PALAEONTOLOGICAL HERITAGE STUDY: COMBINED DESKTOP AND FIELD-BASED ASSESSMENT

Rehabilitation of National Route 6, Section 4, to the south of and along Penhoek Pass between Queenstown and Jamestown, Eastern Cape

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1. SUMMARY

The South African National Roads Agency Limited (SANRAL) are proposing to rehabilitate some 14 km of the N6 tar road to the south of as well as along the Penhoek Pass between Queenstown and Jamestown, Eastern Cape. The study area is largely underlain by Late Triassic fluvial sediments of the Molteno and Elliot Formations (Stormberg Group, Karoo Supergroup) that are extensively mantled by Late Caenozoic superficial sediments (*e.g.* soil, colluvium) and intruded by Jurassic dolerite sills and dykes.

Apart from poorly-preserved, ill-defined trace fossils within sandstones of the Molteno and Elliot Formations, no palaeontological material was observed during field assessment within the Karoo Supergroup bedrocks or superficial sediments along Section 4 of the N6, including the BP01 borrow pit site. The HRQ1 hard rock quarry near Jamestown is excavated into unfossiliferous dolerite. Rehabilitation of the southern portion of Section 4 that overlies Molteno Formation beds will not involve substantial new bedrock excavations and is therefore unlikely to have a significant impact on local fossil heritage. Realignment of road sections along the Penhoek Pass will generate fresh cuttings through the Elliot Formation “red beds” which may expose fossil vertebrate remains such as early dinosaurs, advanced therapsids and amphibians but these are likely to be scarce. Due to extensive superficial sediment cover and weathering the overall palaeontological sensitivity of the study area is rated as LOW and, pending the discovery of significant fossil material during construction, no further palaeontological heritage studies or mitigation are recommended for this project.

Should substantial fossil remains be exposed during construction, however, such as vertebrate bones and teeth, plant-rich fossil lenses or dense fossil burrow assemblages, the ECO should safeguard these, preferably *in situ*, and alert SAHRA as soon as possible so that appropriate action (*e.g.* recording, sampling or collection) can be taken by a professional palaeontologist.

2. OUTLINE OF DEVELOPMENT

The South African National Roads Agency Limited (SANRAL) are proposing to rehabilitate some 14 km of the N6 tar road to the south of as well as along the Penhoek Pass between Queenstown and Jamestown, Eastern Cape (Figs. 1, 2). The proposed engineering works entail the widening of the pass by approximately 5m to extend the climbing lane along the full length of the pass, the widening of stormwater structures and rehabilitation of the roadway approaching the pass. All work is planned to take place within the existing road reserves.

The following brief project description has kindly been provided by Arcus GIBB (Pty) Ltd who have been appointed as the Environmental Assessment Practitioner for this road project:

> The project involves the rehabilitation of National Route 6, section 4, south of and at Penhoek Pass between kilometres 52.0 and 66.2. The section of the road before the Penhoek Pass will only be rehabilitated. The existing road reserve is approximately 32 m. The design cross section for the road will be two 3.7 m lanes with two 2.0 m paved shoulders before the pass.
>
> The scope of the project includes the lengthening of the existing climbing lane from the foot of the pass (at km 61.2) to the summit (at km 65.9). The effect of this will be an overall widening of the roadway by approximately 5.0 m. The cross section in the pass will be two 3.5 m lanes in a northerly direction and one 3.7 m lane south with two 1.0 m paved shoulders and a 2.5 m concrete drain.
>
> The horizontal alignment starts on the existing alignment and starts to deviate to the east with 1.6 m over the first straight. Over the first horizontal curve the alignment reverts back to the existing alignment to cross over the existing rail bridge. The alignment then starts to deviate around the second horizontal curve into the pass with a deviation of 2 m to the north to accommodate the climbing lane. The alignment reverts back to the existing at the crest of the pass.
>
> The scope includes the widening of stormwater structures along the entire project where appropriate. All 450 mm diameter pipes will be replaced.
>
> Material for the construction of the road will be sourced from an existing borrow pit (at position 31°28'55"S, 26°42'36"E, and an existing hard rock quarry at position 31°16'12"S, 26°43'51"E along the N6. The application for these borrow pits is in process and will be submitted to the Department of Mineral Resources.
>
> Since the proposed activities will constitute a linear development of longer than 300 m, input will also be required from the Provincial Heritage Authority in terms of Section 38 of the National Heritage Resources Act (NHRA). As per the provisions of Section 38(8) of the Act, it is envisaged that the requirements will be met in part through the Basic Assessment.
>
> To provide further context for this Basic Assessment, the permitting of the materials sources required for the project will have to be undertaken in accordance with the Regulations pertaining to the Minerals and Petroleum Resources Development Act. Specifically, since this is a SANRAL project, the exemptions provisions of Section 106(1) of the Act will apply, and thus use of any materials sources would be subject to the preparation of an Environmental Management Programme compiled in accordance with Regulation 51 of the MPRDA for the hard rock quarry and the borrow pits that are envisaged to be used.

The present combined desktop and field-based palaeontological heritage assessment has been commissioned by Arcus GIBB (Pty) Ltd as part of the Basic Assessment of the proposed development (Contact details: Dr Norbert Klages, 2nd Floor, Greyville House, Cnr Greyville & Cape Rd, Greenacres, Port Elizabeth 6045; PO Box 63703, Greenacres 6057; Tel: (041) 392 7500; Fax: 041 363 9300; Email: nklages@gibb.co.za).

