments and it will also inform the Environmental Management Plan for the project. The scope of work for this study, as defined by Hatch, is as follows:

> The Subconsultant is required to perform a Palaeontological Impact Assessment for the Transnet Upgrade – Kimberley to De Aar Railway Line in the Northern Cape Province. The assessment will comprise a combined desktop study plus a field assessment.

1.3. Approach to the palaeontological heritage Assessment study

The approach to this palaeontological heritage impact assessment 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 6). 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 along the railway line (25 – 27 September 2012) by the author *plus* one field assistant, 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 area between Kimberley and De Aar 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 combined desktop and field-based study was based on the following:

1. A short project outline provided by Hatch Africa (Pty) Ltd.

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 Kimberley and De Aar region by the author (*e.g.* Almond 2010a, 2010b, 2011, 2012a, 2012b, 2012c among others).

3. A three-day field survey of potentially fossiliferous rock exposures along the Kimberley to De Aar railway line by the author and one field assistant (25 – 27 September 2012).

4. 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 Kimberley to De Aar sector of the Transnet manganese ore export railway line, Northern Cape, showing the railway sector between Kimberley and De Aar that is covered by the present Palaeontological Heritage Assessment report (Map modified from image provided by Hatch Africa (Pty) Ltd).

2. GEOLOGICAL OUTLINE OF THE STUDY AREA

The existing Transnet manganese ore export railway line between Kimberley and De Aar, Northern Cape, lies within the physiographic region of the RSA known as the Upper Karoo (Visser *et al.* 1989, their Fig. 2.1.). The railway line traverses fairly flat-lying terrain at *c*. 1200 to 1350 m amsl (higher towards the south) over the entire route of some 230 km. It crosses the narrow Rietrivier just south of Modderrivier Station and the more deeply incised Orange River some 12 km east of Hopetown. The main topographic highs rising above the adjoining *vlaktes* are low, dolerite-capped *koppies* which are best developed in the southernmost sector near De Aar (*e.g.* Renosterberg range). The climate in this region is semi-arid, summer rainfall regime and the vegetation changes from Kimberley Thornveld (Savannah Biome) in the north to Northern Upper Karoo (Nama-Karoo Biome) in the south.

The geology of the study area between Kimberley and De Aar is covered by three adjacent 1: 250 000 scale geological maps, 2824 Kimberley (sheet explanation by Bosch 1993), 2924 Koffiefontein (sheet explanation by Zawada 1992) and 3024 Colesburg (sheet explanation by Le Roux 1993). Relevant extracts from these sheets are provided in Figs. 3 to 6 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 field study.

All major rock units mapped along the railway line between Kimberley and De Aar are listed in Table 2, 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 below. They include a relatively narrow 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 potentially fossiliferous post-glacial sediments of the Lower Ecca Group (Karoo Supergroup), namely the Prince Albert and Whitehill Formations. However, the Ecca Group rocks are very poorly exposed within the study area and are extensively intruded by Karoo dolerites that have probably compromised much, albeit not all, of their original fossil heritage.

A very short review of the geology of the potentially fossiliferous rock units within the study area is given below (*i.e.* igneous rock units are ignored here), while details of their known fossil heritage are given in Section 3. In Section 4 an illustrated summary of geological and palaeontological observations made during fieldwork along the railway line between Kimberley and De Aar is presented.

Note that frequent reference is made in this report to points (mainly existing stations) along the Kimberley to De Aar railway line as a convenient way of relating the geological and palaeontological data to particular subdivisions of this long linear study area. These 14 points are shown in Figure 1 above and are also indicated on the geological maps in Figures 3 to 6 below.

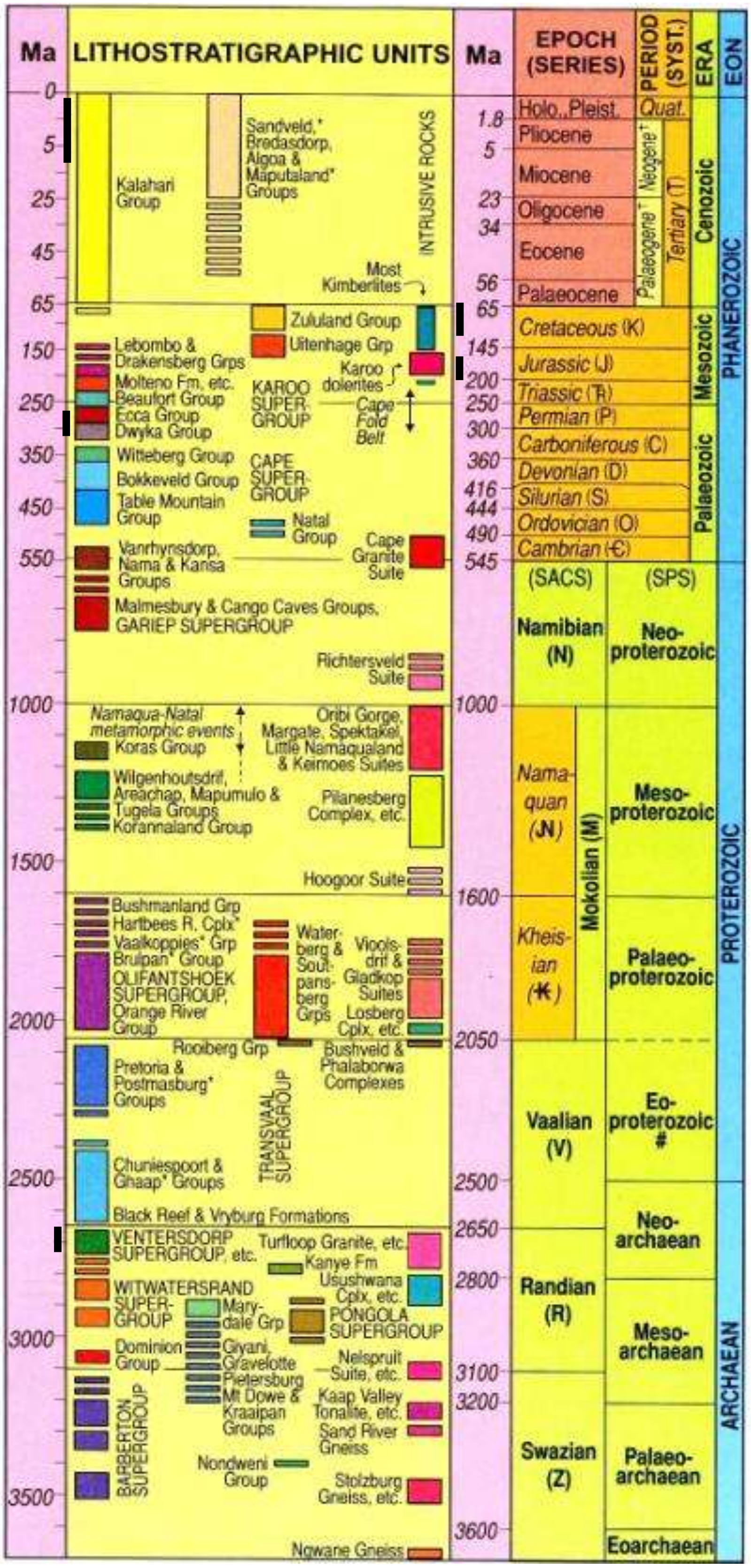

Fig. 2. Stratigraphic column for southern Africa showing the main rock units represented along the manganese ore export line railway between Kimberley and De Aar, Northern Cape (thick vertical black lines) (See also Table 2).

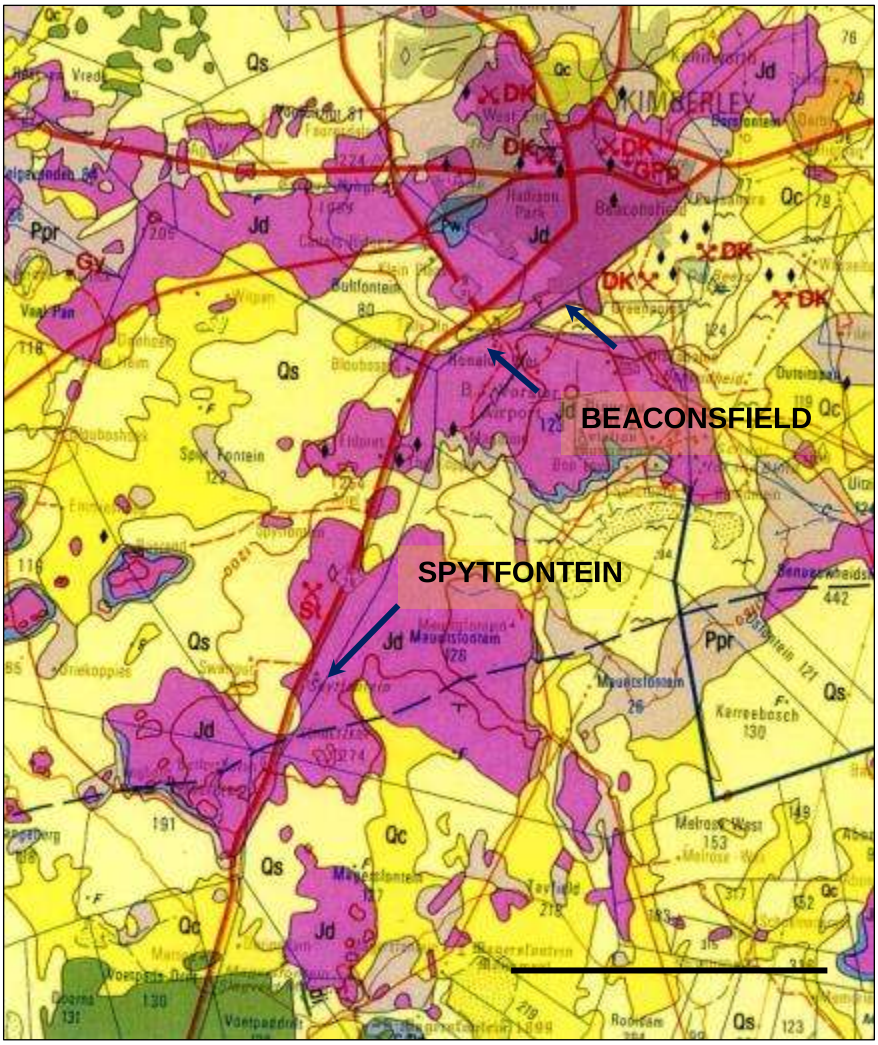

Fig. 3. Extract from 1: 250 000 geology map 2824 Kimberley (Council for Geoscience, Pretoria) showing location of geographical reference points along the Kimberley – De Aar railway line at Beaconsfield and Spytfontein (both underlain by Karoo Dolerite Suite igneous intrusions, Jd). See Table 2 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

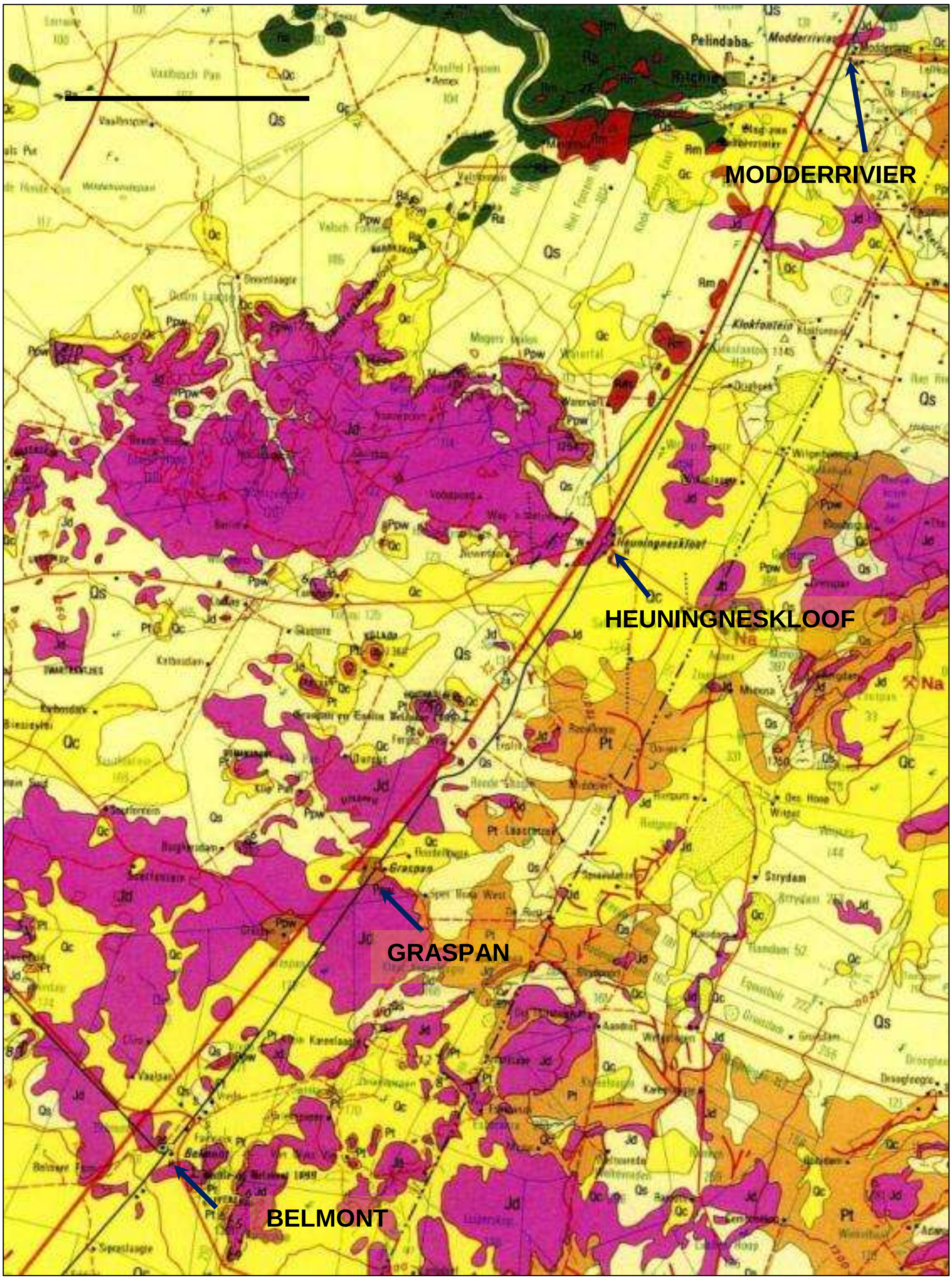

Fig. 4. Extract from 1: 250 000 geology map 2924 Koffiefontein (Council for Geoscience, Pretoria) showing location of geographical reference points along the Kimberley – De Aar railway line at Modderrivier, Heuningneskloof (both underlain by Karoo Dolerite Suite igneous intrusions, Jd), Graspan (underlain by the Lower Ecca Group, Ppw) and Belmont (underlain by Quaternary calcrete, Qc). See Table 2 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

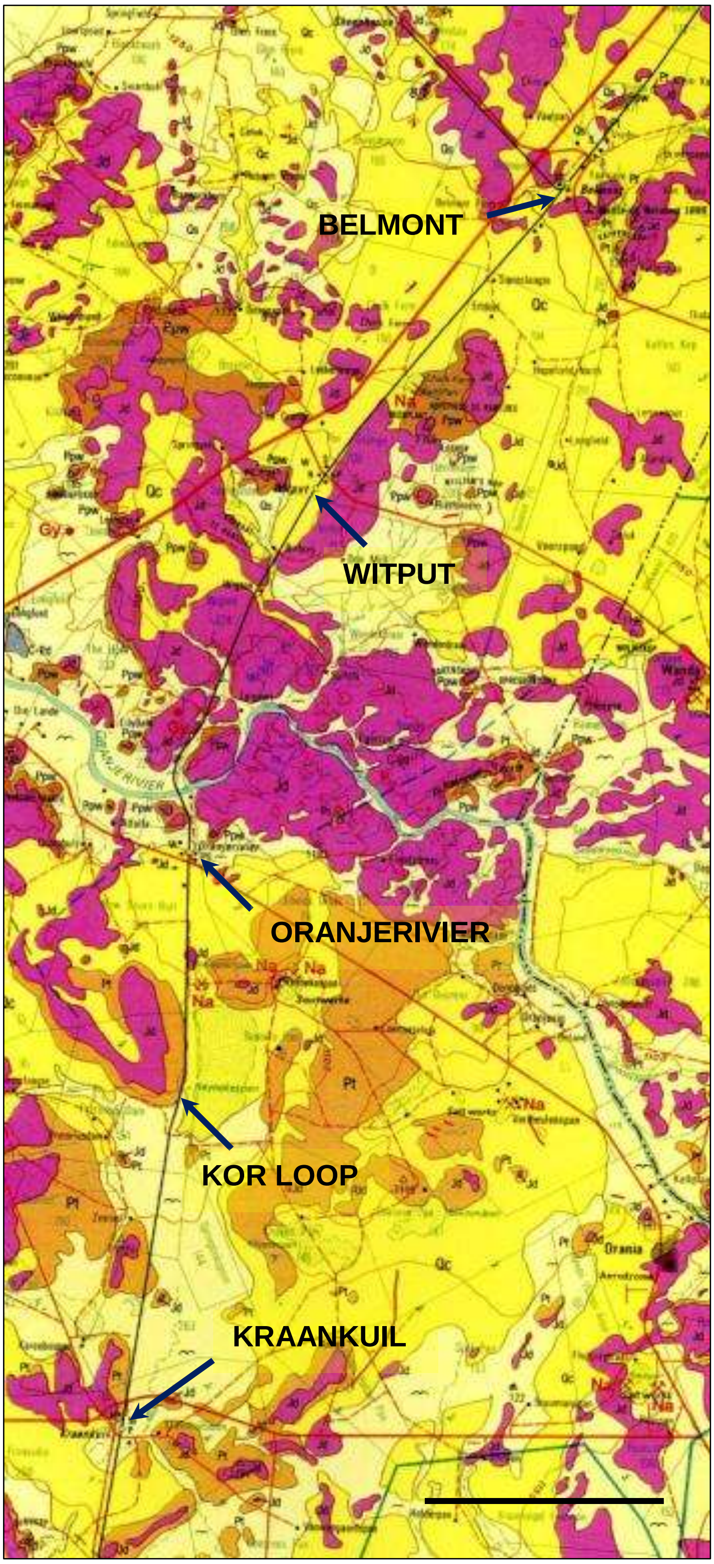

Fig. 5. Extract from 1: 250 000 geology map 2924 Koffiefontein (Council for Geoscience, Pretoria) showing location of geographical reference points along the Kimberley – De Aar railway line at Belmont, Witput, Oranjerivier, KOR Loop and Kraankuil, all of which are underlain by Quaternary calcrete (Qc) and / or alluvial deposits with Ecca Group mudrocks at depth. See Table 2 for summary of geology and fossils within rock units along the Transnet manganese ore export railway line. Scale bar here = *c*. 10 km.