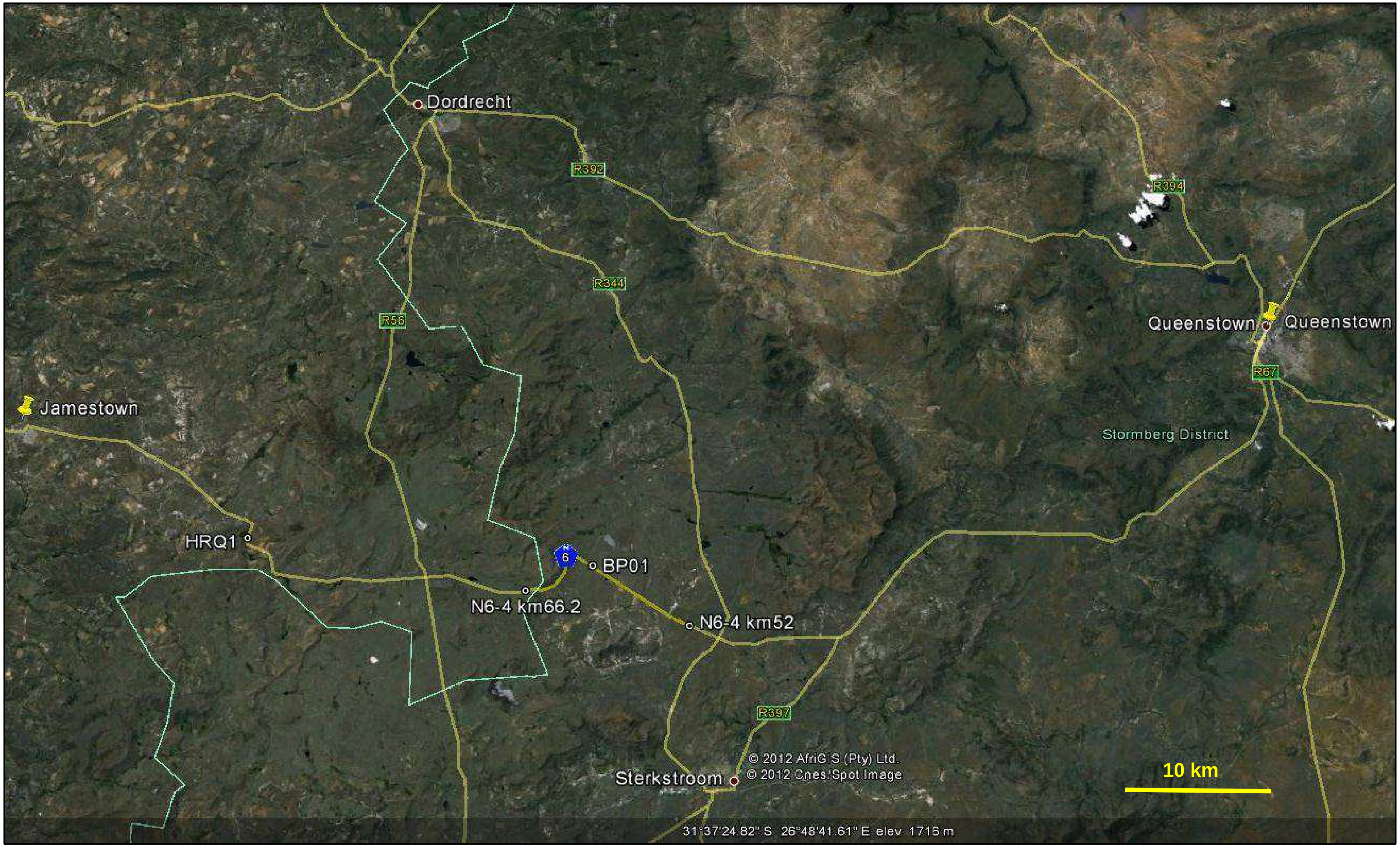

Fig. 1. Google Earth© satellite image of the area between Queenstown and Jamestown, Eastern Cape, showing Section 4 of the N6 (km 52 to 66) as well as the sites of the existing borrow pit (BP01) and hard rock quarry (HRQ1). Note North is to the left.

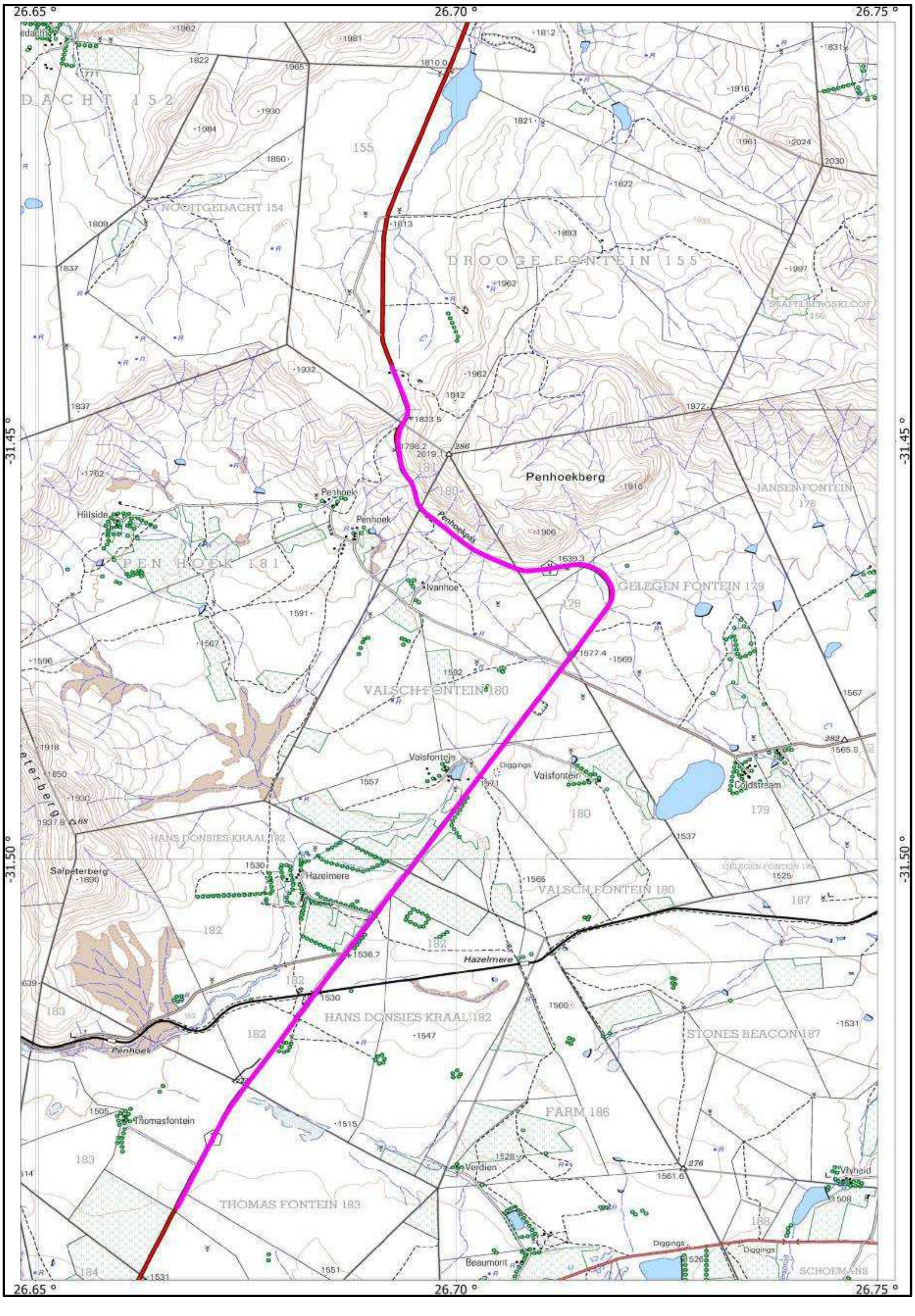

Fig. 2. Abstract from 1: 50 000 topographic maps 3126BC and 3126 DA showing in pink the 14 km length of Section 4 of the N6 north of Queenstown that is to be rehabilitated (Image kindly provided by Arcus GIBB Engineering & Science).