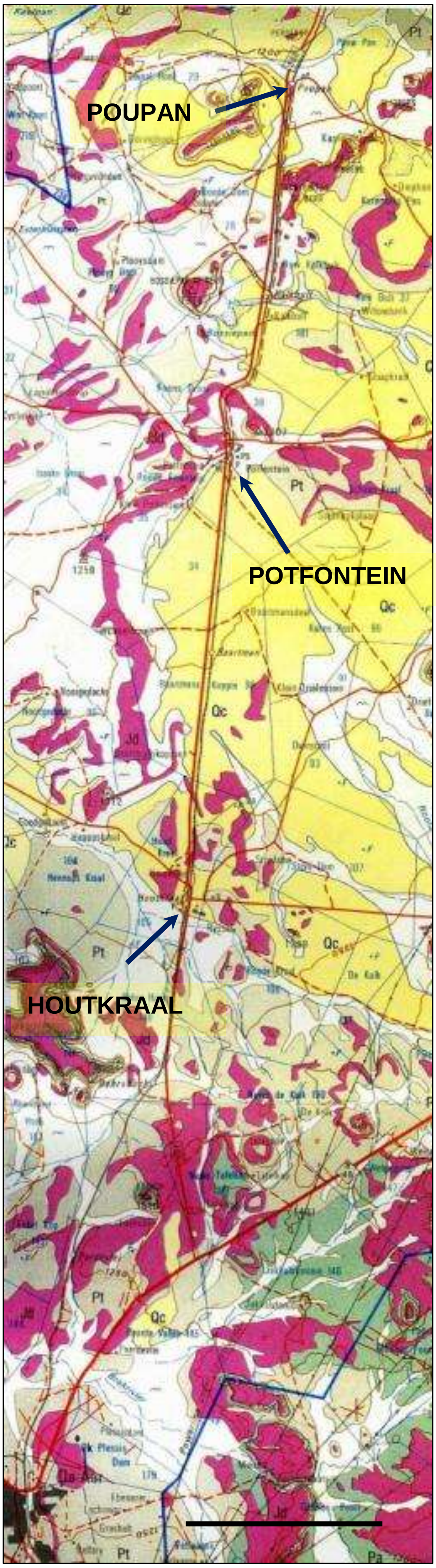

Fig. 6. Extract from 1: 250 000 geology map 3024 Colesburg (Council for Geoscience, Pretoria) showing location of the geographical reference points along the Kimberley – De Aar railway at Poupan, Potfontein and Houtkraal, all of which are underlain by Quaternary calcrete (Qc) and / or alluvial deposits with Ecca mudrocks at depth. See Table 2 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. Prince Albert Formation (Ecca Group)

The post-glacial basinal mudrocks of the **Prince Albert Formation** (**Ppr**) form the lowermost subunit of the Ecca Group. This thin-bedded to laminated mudrock-dominated succesion of Early Permian (Asselian / Artinskian) age was previously known as "Upper Dwyka Shales". Key geological accounts of this formation are given by Visser (1992) and Cole (2005). The Prince Albert succession consists mainly of tabular-bedded mudrocks of blue-grey, olive-grey to reddish-brown colour with occasional thin (dm) buff sandstones and even thinner (few cm), soft-weathering layers of yellowish water-lain tuff (*i.e.* volcanic ash layers). Extensive diagenetic modification of these sediments has led to the formation of thin cherty beds, pearly- blue phosphatic nodules, rusty iron carbonate nodules, as well as beds and elongate ellipitical concretions impregnated with iron and manganese minerals. The brittle rocks are well-jointed and often display a well-developed tectonic cleavage that results in sharp, elongate cleavage flakes ("pencil cleavage"). Extensive bedding planes are therefore rarely encountered in the southern outcrop area close to the Cape Fold Belt while Northern Cape outcrops are much less deformed.

The Prince Albert Formation (Ppr, Ppw) in the Kimberley and Koffiefontein sheet areas consists predominantly of dark, well-laminated basinal mudrocks (shales, siltstones) with minor thin-bedded fine-grained sandstone and siltstone lenses. The mudrocks are sometimes micaceous, carbonaceous or pyritic and typically contain a variety of diagenetic concretions enriched in iron and carbonate minerals (Visser *et al.* 1977, Zawada 1992, Bosch 1993). Some of these carbonate concretions are richly fossilferous (See Section 3.1 below).

The Prince Albert Formation crops out intermittently along the railway line between Kimberley and Graspan (Figs. 3, 4) but in small exposures is difficult to distinguish from the Tierberg Formation. Much of the Ecca shale outcrop area has been modified by extensive near-surface calcretization as well as baking by Karoo dolerite intrusions.

2.2. Whitehill Formation (Ecca Group)

The Whitehill Formation (Ppw / Ppr) is a thin (*c*. 20-30m) succession of well-laminated, carbon-rich mudrocks of Early Permian (Artinskian) age that forms part of the lower Ecca Group. These sediments were laid down about 278 Ma in an extensive shallow, brackish to freshwater basin – the Ecca Sea – that stretched across southwestern Gondwana, from southern Africa into South America (McLachlan & Anderson 1971, Oelofsen 1981, 1987, Visser 1992, 1994, Cole & Basson 1991, MacRae 1999, Johnson *et al*. 2006). Fresh Whitehill mudrocks are black and pyritic due to their high content of fine-grained organic carbon, probably derived from persistent or seasonal phytoplankton blooms that promoted anoxic conditions on the Ecca Sea bed. Near-surface weathering of the pyrite leads to the formation of gypsum, lending a pale grey colour to the Whitehill outcrop (hence informally known as the "*Witband*"). Large (meter-scale) diagenetic nodules and lenses of tough, greyish dolomite are common and often display a stromatolite-like fine-scale banding.

Occurrences of the Whitehill Formation within the Northern Cape study region are described by Visser *et al.* (1977) and Bosch (1993). Natural outcrops are scarce, and exposures of this formation were not encountered along the railway line during the present field study.

2.3. Tierberg and Waterford Formations (Ecca Group)

The **Tierberg Formation** (**Pt**) (Ecca Group, Karoo Supergroup) is a recessive-weathering, mudrock-dominated succession consisting predominantly of dark, well-laminated, carbonaceous shales with subordinate thin, fine-grained sandstones (Visser *et al.* 1977, Prinsloo 1989, Zawada 1992, Bosch 1993, Le Roux 1993, Viljoen 2005, Johnson *et al*., 2006). The Tierberg shales are Early to Middle

Permian in age and were deposited in a range of offshore, quiet water environments below wave base. These include basin plain, distal turbidite fan and distal prodelta settings in ascending order (Viljoen 2005, Almond 2008a). Thin coarsening-upwards cycles occur towards the top of the formation with local evidence of soft-sediment deformation, ripples and common calcareous concretions (often with well-developed cone-in-cone structures). A restricted, brackish water environment is reconstructed for the Ecca Basin at this time. Close to the contact with Karoo dolerite intrusions the Tierberg mudrocks are baked to a dark grey hornfels with a reddish-brown crust or patina (Prinsloo 1989).

Tierberg Fomation mudrocks are mapped intermittently from just south of Heuningneskloof Station down to De Aar (Figs. 4 to 6). It should be noted here that the stratigraphic as well as palaeoenvironmental interpretation of the Ecca / Beaufort boundary rocks in the De Aar – Philipstown area is more complex and unresolved than that suggested by the brief treatment in the Britstown and Colesberg geology sheet explanation by Prinsloo (1989) and Le Roux (1993) respectively. For mapping purposes, the base of the first prominent-weathering sandstone within the Ecca / Beaufort boundary succession has been taken as the base of the Beaufort Group in this region (Le Roux 1993, p. 4, following Nel 1977). The marine or lacustrine, uppermost Ecca Group rocks here, though mapped as offshore / basinal Tierberg Formation, have in fact many features in common with the shallow shelf, storm-dominated, sandstone-rich facies seen at the top of the Ecca succession in the Carnarvon area to the west. These uppermost Ecca Group rocks were previously assigned to the Carnarvon Formation that has since been incorporated into the **Waterford Formation** (*e.g.* Johnson *et al.* 2006). They tend to be more sandstone-rich than the overlying Beaufort Group. The "Carnarvon Facies" is characterised by upward-coarsening, yellowish-weathering, sandstone-rich successions containing storm-generated hummocky cross-stratification and wave ripples, large ferruginous carbonate concretions (*koffieklip*), ball-and-pillow load structures, and pervasive low intensity bioturbation by low diversity trace fossil assemblages. In contrast to the *Mermia* Ichnofacies traces of the basinal Tierberg mudrocks *sensu stricto*, the Carnarvon facies trace fossil assemblages have been assigned to the shallow marine *Cruziana* Ichnofacies as well as the marginal marine *Skolithos* and *Scoyenia* Ichnofacies (*e.g.* Siebrits 1987, Smith & Zawada 1988, 1989, Prinsloo 1989, Rust *et al.* 1991 and references therein). Petrified wood and other plant remains (*e.g.* leaf compressions) are locally abundant. The inshore shelf (shoreface) Carnarvon facies rocks have a gradational contact with the underlying offshore Tierberg mudrocks and are in turn conformably overlain by continental (subaerial), fluvial sediments of the Lower Beaufort Group.

For the purpose of the present fossil heritage study, the upper Ecca Group sediments within the study area near De Aar are assigned to the Waterford Formation, despite their attribution to the Tierberg Formation on the published 1: 250 000 geological maps (Fig. 6) and the key SACS publication by Viljoen (2005). It is important to note that the key holostratotype (Stratotype A) section through the Tierberg Formation identified by Viljoen (2005) is located just to the north of Tierberg, some 18 km northeast of the Renosterberg. On the basis of both sedimentary facies and fossil assemblages, the rocks here closely resemble the tempestite-dominated nearshore "Carnarvon-type" facies of the Waterford Formation.

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

Large sections of the Transnet manganese ore export railway line study area between Kimberley and De Aar are mantled by a range of **superficial sediments** of probable Late Caenozoic (*i.e.* Late Tertiary or Neogene to Recent) age, some of which may be 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 1: 250 000 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** (**Qc**) occur overlying sediments of the Ecca Group as well as the Karoo Dolerite Suite intrusions - the probable source of much of the carbonate - between Kimberley and De Aar. These pedogenic limestone deposits replace or displace the near-surface bedrocks to a depth of several meters. They reflect seasonally arid climates in the region over the last five or so million years and are briefly described for the Kimberley sheet area by Bosch (1993). Although calcrete is still forming in the study area today, it forms subsurface and when exposed at the surface is “almost definitely fossil” (Botha 1988). 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). Key review papers on South African calcretes are those by Netterberg (1978, 1980 among other papers). Calcrete types commonly encountered in the Northern Cape study area include glaebular calcrete (with discrete nodules), honeycomb calcrete (with coalescent glaebules) and hardpan calcrete (solid limestone within at most minor voids). The surface limestones may reach thicknesses of over 10m, but are often much thinner, and are locally conglomeratic with clasts of reworked calcrete as well as exotic pebbles.

Large areas of unconsolidated, reddish-brown to grey aeolian (*i.e.* wind-blown) sands of the Quaternary **Gordonia Formation** (**Kalahari Group**; **Qs**) are mapped in the Transnet manganese ore railway study region, especially on the Kimberley sheet and the northern portion of the Koffiefontein sheet. Then sands are usually well-sorted, with only a minor gravel component, and may be secondarily calcretised. According to Bosch (1993) the Gordonia sands in the Kimberley area reach thicknesses of up to eight meters and consist of up to 85% quartz associated with minor feldspar, mica and a range of heavy minerals. The Gordonia dune sands are considered to range in age from the Late Pliocene / Early Pleistocene to Recent, dated in part from enclosed Middle to Later Stone Age stone tools (Dingle *et al*., 1983, p. 291). Note that the recent extension of the Pliocene - Pleistocene boundary from 1.8Ma back to 2.588 Ma would place the Gordonia Formation almost entirely within the Pleistocene Epoch.

3. 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 between Kimberley and De Aar are summarized in Table 2 (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 tectonic deformation (not usually significant in the present study area), 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 area). The fossil record of the sedimentary rock units underlying the railway development area between Kimberly and De Aar is briefly reviewed below. No further attention is paid here to unfossiliferous units of igneous rocks (*i.e.* Ventersdorp Supergroup, Karoo Dolerite Suite, Cretaceous kimberlite pipes).

3.1. Fossils within the Prince Albert Formation

The fossil biota of the post-Dwyka mudrocks of the **Prince Albert Formation** is usefully summarized by Cole (2005). The typical *Umfolozia / Undichna* – dominated trace fossil assemblages of the non-marine *Mermia* Ichnofacies commonly found in basinal mudrock facies of the Prince Albert Formation throughout the Ecca Basin have been briefly reviewed by Almond (2008a, b). Low diversity Prince Albert trace fossil assemblages within the Kimberley sheet area are briefly mentioned by Bosch (1993). Diagenetic nodules containing the remains of palaeoniscoids (primitive bony fish), sharks, spiral bromalites (coprolites *etc*) and wood have been found in the Ceres Karoo and rare shark remains (*Dwykaselachus*) near Prince Albert on the southern margin of the Great Karoo (Oelofsen 1986). Microfossil remains in this formation include sponge spicules, foraminiferal and radiolarian protozoans, acritarchs and miospores.

The most diverse as well as biostratigraphically, palaeobiogeographically and palaeoecologically interesting fossil biota from the Prince Albert Formation is that described from calcareous concretions exposed along the Vaal River in the Douglas area of the Northern Cape (McLachlan and Anderson 1971, Visser *et al.,* 1977-78). The important Douglas biota contains petrified wood (including large tree trunks), palynomorphs (miospores), orthocone nautiloids, nuculid bivalves, articulate brachiopods, spiral and other "coprolites" (probably of fish, possibly including sharks) and fairly abundant, well-articulated remains of palaeoniscoid fish. Most of the fish have been assigned to the palaeoniscoid genus *Namaichthys* but additional taxa, including a possible acrolepid, may also be present here (Evans 2005). The invertebrates are mainly preserved as moulds.

3.2. Fossils within the Whitehill Formation

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

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

The stratigraphic distribution of the most prominent fossil groups – mesosaurid reptiles, palaeoniscoid fishes and notocarid crustaceans – within the Whitehill Formation has been documented by several authors, including Oelofsen (1987), Visser (1992, 1994) and Evans (2005). Kensley (1975) reported notocarid crustaceans from the Whitehill Formation near Oranjerivier.

3.3. Fossils within the Tierberg and Waterford Formations

The fossil record of the **Tierberg Formation** has been reviewed in detail by Almond (2008a). Rare body fossil records include disarticulated microvertebrates (*e.g.* fish teeth and scales) from calcareous concretions in the Koffiefontein sheet area (Zawada 1992) and allochthonous plant remains (drifted leaves, petrified wood). The latter become more abundant in the upper, more proximal (prodeltaic) facies of the Tierberg (*e.g.* Wickens 1984). Prinsloo (1989) records numerous plant impressions and unspecified "fragmentary vertebrate fossils" (possibly temnospondyl amphibians) within fine-grained sandstones in the Britstown sheet area. Dark carbonaceous Ecca mudrocks are likely to contain palynomorphs (*e.g.* pollens, spores, acritarchs). Bosch (1993) and Visser *et al.* (1977) briefly mention body fossils within the Tierberg mudrocks in the broader Kimberley region. Concretions within the lower part of the formation at Kaffirs Kop 193 (southeast of Belmont) and on Klippiespan 205 contain fish scales, coprolites and sponge spicules. Records of abundant silicified wood within the upper Tierberg succession are here referred to the Waterford Formation (see below).

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

As discussed previously (Section 2.3) it is considered likely that the uppermost Ecca Group rocks in the De Aar study region belong to the **Waterford Formation** rather than the Tierberg Formation as mapped. Rare fragments of poorly-preserved tetrapod bone are recorded in channel lags within the upper Waterford Formation in the Williston sheet area (Viljoen 1989) and the southern Great Karoo. These probably belong to aquatic temnospondyl amphibians ("labyrinthodonts") but large fish and terrestrial therapsids might also be represented. Scattered palaeoniscoid fish scales and fish coprolites are common in the Waterford Formation, and several genera of non-marine bivalves have been described from the southern Karoo (Bender *et al*. 1991, Cooper & Kensley 1984).

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

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

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

3.4. Fossils within the Kalahari Group (including Quaternary calcretes)

The fossil record of the **Kalahari Group** is generally sparse and low in diversity. The **Gordonia Formation** dune sands were mainly active during cold, drier intervals of the Pleistocene Epoch that were inimical to most forms of life, apart from hardy, desert-adapted species. Porous dune sands are not generally conducive to fossil preservation. However, mummification of soft tissues may play a role here and migrating lime-rich groundwaters derived from the underlying bedrocks (including, for example, dolerite) may lead to the rapid calcretisation of organic structures such as burrows and root casts. Occasional terrestrial fossil remains that might be expected within this unit include calcretized rhizoliths (root casts) and termitaria (*e.g. Hodotermes*, the harvester termite), ostrich egg shells (*Struthio*) and shells of land snails (*e.g. Trigonephrus*) (Almond 2008a, Almond & Pether 2008). Other fossil groups such as freshwater bivalves and gastropods (*e.g. Corbula, Unio*) and snails, ostracods (seed shrimps), charophytes (stonewort algae), diatoms (microscopic algae within siliceous shells) and stromatolites (laminated microbial limestones) are associated with local watercourses and pans. Microfossils such as diatoms may be blown by wind into nearby dune sands (Du Toit 1954, Dingle *et al*., 1983). These Kalahari fossils (or subfossils) can be expected to occur sporadically but widely, and the overall palaeontological sensitivity of the Gordonia Formation is therefore considered to be low. Underlying calcretes of the **Mokolanen Formation** might also contain trace fossils such as rhizoliths, termite and other insect burrows, or even mammalian trackways. Mammalian bones, teeth and horn cores (also tortoise remains, and fish, amphibian or even crocodiles in wetter depositional settings such as pans; Partridge & Scott 2000) may be expected occasionally expected within Kalahari Group sediments and calcretes, notably those associated with ancient, Plio-Pleistocene alluvial gravels.