2.1. National Heritage Resources Act

The extent of the proposed development (over 5000 m^2 or linear development of over 300m) falls within the requirements for a Heritage Impact Assessment (HIA) as required by Section 38 (Heritage Resources Management) of the South African National Heritage Resources Act (Act No. 25 of 1999). 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

Minimum standards for the palaeontological component of heritage impact assessment reports are currently being developed by SAHRA. The latest version of the SAHRA guidelines is dated August 2011.

2.2. Approach used for this palaeontological study

The brief for the present palaeontological specialist study as defined by Arcus GIBB is as follows:

A phase one palaeontological impact assessment is to be undertaken and must address the following:

- Assess each borrow pit and quarry site identified by the project engineers. On Penhoek Pass1 borrow pit and 1 hard rock quarry have been identified by the engineers;
- Assess those areas where passing lanes are to be constructed to determine whether any heritage resource is likely to be affected as a result of the road widening;
- Include recommendations for the conservation of identified heritage resources.

This report provides a basic assessment of the observed or inferred palaeontological heritage within the Penhoek Pass study area, with recommendations for any specialist palaeontological mitigation where this is considered necessary. The report is based on (1) a review of the relevant scientific literature, (2) geological maps, (3) previous palaeontological heritage assessments for other developments in the region (*e.g.* Almond 2011), (4) the author's field experience with the formations concerned and their palaeontological heritage, and (5) a two-day field assessment on 17-18 May 2012 carried out by the author.

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 during the compilation of the final report). This data is then used to assess the palaeontological sensitivity of each rock unit to development (Provisional tabulations of palaeontological sensitivity of all formations in the Western, Eastern and Northern Cape have already been compiled by J. Almond and colleagues; *e.g.* Almond et al. 2008). The likely impact of the proposed development on local fossil heritage is then determined on the basis of (1) the palaeontological sensitivity of the rock units concerned and (2) the nature of the development itself, most notably the extent of fresh bedrock excavation envisaged.

When rock units of moderate to high palaeontological sensitivity are present within the development footprint, a field assessment study by a professional palaeontologist is usually warranted. Most detrimental impacts on palaeontological heritage occur during the construction phase when fossils may be disturbed, destroyed or permanently sealed-in during excavations and subsequent construction activity. Where specialist palaeontological mitigation is recommended, this may take place before construction starts or, most effectively, during the construction phase while fresh, potentially fossiliferous bedrock is still exposed for study. Mitigation usually involves the judicious sampling, collection and recording of fossils as well as of relevant contextual data concerning the surrounding sedimentary matrix. It should be emphasised that, *provided* appropriate mitigation is carried out, many developments involving bedrock excavation actually have a *positive* impact on our understanding of local palaeontological heritage. Constructive collaboration between palaeontologists and developers should therefore be the expected norm.

The focus of the field-based assessment work is *not* simply to survey the development footprint or even the development area as a whole (*e.g.* farms or other parcels of land concerned in the development). Rather, the palaeontologist seeks to assess or predict the diversity, density and distribution of fossils within and beneath the study area, as well as their heritage or scientific interest. This is primarily achieved through a careful field examination of one or more representative exposures of all the sedimentary rock units present (*N.B.* Metamorphic and igneous rocks rarely contain fossils). The best rock exposures are generally those that are easily accessible, extensive, and fresh (*i.e.* unweathered) and include a large fraction of the stratigraphic unit concerned (*e.g.* formation). These exposures may be natural or artificial and include, for example, rocky outcrops in stream or river banks, cliffs, quarries, dams, dongas, open building excavations or road and railway cuttings. Uncemented superficial deposits, such as alluvium, scree or wind-blown sands, may occasionally contain fossils and should also be included in the scoping study where they are well-represented in the study area. It is normal practice for impact palaeontologists to collect representative, well-localized (*e.g.* GPS and stratigraphic data) samples of fossil material during field assessment studies. However, fossil collection should be supported by a permit from the relevant heritage heritage authority and all fossil material collected must be properly curated within an approved repository (usually a museum or university collection).

Before fieldwork commenced, a preliminary screening of satellite images and 1: 50 000 maps of the Penhoek Pass study area was conducted to identify any sites of potentially good bedrock exposure to be examined in the field. These sites might include, for example, natural exposures (*e.g.* stream beds, rocky slopes, stream gullies) as well as artificial exposures such as quarries, dams and cuttings along farm tracks.

Note that while fossil localities recorded during fieldwork within the study area itself are obviously highly relevant, most fossil heritage here is embedded within rocks beneath the land surface or obscured by surface deposits (soil, alluvium *etc*) and by vegetation cover. In many cases where levels of fresh (*i.e.* unweathered) bedrock exposure are low, the hidden fossil resources have to be *inferred* from palaeontological observations made from better exposures of the same formations elsewhere in the region but outside the immediate study area. Therefore a palaeontologist might reasonably spend far *more* time examining road cuts and borrow pits close to, but outside, the study area than within the study area itself. Field data from localities even further afield (*e.g.* an adjacent province) may also be adduced to build up a realistic picture of the likely fossil heritage within the study area.

On the basis of the desktop and 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. Mitigation by a professional palaeontologist – normally involving the recording and sampling of fossil material and associated geological information (*e.g.* sedimentological data) – is usually most effective during the construction phase when fresh fossiliferous bedrock has been exposed by excavations, although pre-construction recording of surface-exposed material may sometimes be more appropriate. To carry out mitigation, the palaeontologist involved will need to apply for a palaeontological collection permit from the relevant heritage management authority (*i.e.* SAHRA, Cape Town). 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.

GPS data for all localities mentioned in the text is provided in the Appendix.

2.3. 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.

The main limitation during the present field-based basic assessment of palaeontological heritage along Penhoek Pass was the low level of fresh bedrock exposure, apart from occasional road cuttings, due to extensive scree, soil and vegetation cover.