Table 2. Fossil heritage of rock units cropping out along the Kimberley to De Aar 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	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 Scattered records, many poorly studied and of uncertain age	any substantial fossil finds to be reported by EO 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 (Possible peak calcrete formation 2.6-2.5 Ma)	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 EO to SAHRA
KIMBERLITE INTRUSIONS (diamond symbol)	Kimberlite / olivine melilitite / carbonatite volcanic pipes and related intrusions (fissure fills), sometime diamondiferous. JURASSIC, CRETACEOUS TO PALAEOCENE *c.* 120 - 77 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
KAROO DOLERITE SUITE (Jd)	intrusive dolerites (dykes, sills), associated diatremes EARLY JURASSIC (182-183 Ma)	no fossils recorded or expected	ZERO (also cause baking of adjacent fossiliferous sediments)	none

GEOLOGICAL UNIT	ROCK TYPES & AGE	FOSSIL HERITAGE	PALAEONT-OLOGICAL SENSITIVITY	RECOMMENDED MITIGATION
Tierberg and Waterford Formations (Pt) ECCA GROUP	Dark basinal, prodelta and submarine fan mudrocks with minor sandstones (Tierberg Fm) OR Storm-influenced coastal sandstones and mudrocks (Carnarvon facies of Waterford Fm) EARLY TO MIDDLE PERMIAN	Locally abundant non-marine trace fossils (*Mermia* and *Cruziana* ichnofacies), common petrified wood, plant debris, microvertebrates incl. fish scales as well as sponge spicules, coprolites in diagenetic concretions	MEDIUM	Any substantial fossil finds to be reported by EO to SAHRA
Whitehill Formation (Pp / Ppw in part) ECCA GROUP	Carbonaceous offshore non-marine mudrocks within minor volcanic ashes, dolomite nodules EARLY PERMIAN	well-preserved mesosaurid reptiles, rare cephalochordates, variety of palaeoniscoid fish, small eocarid crustaceans, insects, low diversity of trace fossils (*e.g.* king crab & eurypterid trackways, possible shark coprolites), palynomorphs, petrified wood and other sparse vascular plant remains (*Glossopteris* leaves, lycopods *etc*)	HIGH	Pre-construction field assessment by professional palaeontologist
Prince Albert Formation (Ppr / Ppw; 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
Makwassie Formation (Rm) VENTERSDORP SUPERGROUP	Porphyritic felsite lavas LATE ARCHAEAN 2.67 Ga	no fossils recorded or expected	ZERO	none recommended any substantial fossil finds to be reported by EO to SAHRA
Allanridge Formation (Ra / Ral) VENTERSDORP SUPERGROUP	lavas and volcaniclastic sediments LATE ARCHAEAN 2.7 Ga	no fossils recorded or expected *NB* Glacially striated pavements in Kimberley area are of geoconservation interest	ZERO	none recommended any substantial fossil finds to be reported by EO to SAHRA

4. SUMMARY OF GEOLOGICAL & PALAEONTOLOGICAL FIELD OBSERVATIONS

A short, illustrated account of the most informative geological and palaeontological sites examined during the course of fieldwork is given in this section. Fieldwork focused on sites of good bedrock exposure along or close to the Kimberley – De Aar railway line and the accompanying service road.

The geological and palaeontological observations have been related to points (mainly existing stations) along the Kimberley to De Aar railway line as a convenient way of subdividing this long linear study area. The geographic positions of these fourteen points are shown in Figure 1 and they are also indicated on the geological maps in Figures 3 to 6.

The terrain within the study area is generally very flat with little natural bedrock exposure, so most of the useful sites are within existing borrow pits, as well as quarries, road and railway cuttings. In many railway sectors useful natural or artificial rock exposures are not available so paleontological sensitivity here needs to be inferred from exposures in the broader study region.

Only very sparse fossil material (almost exclusively trace fossils) was noted during the present survey along the railway line (Section 5). Unless noted otherwise, no fossils were found at the sites examined and described below. GPS locality data for all numbered sites mentioned in the text are provided in an appendix. The hammer used as scale in most of the field photographs is 27 cm long.

4.1. Beaconsfield & Spytfontein

These two stations are entirely underlain by extensive subhorizontal sheets (sills) of Karoo Dolerite (Jd) (Fig. 3). These major igneous bodies have been intruded within the Lower Ecca Group mudrocks (Ppr, Pw), usually in close association with the Whitehill Formation, which are extensively baked in consequence (Bosch 1993). Good exposures of both weathered and fresh Karoo dolerite are exposed in the extensive OMV Crushers quarry on the eastern side of the railway some 6.45 km NNE of Spytfontein station (28º 49’ 18.95” S, 24º 42’ 51.09” E; Fig. 7). The uppermost few meters of dolerite here are weathered, reddened and intruded with calcrete veins, and the outcrop is mantled with reddish sands. Road cuttings exposing typical onionskin weathering and rounded corestones within weathered dolerite are seen on the west side of the R29 / N12 shortly south of Spytfontein. Large blocky, weathered-out dolerite corestones are seen adjacent to the railway tracks near Magersfontein (Loc. 901).

Some 0.32 km south of Spytfontein deeply-weathered, dipping blue-grey Ecca shales are exposed in a borrow pit (Loc. 901). The shales – probably belonging to the Prince Albert Formation - are transected by veins of secondary ferruginous minerals and intruded by well-jointed dolerite (Fig. 8). No fossils were observed here.

Fig. 7. Exposure of fresh Karoo dolerite in a quarry adjacent to the railway line *c*. 6.45 NNE of Spytfontein (Photo by kind permission of OMV Crushers).

Fig. 8. Deeply-weathered Lower Ecca shales (probably Prince Albert Formation) intruded by dolerite, borrow pit *c*. 0.32 km south of Spytfontein (Loc. 901).

Several Kimberlite pipes of Late Cretaceous age (77-120 Ma) are mapped on the south-eastern margins of Kimberley near Beaconsfield as well as *c*. 10 km NNE of Spytfontein, but none lie close to the railway study area. The dolerite bedrocks are mantled by calcrete (Qc) and Kalahari sands (Qs). Deep-hued orange-brown aeolian sands of the Gordonia Formation can be seen near Ronald's Vlei, for example.

4.2. Modderrivier

The Modderrivier station, about 2 km north of the Rietrivier, is underlain by Karoo dolerite that intrudes the Lower Ecca Group (Ppw) in this region (Fig. 4). There is no useful bedrock exposure at the station site. The Ecca sediments and dolerites are mantled with Quaternary sands (Qg) and calcretes (Qc) in this area and overlie much older, late Archaean, volcanics of the Venterdorp Supergroup shortly to the north.

Extensively calcretised, deeply-weathered, grey-green micaceous Ecca shales are well-exposed in a borrow pit *c*. 8.12 km north of Modderrivier station (Loc. 903). The calcrete is variously nodular or forms a surface hardpan up to 1.5 m thick. Extensive sheets and veins of calcrete penetrate down into the Ecca Group bedrocks along joints and other fractures, causing local buckling of the shale bedding (Fig. 9). Thicker surface developments of calcrete contain reworked clasts of older calcretes as well as gravels, perhaps infilling previous hollows in the landscape.

Isolated boulders and blocks of Ventersdorp Supergroup rocks are seen at various points along the railway line north of Modderrivier (*e.g.* Locs. 903, 904). These are well-jointed, grey-green lavas of the Allanridge Formation (Ra) that often display abundant empty gas vesicles or mineral-infilled amygdales up to 2 cm across towards the top of individual flows (Fig. 10); elsewhere the lavas are massive and porphyritic.

The Karoo bedrocks are covered by silty alluvium along banks of the Rietrivier. 1.68 km southwest of the river a borrow pit exposes well-developed calcrete veining within greenish-buff sandy alluvium overlying highly weathered dolerite (Loc. 905). A rubbly surface of reworked calcrete gravels can be seen here (Fig. 11).

Fig. 9. Lower Ecca shales cut by steep sheets and veins of calcrete *c*. 8.12 km N of Modderrivier station (Lcc. 903).

Fig. 10. Boulder of Allanridge Formation (Ventersdorp Supergroup) lava showing abundant gas bubbles or vesicles (Loc. 903).

Fig. 11. Greenish-buff alluvium heavily veined with calcrete and overlain by coarse calcrete gravels, c. 1.68 km southwest of the Rietrivier (Loc. 905)

4.3. Heuningneskloof

The Heuningneskloof station area is underlain by Karoo dolerite (Jd) mantled with Quaternary calcrete (Qc) (Fig. 4). A small borrow pit *c*. 9.6 km northeast of the study site (Loc. 906, Fig. 12) exposes over 2 m of orange-brown Kalahari sands of aeolian origin (Gordonia Formation, Qg). The sands are well-sorted, contain sparse gravel clasts (*e.g.* of calcrete) and have been locally disturbed by plant roots (rhizoturbation).

Excellent sections through thick, false-bedded surface calcrete hardpan are exposed in a deep, trench-like borrow pit 1.76 km NE of the station (Loc. 908). The underlying dolerite is not visible here. Several generations of mature calcretes are developed here separated by reddish sandy soils (Figs. 13-14). The base of the uppermost calcrete hardpan contains lenses of coarse angular gravels of hornfels as well as weathered dolerite. Subfossil plant root systems are preserved as ferruginous rootlets as well as calcretised rhizoliths up to 10 cm across (Fig. 14). Similar well-developed hardpans can be seen in a pair of borrow pits *c*. 1.32 km SW of Heuningneskloof (Locs. 909, 910). Here the carbonaceous remains of subfossil plant rootlets are still preserved within the hardpan (Fig. 15).

Fig. 12. Typical orange-brown hued aeolian sands of the Gordonia Formation (Kalahari Group), *c*. 9.6 km NE of Heuningneskloof station (Loc. 906).

Fig. 13. Thick, mature calcrete hardpan showing false bedding and possible vertical rhizoliths, borrow pit *c*. 1.76 km NE of Heuningneskloof (Loc. 908).

Fig. 14. Dense development of subvertical calcretised rhizoliths (root casts) towards base of calcrete hardpan overlying reddish sandy soils north of Heuningneskloof (Loc. 908).

Fig. 15. Carbonaceous remains of subfossil rootlets embedded in calcrete hardpan, borrow pit 1.32 km SW of Heuningneskloof (Loc. 909).

Fig. 16. Thinly-bedded, baked mudrocks of the Tierberg Formation exposed in a borrow pit c. 4.25 km SW of Heuningneskloof (Loc. 911).

Good exposures of thinly-bedded, tabular mudrocks of the Tierberg Formation (Pt) are seen in a borrow pit 4.25 km SW of Heuningneskloof station (Loc. 911). The sediments are buff-coloured to grey or grey-green, finely-laminated (Fig. 16) and have been baked by a dolerite intrusion that is exposed in the floor of the pit, imparting a tough weathering character. Thin calcrete layers have developed along some of the bedding planes. No fossils were observed at this site.

4.4. Graspan

The station at Graspan is underlain by basinal mudrocks of the Lower Ecca Group (Ppw, Ecca Group) that are intruded by Karoo dolerites (Jd) and overlain by Quaternary calcrete (Qc) (Fig. 4). Good exposures of the Ecca mudrocks (probably Prince Albert Formation), baked and intruded by dolerite, are seen in a series of shallow to deep borrow pits on the southern outskirts of the station (Fig. 17, Loc. 914). The mudrocks are locally calcretised and ferruginised near-surface and have been hardened due to thermal metamorphosis. Interbedded grey-green siltstones and thin, tabular, buff-coloured wackes (possibly distal turbidites) display locally abundant, low-diversity trace fossil assemblages comprising a range of simple horizontal burrows ("*Planolites*" / "*Palaeophycus*") of various dimensions (Figs. 18 and 19). Some burrows appear to branch, but this may well be due to overlap.

Highly baked grey-green Ecca shales (Ppw or Pt) are also exposed in a borrow pit 4.38 km SW of Graspan (Loc. 915) but no trace fossil assemblages were recorded here. Just north of Graspan calcrete overlying dolerite is exposed in a borrow pit (Loc. 913). In a shallow borrow pit some 4.62 km NE of Graspan weathered dolerite is capped by *c*. 0.5 m of bright orange-brown, finely-gravelly soils containing sparse, dispersed larger clasts of hornfels (Fig. 20). All these larger "exotic" clasts appear to be flaked (LSA, MSA) suggesting that these surface deposits are no older than Pleistocene.

Fig. 17. Deep borrow pit at Graspan showing well-bedded Lower Ecca mudrocks intruded and displaced by a dolerite sill (dark grey-green), Loc. 914.

Fig. 18. Baked Lower Ecca siltstones showing abundant, secondarily ferruginised horizontal burrows, Graspan (Loc. 914) (Scale = *c*. 16 cm).

Fig. 19. Bioturbation of Lower Ecca sandstone bed by at least two forms of simple horizontal burrows, Graspan (Loc. 914).

Fig. 20. Orange-brown finely-gravelly soils overlying dolerite in a borrow pit 4.62 km NE of Graspan (Loc. 912). The larger embedded gravel clasts are of hornfels and are all anthropogenically flaked.

4.5. Belmont and Witput

The stations at Belmont and Witput are underlain by Quaternary calcrete (Qc) overlying Jurassic dolerites (Jd) that in this area intrude sediments of the Tierberg Formation (Ecca Group, Pt) (Fig. 5). The Ecca bedrocks are not well-exposed close to the railway line in these areas, however. Highly-weathered dolerite showing a platy weathering style and extensively penetrated by calcrete veins is exposed in a shallow borrow pit *c*. 2.21 km NE of Belmont (Fig. 21, Loc. 916). The dolerite is overlain by thin reddish soils which also mantle calcrete hardpans in the region. A large salt pan (Chalk Farm Salt Pan) is situated over Lower Ecca Group mudrocks (Ppw) 5 km to the NE of Witput Station.

No fossils were observed within the Ecca sediments in this area. Their palaeontological sensitivity is rated as LOW. It is noted that rare body fossils – including fish scales, coprolites and sponge spicules - are recorded from concretions within the lower part of the Tierberg Formation at Kafferskop, some 4 km SE of Belmont, by Visser *et al.* (1977, p. 162).

Fig. 21. Platy-weathering Karoo dolerite traversed by a network of calcrete veins at Loc. 916, 2.21 km NE of Belmont.

4.6. Oranjerivier

The station at Oranjerivier is underlain by Quaternary calcrete (Qc) as well as alluvium (Fig. 5). These Late Caenozoic superficial deposits mantle Lower Ecca Group sediments (Ppw) that are extensively intruded in this area by Jurassic Karoo dolerites (Jd). There are no exposures of potentially fossiliferous Ecca bedrocks in the station area.

Good railway cuttings through several meters of alluvial deposits are present between the station and the Orange River to the north (Loc. 917) (Fig. 22). Weathered, flaky grey Lower Ecca shales (probably Prince Albert Formation) are unconformably overlain by a thin (few dm) horizon of well-rounded pebbles and cobbles (mainly reworked dolerite corestones, also hornfels), partially calcretised, and then some 3 m of silty brownish-buff alluvium with sparsed dispersed gravels. Massive to bedded surface gravels on top largely comprise dolerite and hornfels.

Fig. 22. Alluvial deposits of the Orange River (basal calcretised cobble layer, silts with sparse gravels, surface gravel horizon) overlying Lower Ecca Group mudrocks in railway cutting north of Oranjerivier Station (Loc. 917).

Reasonably good exposures of Lower Ecca sediments are seen on the north-facing slopes of the dolerite-capped Doringbult koppies between Oranjerivier Station and Hopetown. Fossils of notocarid crustaceans have been recorded from carbonaceous mudrocks of the Whitehill Formation near Oranjerivier by Kensley (1975).

4.7. KOR Loop

The KOR loop area situated some 300-400 m west of the edge of the large Reynekespan is underlain by calcrete capping mudrocks of the Tierberg Formation (Ecca Group) (Fig. 5). Pale, calcretised sediments deflated from several pans in this area can be clearly seen on satellite images stretching south and south-eastwards as far as Kraankuil Station and beyond. Excellent exposures through the grey Ecca mudrocks and the associated Quaternary calcretes are seen in a deep trench adjacent to the KOR station area (Loc. 919). The Tierberg shales are crumbly, baked by dolerite intrusions, and extensively cut by numerous veins, horizons and occasional pillars of calcrete (Fig. 23). Elongate, oblate diagenetic concretions of buff to rusty-brown colour are abundant at some horizons within the Ecca succession (Fig. 24). They are probably siliceous in composition, slightly ferruginised and apparently unfossiliferous.

Horizontal and vertical expansion due to precipitation of large volumes of pedogenic limestone within fractures and along bedding planes has caused small-scale buckling, folding, faulting (block faulting, imbricate thrusting) and other disruption of the Ecca bedrocks (This probably applies to the bedrocks underlying the pan areas) (Fig. 25). Pillars of calcrete up to a meter wide are of uncertain origin; they are possibly related to plant root systems (*i.e.* megarhizoliths) (Fig. 26). Reworked calcrete gravels mantle the calcretised bedrocks. At the southern end of the pit buff soils contain abundant reworked calcrete clasts as well as occasional blocks of hornfels and are mantled by downwasted calcrete surface gravels (Fig. 27).

No fossil remains were observed in this area. It is noted, however, that important fossil mammal remains have been recorded in association with ancient pan sediments in the Northern Cape. For example, Late Pleistocene Florisian Mammal Age (estimated 300-200 000 BP) have been recorded from pan sediments at Bundu Pan 22 km to the northwest of Copperton (Kiberd 2006), and somewhat younger fossil teeth are reported from subsurface gravels in a borrow pit on the farm Hoekplaas, also near Copperton (Almond 2012d and refs. therein).

Fig. 23. Deep borrow pit into extensively calcretised Tierberg Formation mudrocks at KOR loop site (Loc. 919).