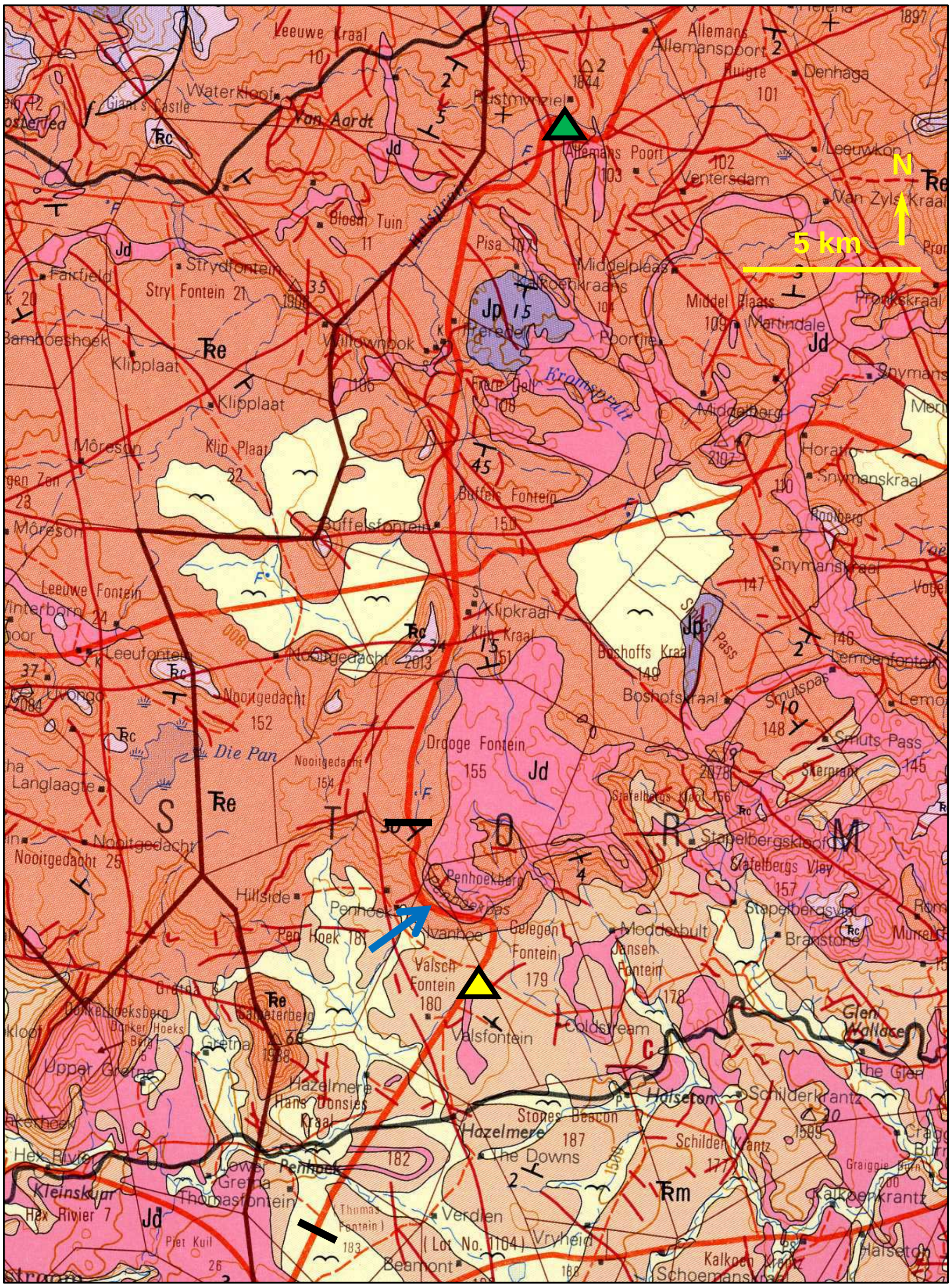

Fig. 3. Extract from 1: 250 000 geology sheet 3126 Queenstown (Council for Geoscience, Pretoria) showing the location of Section 4 along the N6 (between the two short black lines), Penhoek Pass (blue arrow), the existing borrow pit BP01 (yellow triangle) and the existing hard rock quarry HRQ1 (green triangle).

2. GEOLOGICAL CONTEXT

Section 4 of the N6 tar road initially runs northwards across rolling agricultural lands at around 1550m amsl before ascending a low escarpment along the southern margin of the Stormberge Range *via* the Penhoek Pass (Fig. 5). The plateau at the top of the pass lies at around 1880m amsl. There is very little bedrock exposure in lower-lying region in the south, and even in the steeper escarpment region exposure is largely limited to occasional short road cuttings and small erosional gullies due to the extensive blanket of colluvial surface deposits here.

The geology of the Penhoek Pass study area is outlined in the 1: 250 000 geology sheet 3126 Queenstown (Council for Geoscience, Pretoria; Johnson 1984) (Fig. 3). The area is underlain by Late Triassic fluvial sediments of the **Stormberg Group** (Karoo Supergroup) that are extensively intruded and baked by Late Jurassic igneous dykes and sills of the **Karoo Dolerite Suite** as well as being mantled by Late Caenozoic **superficial deposits** such as colluvium (scree *etc*) and alluvium. The lower lying region at the foot of the Penhoek Pass is assigned to the **Molteno Formation** (TRm) while the slopes of the escarpment are referred to the lower part of the **Elliot Formation** ("Red Beds") (TRe). Laterally extensive, prominent-weathering buff channel sandstones of the Lower Elliot Formation are responsible for the prominent stepped or striped hillslopes along the southern Stormberg Escarpment in the Penhoek Pass area (*e.g.* Penhoekberg) as well as nearby outliers such as Salpetersberg at the foot of the pass (Fig. 6).

2.1. Molteno Formation

The Molteno Formation is a stratigraphically complex wedge of perennial braided alluvial sediments of estimated Late Triassic age that crops out around the margins of the Stormberg Group outcrop area centred on the Drakenberg highlands. At its thickest, in the south, the formation reaches 600-650m and has been subdivided into a series of five members but it tapers rapidly towards the north. The sandstone-rich Molteno succession is more resistant-weathering than the underlying and overlying rocks (Burgersdorp and Elliot Formations respectively) and therefore tends to form a topographic escarpment.

Useful short geological accounts of the Molteno Formation are given by Dingle *et al.* (1983), Visser (1984), Smith *et al.* (1998), Hancox (2000) and Johnson *et al.* (2006), while a short description of these rocks in the Queenstown 1: 250 000 geology sheet area is provided by Johnson (1984). Key technical papers include those by Turner (1975. 1983), Eriksson (1984), Christie (1981), Dingle *et al.* (1983), Cairncross *et al.* (1995), Anderson *et al.* (1998) and Hancox (1998); fuller geological references are provided by Hancox (2000).

The Molteno succession is made up of an alternation of laterally-persistent, erosive-based, medium- to coarse-grained, feldspathic sandstones and subordinate olive-grey to reddish mudrocks. These rocks were deposited in braided alluvial channels, overbank floodplains and lakes on an extensive, northwards-flowing alluvial braidplain. The sandstones typically show a "glittering" appearance due to extensive development of secondary quartz overgrowths. Internal sedimentary structures include trough and planar cross-bedding, flat-lamination and overturned cross-bedding. Numerous fining-upwards sequences of 5-50m thickness, averaging 20-30m, are commonly present within the Molteno succession (Johnson 1984). These sequences, which can be readily seen on aerial and satellite images, grade upwards from pebbly, coarse sandstones at the base through finer sandstones, siltstones and finally into carbonaceous, thinly-bedded to laminated claystones. These last may be highly fossiliferous. Thin, lenticular coals were formed in peaty swamp settings on the alluvial floodplain, but many so-called "coals" are effectively only carbonaceous mudstones. Humid, warm climates with a pronounced seasonality are suggested by the rich plant and insect life preserved in these sediments, especially the finer-grained mudrocks, as well as by the sedimentology and fossil soils (Hancox 2000). However, some authors infer an alternation of warm, dry summers and cool, wet winters (*e.g.* Anderson *et al.* 1998, Johnson *et al.* 2006). The precise age of the Molteno Formation has not yet been established, but a Late Triassic (Carnian, 228-216.5 Ma) age is favoured for at least the lower part of the formation by most recent authors on the basis of the fossil plants (*Dicroidium* Flora) and palynomorphs (*Allisporites / Falcisporites* assemblages) as well as biostratigraphic correlation with Australian Triassic successions (Hancox 2000, Rubidge 2005).