Fig. 24. Elongate oblate siliceous nodules within the Tierberg Formation at KOR loop area (Loc. 919).

Fig. 25. Folding and thrusting of Ecca mudrocks as a result of expansion due to extensive calcrete precipitation (Loc. 919).

Fig. 26. Pillar-like structure of calcrete penetrating Ecca mudrocks – possibly related to plant root systems or a bedrock fracture or groundwater conduit (Loc. 919).

Fig. 27. Well-consolidated buff soils with abundant clasts of reworked calcrete overlying calcrete hardpan at Loc. 919. Note also downwasted surface gravels of calcrete here.

4.8. Kraankuil

The station at Kraankuil is underlain by mudrocks of the Tierberg Formation (Pt) that are mantled with alluvium and backed by the intrusion of dolerites (Jd) (Fig. 5). Good exposures of heavily-calcretised grey-green, laminated Tierberg mudrocks are seen in a borrow pit 3.82 km to the north (Fig. **) (Loc. 920). The mudrocks here contain diagenetic concretions of ferruginous carbonate. Crumbly, calcretised Tierberg mudrocks are also exposed in a large pit *c*. 450 m west of the station area (Loc. 921) where they are capped by orange-brown soils (Fig. 29). Surface gravels in this area consist of reworked hornfels, ferruginous siliceous nodules as well as ferruginous carbonate nodules showing cone-in-cone structure (see below).

Crumbly grey-green Tierberg shales are exposed in roadside borrow pits 4.4 km and 6.9 km south of Kraankuil (Locs. 922, 923). The Ecca rocks here contain large, lenticular to reniform, rusty-brown, ferruginous carbonate concretions up to 30 cm thick and several meters across (Fig. 31). Many of the nodules show well-developed cone-in-cone structures that have a superficial resemblance to stromatolites but are in fact generated abiotically during precipitation under considerable overburden pressure (Fig. 32); they are a common form of pseudofossil.

The Ecca bedrocks in this area are covered by pale orange-brown, well-consolidated (calcified), sandy and sparsely gravelly older soils that contain occasional flaked hornfels artefacts and are therefore Pleistocene age or younger. The overlying younger soils are buff and contain reworked calcrete gravels (Figs. 30 & 33). Surface gravels include reworked hornfels artefacts.

Fig. 28. Grey laminated Tierberg Formation mudrocks traversed by calcrete veins and sheets to the north of Kraankuil (Loc. 920)

Fig. 29. Borrow pit at Kraankuil Station showing calcretised Tierberg Formation mudrocks overlain by reddish soils and surface gravels (Loc. 921).

Fig. 30. Weathered Tierberg shales overlain with well-consolidated orange-brown older soils in a borrow pit 6.9 km south of Kraankuil Station (Loc. 923).

Fig. 31. Large reniform diagenetic concretion of ferruginous carbonate within the Tierberg Formation at Loc. 922, some 4.4 km south of Kraankuil Station.

Fig. 32. Close-up view of the surface of a ferruginous carbonate nodule at Loc. 922 showing abiotic stromatolite-like lamination that is known as cone-in-cone structure. Field of view *c*. 15 cm across.

Fig. 33. Soil profile overlying Tierberg mudrocks at borrow pit Loc. 922 showing older, well-calcified soils below and younger soils with sparse calcrete gravels above.

4.9. Poupan

The station at Poupan is underlain by Quaternary alluvium and calcrete (Qc) (Fig. 6). The underlying Tierberg Formation (Pt) bedrocks are extensively intruded by Jurassic dolerites (Jd). A large borrow pit on the northern edge of the Poupan area (Loc. 924) exposes Tierberg mudrocks overlain by a thick (several meters) succession of reddish-brown soils with nodular calcrete that are capped by a mature, prominent-weathering calcrete hardpan (*c*. 1.5 m thick) (Fig. 34). Overlying the hardpan are 2-3 m of orange-brown, well-sorted, semi-consolidated aeolian sands of the Gordonia Formation containing sparse fine gravel clasts (Fig. 35). Surface gravels are absent here.

Fig. 34. Calcretised sandy soils overlain by a calcrete hardpan and then orange-brown aeolian sands of the Gordonia Formation, large borrow pit at Poupan (Loc. 924).

Fig. 35. Close-up of orange-brown, well-sorted aeolian sands overlying the calcrete hardpan at Poupan (Loc. 924).

4.10. Potfontein

The station at Potfontein is underlain by Quaternary alluvium and calcrete (Qc) (Fig. 6). The underlying Tierberg Formation (Pt) bedrocks are extensively intruded by Jurassic dolerites (Jd). Good exposures of thick, mature calcrete hardpan are seen in several borrow pits the Kalkbult area some 7.3 km NNE of Potfontein Station (*e.g.* Loc. 925) (Fig. 36). The hardpan here is over 4 m thick and somewhat brecciated in the upper part. It is overlain by calcrete gravels and thin orange-brown soils. Railway cuttings through Karoo dolerite and dolerite corestones occur 3.3 km north of Potfontein.

Fig. 36. Thick mature calcrete hardpan exposed in a borrow pit in the Kalkbult area (Loc. 925), *c.* 7.3 km NNE of Potfontein station.

A deep cutting through calcretised superficial sediments is seen in a large roadside borrow pit *c*. 6.25 km south of Potfontein Station (Loc. 926) (Fig. 37). The floor of the pit is sandy. It is overlain by a thick lower calcrete hardpan (4 or more m thick) containing gravel lenses. The gravels are angular to water-worn and subrounded (Fig. 38). They include reworked calcrete pebbles, mudrock, hornfels and dolerite and are locally crudely bedded. Flaked hornfels clasts are quite common at surface here, but it was not established if they are weathering out of these lower gravels or come from higher up in the succession. The main hardpan is overlain by a thick succession of nodular calcretised sands and thin hardpans as well as thin gravel lenticles. Vertical cracks are infilled with calcrete (Fig. 39). Orange-brown calcretised sandy soils form a ledge above this sequence. The base of the ledge contains subrounded sheetwash gravels. At the top of the exposure are downwasted surface gravels composed of hornfels (some flaked), mudrock, calcrete and dolerite. The complexity of this succession probably reflects fluctuating Pleistocene climates.

Fig. 37. Thick lower calcrete hardpan overlain by nodular calcretised orange-brown sands, borrow pit 6.25 km S of Potfontein (Loc. 926).

Fig. 38. Detail of poorly-sorted polymict gravels embedded within the thick lower calcrete hardpan at Loc. 926.

Fig. 39. Thick reddish-brown sandy soils with nodular calcrete overlying main calcrete hardpan at Loc. 926.

4.11. Houtkraal

The station at Houtkraal is underlain by Quaternary calcrete (Qc) overlying dolerite and the Tierberg Formation (Pt) (Fig. 6). Sections through deep calcrete hardpans are exposed in borrow pits 7.63 km to the north (Loc. 927). At Houtkraal itself can be seen low dolerite koppies with corestones and thin reddish soils (Fig. 40). Surface gravels contain abundant hornfels, some of which is flaked.

A sizeable borrow pit at Houtkraal Station (Loc. 929) exposes deeply calcretised greyish Tierberg Formation mudrocks capped by a thick calcrete hardpan (Fig. 41). This is overlain in turn by sandy soils capped by a second, younger calcrete hardpan and then Recent soils with abundant flaked hornfels artefacts. The thick upper hardpan also contains weathered / patinated rusty-brown hornfels artefacts. A witness section in the pit exposes lenticles of poorly-sorted gravels up to 1m thick towards the base of the upper hardpan. The gravels comprise platy mudrock clasts, weathered dolerite, hornfels and rounded reworked calcrete cobbles (Fig. 42).

Fig. 40. Low bult or koppie of Karoo dolerite at Houtkraal showing desert-varnished corestones. Renosterberg in the background.

Fig. 41. Calcretised Tierberg shales overlain by soils and a thick upper calcrete hardpan, borrow pit at Houtkraal Station (Fig. 929).

Fig. 42. Detail of thick upper calcrete hardpan at Houtkraal Station (Loc. 929) showing poorly-sorted basal gravels.

Gulley erosion close to the railway line due west of Loskop and *c*. 14.37 km SSW of Houtkraal Station (Locs. 930-932) has exposed dark grey laminated Ecca mudrocks containing large sphaeroidal ferruginous carbonate concretions (Fig. 43). Buff, well-indurated gravelly soils and calcrete overlying the Ecca bedrocks contain abundant embedded artefacts (Fig. 44). Extensive sheets of alluvial and downwasted surface gravels in this area consist largely of hornfels clasts, a high proportion of which are flaked, as well as platy mudrock and calcrete and occasional cryptocrystalline silica (MSA, LSA) (Fig. 45). Artefacts vary in the degree of development of a surface patina and some are water-worn while others appear much sharper and fresher. Rare fragments of silicified wood that have weathered out of the Ecca Group here also occur at surface (Fig. 46). This suggests that upper Ecca Group bedrocks are present here, equivalent to the Carnarvon facies of the Waterford Formation, rather than the Tierberg Formation as mapped (See Section 2.3).

Fig. 43. Upper Ecca Group mudrocks containing large ferruginous carbonate concretions near Loskop (Loc. 931).

Fig. 44. Buff, well-consolidated gravelly alluvial soils overlying Ecca Group bedrocks at Loc. 931. The gravels here contain abundant flaked hornfels artefacts.

Fig. 45. Downwasted surface gravels near Loskop (Loc. 932) including numerous flaked hornfels artefacts.

Fig. 46. 6 cm–long fragment of silicified wood weathered out from the upper Ecca Group (Waterford Formation equivalent), surface gravels at Loc. 932 near Loskop, *c*. 14.4 km south of Houtkraal Station. The Middle Permian fossil wood shows well-developed seasonal growth lines.

At locality 933, 17.4 km SSW of Houtkraal the surface gravels are dominated by weathered dolerite clasts with minor hornfels, commonly flaked (Fig. 47).

Thick orange-brown silty and sandy alluvium is exposed in dongas at Loc. 934, some 18.4 km SSW of Houtkraal. Finer material here may be reworked by winds. The silty and sediments are partially calcretised and overlie alluvial gravels of blackish hornfels (often flaked), dolerite and calcrete (Fig. 48). Coarser gravels in stream beds are often heavily calcretised and contain flaked artefacts.

A good exposure of *in situ* fine-grained black hornfels capped by dolerite is exposed in a small quarry just north of a stream bed at Loc. 935, some 23.3 km SSW of Houtkraal (Fig. 49). The fresh hornfels here is black, fine-grained and shows an excellent conchoidal fracture.

Fine, well-sorted surface gravels at Loc. 936, on the south side of the stream bed some 23.76 SSW of Houtkraal and 6 km north of De Aar, underlie thin silty alluvial soils (Fig. 50). The gravels contain abundant flaked hornfels artefacts as well as fairly common small fragments of silicified wood. The latter have weathered out of the underlying upper Ecca Group rocks and are common within surface gravels in the De Aar area (Almond 2012a, 2012b) (Fig. 51).

Fig. 47. Dolerite-rich surface gravels to the southwest of Loskop (hill in the background built of Lower Beaufort Group sediments capped by dolerite) (Loc. 933).

Fig. 48. Reddish-brown, fine-grained alluvium at Loc. 934 showing moderate levels of calcretisation. Stream gravels here are calcretised and rich in hornfels artefacts.

Fig. 49. Dark-grey weathering massive hornfels capped by rusty brown dolerite at Loc. 935, 23.3 km SSW of Houtkraal.

Fig. 50. Silty alluvial soils underlain by fine gravels at Loc. 936 on the northern outskirts of De Aar.

Fig. 51. Close-up of surface gravels at Loc. 936 showing occasional fragments of silicified wood (arrowed) as well as calcrete clasts and abundant flaked hornfels.

5. CONCLUSIONS AND RECOMMENDATIONS

The construction phase of the proposed developments along the Transnet Kimberley - De Aar 16 Mtpa manganese ore railway would entail only minor excavations into the superficial sediment cover as well as locally into the underlying bedrock. These excavations might disturb, damage or destroy scientifically valuable fossil heritage exposed at the surface or buried below ground. Other infrastructure components (*e.g.* construction camps) may seal-in buried fossil heritage, but this will be temporary. 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.

Desktop and field-based surveys of the railway line between Kimberley and De Aar show that (1) only a limited range of rock units will be directly affected by the proposed developments and (2) none of these rock units as exposed within the study area are of high palaeontological sensitivity near-surface. Well-preserved fossil remains may occur within fresher (unweathered) bedrocks at depths of many meters, but these are unlikely to be directly affected by the proposed railway developments.

Igneous rocks such as Late Archaean (2.7 billion years old) lavas of the Ventersdorp Supergroup and the Early Jurassic Karoo dolerites are entirely unfossiliferous. Permian marine to non-marine basinal mudrocks of the Lower Ecca Group (Prince Albert and Whitehill Formations) are palaeontologically sensitive in some areas of the Northern Cape (*e.g.* Kimberley, Douglas). However, their original fossil heritage has been seriously compromised along the Kimberley – De Aar railway line due to (1) baking by dolerite intrusions, (2) near-surface weathering as well as (3) extensive formation of calcrete (pedogenic limestone) in Quaternary times. The same applies to stratigraphicallly higher subunits of the Ecca Group such as the Middle Permian Tierberg and Waterford Formations whose original palaeontological sensitivity is ranked as medium. A very high proportion of the pre-Caenozoic bedrocks in the study area are covered with a thick (several meters or more) mantle of Late Caenozoic deposits, notably Quaternary calcrete hardpans, Kalahari sands (Gordonia Formation), surface gravels, alluvium and soils so that they are mainly exposed only in borrow pits, railway and road cuttings. These superficial deposits are generally of low palaeontological sensitivity.

Only very limited fossil to subfossil remains were observed within sedimentary rocks along the Kimberley - De Aar railway line during the present field study. Low diversity trace fossil assemblages occur within Lower Ecca mudrocks (probably Prince Albert Formation) at Graspan. Stromatolite-like structures within large (meter-scale) nodules of the Tierberg Formation (*e.g.* Kraankuil area) are pseudofossils, formed abiotically during late diagenetic carbonate precipitation. Calcretised rhizoliths, and occasional carbonaceous rootlets, occur within and at the base of calcrete hardpans, such as in the Heuningneskloof area. Small fragments of petrified wood are quite common among surface gravels overlying the Waterford Formation (erroneously mapped as Tierberg Formation) between Houtkraal and De Aar. Anthropogenically flaked hornfels clasts are a common component of surface gravels along much of the railway line and, apart from their obvious archaeological importance, are of geological interest in constraining the age of superficial sediment horizons (*e.g.* alluvial gravels, older consolidated soils) within which they are occasionally embedded.

Due to the low to very low palaeontological sensitivity of all rock units encountered along the Kimberley - De Aar sector of the manganese ore export railway line, the proposed developments are rated as of low palaeontological heritage significance. There are therefore no objections on palaeontological heritage grounds to the proposed developments and no further specialist studies are recommended here, pending the discovery of significant new fossils during the construction phase.

It is recommended that:

- The Environmental Officer (EO) responsible for the railway development should be aware of the possibility of important fossils (*e.g.* mammalian bones, teeth) being present or unearthed on site and should regularly monitor all substantial excavations into superficial sediments as well as fresh (*i.e.* unweathered) sedimentary bedrock for fossil remains;

- In the case of any significant fossil finds (*e.g.* vertebrate teeth, bones, burrows, petrified wood) made during construction, these should be safeguarded - preferably *in situ* - and reported by the EO as soon as possible to the relevant heritage management authority (SAHRA, Cape Town. Contact details: SAHRA, 111 Harrington Street, Cape Town. PO Box 4637, Cape Town 8000, South Africa. Phone: +27 (0)21 462 4502. Fax: +27 (0)21 462 4509. Web: www.sahra.org.za) so that appropriate mitigation (*i.e.* recording, sampling or collection) by a palaeontological specialist can be considered and implemented, at the developer's expense; and

- These recommendations should be incorporated into the Environmental Management Plan (EMP) for the manganese ore export railway line project.

The palaeontologist concerned with mitigation work will need a valid collection permit from SAHRA. All work would have to conform to international best practice for palaeontological fieldwork and the study (*e.g.* data recording fossil collection and curation, final report) should adhere to the minimum standards for Phase 2 palaeontological studies recently published by SAHRA (2013).

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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.

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

APPENDIX: GPS LOCALITY DATA FOR NUMBERED SITES LISTED IN TEXT

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

Location number	South	East
899	S28 50 55.6	E24 41 59.1
900	S28 51 20.6	E24 41 52.2
901	S28 52 46.1	E24 41 07.4
902	S28 54 54.7	E24 40 17.7
903	S28 57 11.6	E24 39 36.9
904	S29 00 14.0	E24 38 42.5
905	S29 03 06.6	E24 37 06.5
906	S29 07 26.6	E24 35 02.0
907	S29 11 08.5	E24 32 53.7

Location number	South	East
908	S29 11 10.3	E24 32 53.1
909	S29 12 41.8	E24 31 58.4
910	S29 12 39.3	E24 32 00.5
911	S29 14 02.9	E24 31 05.0
912	S29 17 06.1	E24 28 35.1
913	S29 18 52.4	E24 27 03.1
914	S29 19 12.9	E24 26 50.2
915	S29 21 04.7	E24 25 22.4
916	S29 24 03.3	E24 22 53.4
917	S29 39 22.9	E24 12 24.3
918	S29 39 33.8	E24 12 24.6
919	S29 46 04.2	E24 12 03.6
920	S29 50 47.1	E24 11 12.2

Location number	South	East
921	S29 52 54.5	E24 10 29.6
922	S29 55 10.9	E24 10 19.6
923	S29 56 29.7	E24 10 06.3
924	S30 01 48.5	E24 09 09.1
925	S30 08 21.5	E24 08 02.5
926	S30 15 34.5	E24 06 34.3
927	S30 18 59.3	E24 06 09.0
928	S30 22 32.6	E24 05 48.6
929	S30 23 17.4	E24 05 45.2
930	S30 30 32.2	E24 03 07.5
931	S30 30 32.2	E24 03 07.8
932	S30 30 31.1	E24 03 08.2
933	S30 31 57.9	E24 02 25.0
934	S30 32 33.1	E24 02 16.6
935	S30 35 11.6	E24 01 43.4
936	S30 35 30.7	E24 01 37.8
937	S30 35 51.0	E24 01 37.2