The Molteno Formation rocks underlying the lower-lying, rolling hilly terrain south of the Penhoek Pass are very poorly exposed. Isolated low roadside crags of cross-bedded, greyish-buff, glittering, coarse gritty sandstones show pitted, karst-like weathering styles that may be due to silica dissolution (Fig. 7). Potentially fossiliferous Molteno mudrocks are nowhere exposed here. Greenish-grey baked Molteno mudrocks and sandstones (*i.e.* flinty hornfels, quartzites) are represented as float blocks along the roadside at several localities (*e.g.* Loc. 537, near Valschfontein). Some blocks contain fine pale linear structures and mottled textures that may represent fossil burrows. The Molteno sandstones in borrow pit BP01 are pale, baked and highly weathered, while the hornfels show blocky weathering (Fig. 8). Cross-bedding is clearly seen within sandstones in adjacent road cuttings.

2.2. Lower Elliot Formation

The Elliot Formation is a typical arid continental “red bed” succession of Late Triassic to Early Jurassic age that reaches a thickness of up to 500- 550m in the southern outcrop area. The type section is located in Barkly Pass near the town of Elliot in the Eastern Cape (Visser & Botha 1980, Smith *et al.* 1998). The predominantly fluvial succession consists largely of reddish to maroon, structureless overbank mudrocks and fine- to medium-grained channel sandstones. These rocks are interpreted as a distal facies equivalent to the more proximal alluvial braidplains of the underlying Molteno Formation (Turner 1983, 1986). Sedimentary settings in the southern Elliot outcrop area include meandering rivers in the lower Elliot, braided stream systems in the middle Elliot and sandstone-dominated flood-fan (flash-flood), playa lake and aeolian dune complexes in the upper Elliot (with subordinate volcanics). A major period of erosional landscape degradation marked by a prominent fossiliferous calcrete nodule palaeosol occurs in the middle Elliot Formation (*Tritylodon* Acme Zone; Kitching & Raath 1984, Smith & Kitching 1997). Prevailing semi-arid to arid climates during Elliot Formation times are indicated by the reddish-hued mudrocks (oxidised iron minerals), desiccation cracks, abundant pedogenic carbonates (palaosol or fossil soil calcretes, rhizocretions) and the taphonomic styles of the fossils vertebrate remains (*e.g.* sun-cracked bones). During deposition of the Elliot Formation climates became increasingly arid, culminating in the establishment of the Clarens sand sea in Early Jurassic times.

Sedimentary bedrocks close to the contact with the Molteno Formation, as at Penhoek Pass, can be assigned to the lower Elliot Formation of Late Carnian / Norian to Rhaetian age. Useful accounts of the lower Elliot sediments are provided by Kitching and Raath (1984) and Hancox (2000). This sandier lower portion of the Elliot succession is dominated by greyish red to pale red mudrocks and consists of several fining-upwards sequences of 25-50m thickness. Yellowish to pale red, tabular to lenticular sandstone units up to 7m thick with erosive bases are massive to cross-bedded and were laid down within the channels and on point bars of large volume, high sinuosity meandering rivers. Basal channel lags comprise intraformational breccio-conglomerates with mudflakes, occasional small rounded quartz pebbles and fragmentary reworked bone. Thinner sheet sandstones and coarsening-upwards packages were deposited by crevasse splay systems on the proximal flood plain when the rivers burst their banks during flood episodes. The overbank mudrocks are usually massive and contain numerous calcretised palaeosols (fossil soil horizons). The dominant palaeocurrent directions within the southern outcrop area of the lower Elliot vary from northwest to northeast.

Useful geological overviews of the Elliot Formation are provided by Tankard *et al.* (1982), Dingle *et al.* (1983), Hancox (2000, with extensive references to the earlier literature), Smith *et al.* (2002) and Johnson *et al.* (2006). More detailed accounts of the sedimentology of the Elliot Formation “red beds” can be found in Visser and Botha (1980), Visser (1984) as well as excellent recent publications by Smith and Kitching (1997) and Bordy *et al.* (2004a, 2004b, 2004c). General remarks on the Elliot Formation of the Queenstown sheet area are provided by Johnson (1984).

The age of the Elliot Formation remains poorly constrained, with estimates ranging from Late Triassic (Carnian / Norian / Rhaetian) to Early Jurassic (Hettangian – Pliensbachian), *i.e.* within the period 235 to 183 Ma (See discussion in Hancox 2000, Smith *et al.* 2002, Rubidge 2005).

The laterally persistent, prominent-weathering thicker channel sandstones of the Elliot Formation are largely responsible for the stepped slopes along the Stormberg escarpment as well as on nearby hills such as Salpeterberg (Fig. 6). Good examples showing massive to tabular cross-bedded architectures are exposed in road cuttings along Penhoek Pass (Figs. 9. 10). The channel bases are often erosive but few examples of basal channel breccias or mudflake intraclast breccio-conglomerates were observed. Locally the buff sandstones pass laterally into greyish, micaceous and possibly carbonaceous sandstones and siltstones with loading features. Elliot Formation mudrock exposure is limited to a few roadcuts and erosional gullies. The mudrocks vary from grey-green to maroon, massive to well-bedded, and are often deeply weathered (Figs. 9, 15). The surface of mudrock exposures is often obscured by a thin muddy veneer generated by sheetwash that makes fossil recording difficult. Thin-bedded purplish-grey or brick-red sandstones interbedded with mudrocks are well exposed in several roadcuts between the top of Penhoek Pass and Jamestown (*e.g.* Loc. 551, just east of the main hardrock quarry HRQ1; Fig. 11).

2.3. Karoo Dolerite Suite

The Late Triassic Stormberg Group sediments across the study area are extensively intruded and thermally metamorphosed (baked) by subhorizontal sills and steeply inclined dykes of the **Karoo Dolerite Suite** (Jd). A good example in the study area is the major sill capping Penhoekberg. These Early Jurassic (*c*. 183 Ma) basic intrusions were emplaced during crustal doming and stretching that preceded the break-up of Gondwana (Duncan and Marsh 2006). The hot dolerite magma baked adjacent Stormberg Group mudrocks and sandstones to form dark grey, splintery hornfels and quartzites respectively, as well seen in the small roadside quarry towards the top of the Penhoek Pass (Fig. 14, Loc. 545). Abundant prominent-weathering spheroidal nodules of probable siliceous composition are seen within thermally metamorphosed channel sandstones of the Elliot Formation in Penhoek Pass (Fig. 13, Loc. 540).

The main hard rock quarry (HRQ1) located some 20 km south of Jamestown is excavated into a large dolerite sill intrusive into the Elliot Formation that shows well-developed polygonal columnar jointing and coarse-grained, pink- and grey-speckled dolerite facies (Fig. 12). Good examples of baked country rocks were not seen at this locality and extension of this quarry is unlikely to have any significant impact on fossils preserved within these sediments. Thermally metamorphosed Molteno sediments – pale greenish-grey, flinty, porcellanous hornfels and quartzites - are encountered adjacent to the N6 just south of the foot of Penhoek Pass as well as in the borrow pit BP01 (Loc. 538). This borrow pit is largely excavated into Karoo dolerite which here shows excellent examples of onionskin weathering, *sabunga* (weathered dolerite grit) and corestone formation. The Molteno Formation country rocks here have been extensively baked, blocky weathering and are deeply weathered; they are very unlikely to yield useful fossil material (Fig. 8)

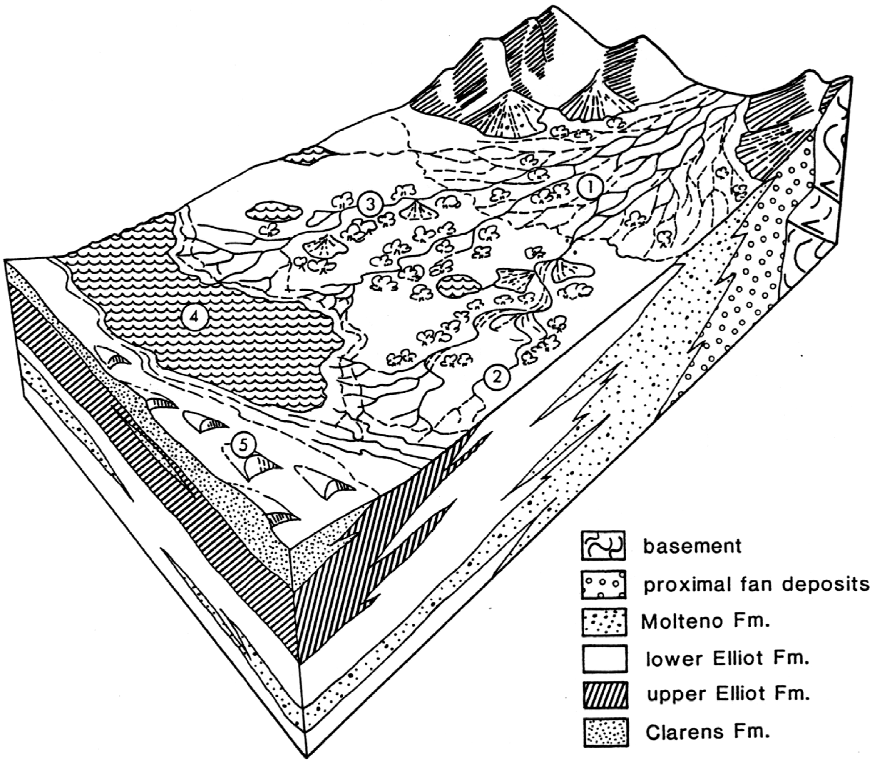

Figure 33 Looking eastwards over 1000 km-long slice through the upper Karoo Basin showing the depositional environments and lateral facies relationships of the Molteno, Elliot and Clarens formations (modified from Turner, 1986). In response to pulses of uplift in the southeasetrn mountains large brided fans(1) prograded into the semi arid Elliot basin. Basinwards, the rivers became more sinuous (3). Expansive semi arid floodplains drained by ephemeral crevasse splay channels (2) accumulated mostly silt (some brought in as loess). In the drier distal parts of the basin, end-point playas (4) and aeolian dune fields (5) developed.

Fig. 4: Inferred depositional settings of sediments of the Stormberg Group, including the Molteno and lower Elliot Formations in the study area (From Smith *et al.* 2002).

2.4. Late Caenozoic superficial deposits

Various types of superficial deposits ("drift") of Late Caenozoic (largely Quaternary to Recent) age occur widely throughout the Karoo region, including in the study area. They include pedocretes (*e.g.* calcretes or soil limestones), colluvial slope deposits (sandstone and dolerite scree, downwasted gravels *etc*), sheet wash, river channel alluvium and terrace gravels, as well as spring and pan sediments (Johnson & Keyser 1979, Le Roux & Keyser 1988, Cole *et al.,* 2004, Partridge *et al*. 2006). Only the larger tracts of Quaternary to Recent **alluvium** overlying the Stormberg Group above and below the escarpment are shown on the 1: 250 000 geological map (pale yellow with "flying bird" symbol in Fig 3). In practice, a high proportion of the Stormberg Subgroup bedrocks are in fact mantled by superficial deposits in the broader study region.

Yellow sandy soils overlying the Molteno Formation outcrop area locally have a sparse cover of surface gravels of silcrete (and / or fine-grained hornfels), some of which are flaked (Fig. 16).

Blocky colluvium and corestones released by weathering and erosion of dolerite intrusions as well as Elliot Formation channel sandstones blanket most of the mountain slopes along the Stormberg escarpment, usually completely obscuring the underlying fossiliferous Karoo Supergroup sediments (Figs. 6, 15). Dolerite megaclasts are often suspended in orange-brown lateritic muds suggesting downslope remobilisation of doleritic colluvium and soils as debris flows.

Fig. 5. View looking northwards towards the dolerite-capped Stormberge Escarpment from the grassy vlaktes at the base of the Penhoek Pass. The N6 tar road ascends the escarpment here from right to left.

Fig. 6. Typical stepped topography of the Penhoek Pass area (view from top of pass SE towards Penhoekberg) formed by alternation of soft-weathering mudrocks of the Elliot Formation with subhorizontal tough-weathering Elliot channel sandstones as well as much younger dolerite sills. Note generally low levels of bedrock exposure here.

Fig. 7. Low, isolated rocky exposure of Molteno Formation glittering sandstones towards the foot of Penhoek Pass (Loc. 536) (Hammer = 27 cm). The highly rugged, pitted surfaces suggest that karstic (*i.e.* solution) palaeo-weathering processes may have been involved here.

Fig. 8. Highly-weathered dolerite dyke (dark olive-brown) intruding baked, deeply-weathered pale buff Molteno Formation sandstones in borrow pit BP01 (Loc. 538).

Fig. 9. Buff, lenticular channel sandstones and reddish to grey-green massive to vaguely bedded mudrocks of the Lower Elliot Formation, upper Penhoek Pass (Loc. 547).

Fig. 10. Tabular cross-bedded channel sandstones of the Lower Elliot Formation, lower part of Penhoek Pass (Loc. 540) (Hammer = 27 cm).

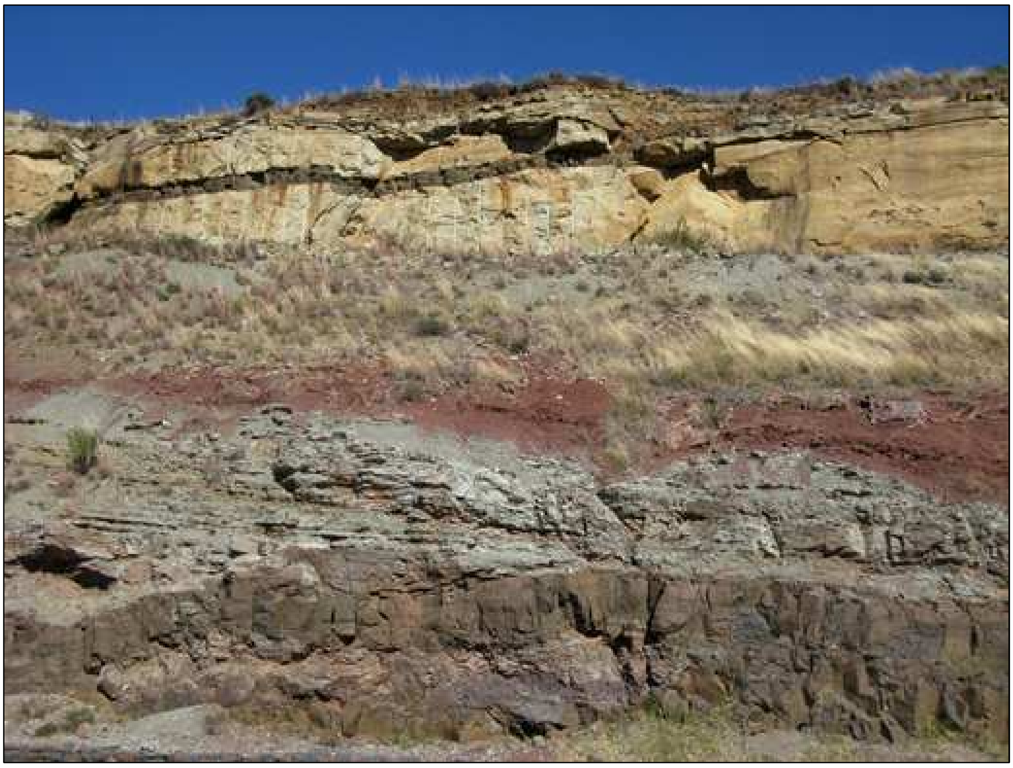

Fig. 11. Excellent exposure of well-bedded greyish-green and reddish-brown mudrocks of the Elliot Formation just east of the hardrock quarry HRQ1 (Loc. 551; outside the study area). Note thin dolerite sills intruding the mudrocks at the base of the exposure as well as the channel sandstone in the background.

Fig. 12. General view towards the south of the hardrock quarry HRQ1 which is excavated into a major subhorizontal dolerite sill (Loc. 550). Note well developed vertical columnar jointing in the rear quarry face.

Fig. 13. High-angle contact between a dolerite dyke (olive-brown, RHS) and a pale grey channel sandstone of the Lower Elliot Formation, lower Penhoek Pass (Hammer = 27 cm). The abundant siliceous sphaeroidal nodules within the sandstone are probably a consequence of thermal metamorphism during intrusion (Loc. 540).

Fig. 14. Contact between intrusive dolerite body and thermally metamorphosed Elliot Formation sediments (hornfels, quartzite) in a small quarry towards the top of Penhoek Pass (Loc. 545). Note contrast between well-jointed central part of intrusion and weathered exterior (*sabunga*).

Fig. 15. Thick mantle of poorly-sorted colluvium - mainly subrounded dolerite corestones within a reddish muddy matrix – overlying weathered mudrocks of the Elliot Formation, Penhoek Pass (Loc. 543a) (Hammer = 27 cm).

Fig. 16. Sandy soils and downwasted surface gravels of silcrete overlying the Molteno Formation outcrop area at the foot of the Penhoek Pass (Loc. 534).

3. PALAEONTOLOGICAL HERITAGE

The fossil heritage that has been previously recorded from the main rocks units that are represented in the Penhoek Pass study area is briefly outlined here.

3.1. Fossils within the Molteno Formation

In terms of plant and insect fossils, but not vertebrates or traces, the Molteno Formation is one of the most productive rock units within the Main Karoo Basin. Indeed, it has produced the richest known floras of Triassic age anywhere in the world and its palaeontological sensitivity towards development is correspondingly high (Almond *et al.* 2008). Excellent reviews of the Molteno fossil biota have been provided by Cairncross *et al.* (1995), Anderson *et al.* (1998), Anderson and Anderson *in* MacRae (1999), Hancox (2000) and Anderson (2001). These key accounts include references to the extensive technical literature on the Molteno flora and fauna stretching back to pioneering work by Wyley (1856) and Stow (1871) on coals and petrified forests as well as by Alex du Toit in the early 1900s on fossil plant remains (See Hancox 2000 for early references). Here may be mentioned only the key systematic and synthetic papers on the Molteno palaeoflora published by John and Heidi Anderson that are listed towards the end of this report as well as the early collections of Molteno coal measure plants around Aliwal North by Alfred (Gogga) Brown in the late nineteenth century (MacRae 1999).

The fossil biota recorded so far from the Molteno Formation may summarised as follows:

- A very rich **megaflora** of fossil foliage, fruits, seeds and stems, mostly preserved as carbonaceous compressions within mudrocks. The flora contains over sixty genera and is strongly dominated by "pteridophytes" (over 50 species of spore-bearing ferns, including horsetails) and a rich variety of gymnosperms (27 genera, 114 species, including ginkgophytes, cycads, conifers and "seed ferns"). The four dominant plant genera are the characteristic Triassic "seed fern" *Dicroidium* (Peltaspermales), the maidenhair tree relative *Sphenobaiera* (Ginkgoales), the conifer *Heidiphyllum* (Voltziales) and the horsetail fern *Equisetum* (Equisetales). Over 200 plant species have been identified, including sixteen orders of gymnosperms alone. Minor groups include bryophytes such as mosses, liverworts and club-mosses;
- **Silicified woods**, including petrified tree trunks, now assigned to a range of gymnospermous genera (Bamford 1999, 2004);
- Poorly-studied **palynomorph assemblages** dominated by pteridophyte spores and gymnosperm pollens assigned to the Triassic *Allisporites / Falcisporites* assemblage (Hancox 2000 and refs. therein);
- Rare **fossil fish** belonging to four genera, representing the only vertebrate body fossils from the formation (Anderson *et al.* 1998);
- Relatively abundant and diverse **fossil insects** associated with compression floras in fine-grained mudrocks. These important insect assemblages comprise several thousand specimens of about 350 species, mainly preserved as disarticulated wings but with some intact or partially intact bodies. They are dominated by cockroaches, beetles, bugs and dragonflies and include eighteen different insect orders. The only other terrestrial arthropods recorded so far are extremely rare spiders (Selden *et al.* 1999, Selden 2009);
- Rare shelly invertebrates including three genera of **conchostracans** (freshwater clam shrimps) and two genera of **bivalves**;
- Occasional **trace fossils** including dinosaur trackways (among the earliest indirect evidence for dinosaurs; Raath *et al.* 1990, Raath 1996), invertebrate burrows of the *Scolicia* Group, perhaps generated by gastropods (Turner 1975), *Skolithos* vertical burrows, arthropod traces and a few unnamed forms (Hancox 2000).

The absence of fossilised bone and coprolites of vertebrates is notable and, at least in the former case, is attributed to the diagenetic dissolution of bone under humic, poorly-oxygenated and acid conditions that rather favour the preservation of plant remains (Anderson *et al.* 1998).

The Molteno fossil flora is of considerable palaeontological interest in documenting the explosive radiation of Mesozoic, gymnosperm-dominated floras in the later Triassic Period, while the associated rich insect fauna shows great promise in illuminating early plant – insect interactions during this critical period in Earth history (See numerous references by J. & H Anderson listed below). Over one hundred Molteno plant fossil assemblages from some seventy localities have been recorded so far (Anderson 2001), with the richest assemblages yielding over seventy species. Insects are recorded from over forty localities.

The only fossils observed within the very poorly exposed Molteno Beds in the Penhoek Pass study area were vague horizontal burrows in some of the sandstone beds (Loc. 537).

3.2. Fossils in the Lower Elliot Formation

The Late Triassic to Early Jurassic Elliot Formation as a whole contains a comparatively rich fossil reptile fauna dominated by early dinosaurs (principally sauropodomorphs) as well as rare amphibians, turtles, fish and advanced mammal-like reptiles (cynodont therapsids). Other fossil elements include petrified woods, phyllopod crustaceans (conchostacans or "clam shrimps") and trace fossils, principally tetrapod trackways. Following the benchmark palaeontological studies of the Stormberg Group fossil biotas by Haughton (1924), Kitching and Raath (1984) as well as Ellenberger (1970 and earlier works) and Olsen and Galton (1984), the fossil record of the Lower Elliot Formation has been recently reviewed by Anderson *et al.* (1998), Hancox (2000), Smith *et al.* (2002), Knoll (2004), and Rubidge (2005). The interested reader is also referred to the less technical, well-illustrated accounts by MacRae (1999) and McCarthy & Rubidge (2005).

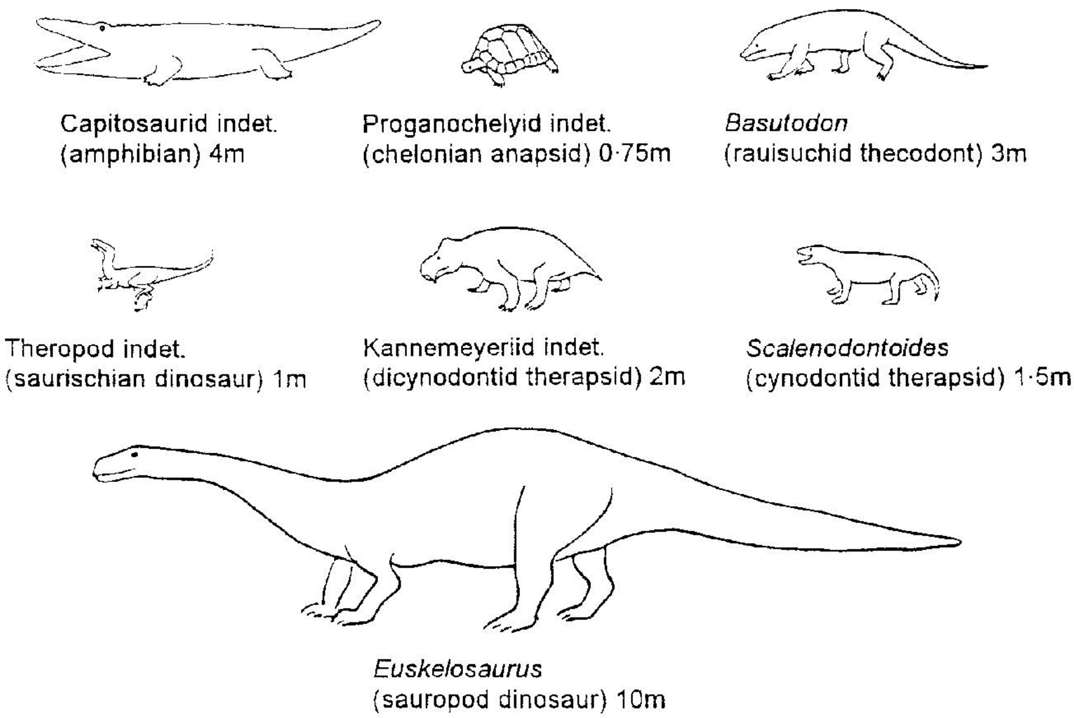

Fig. 17: Inferred or recorded tetrapod fauna of the *Eukelesaurus* Assemblage Zone based on skeletal material as well as vertebrate trackways (From Anderson *et al.* 1998). Note that a range of sauropodomorph dinosaurs are now recognised from this horizon.

The fossil assemblages of the lower Elliot Formation have been assigned to the ***Euskelesaurus* Assemblage Zone** of Late Triassic (Carnian / Norian / Rhaetian) age (Kitching & Raath 1984, Rubidge 2005). However, this assemblage zone has not yet been formally defined, not least because the genus *Euskelesaurus* has now been recognised as a *nomen nudum* that comprises a range of Late Triassic sauropodomorph dinosaurs (Yates 2003). This was one of the first dinosaur genera to be described from South Africa (Huxley 1866, 1867). The Elliot fauna is now recognised as one of the most important Late Triassic / Early Jurassic dinosaur assemblages known.

The main components of the lower Elliot Formation biotas (Figs. 17, 18) are:

- Rare large (4m) **temnospondyl amphibians** or capitosaurs (Ellenberger 1970, Olsen & Galton 1984, Warren & Damiani 1999, Damiani & Rubidge 2003). These crocodile-sized freshwater predators were piscivorous, but fossil fish remains have not yet been recorded from the lower Elliot Formation.
- A range of medium to large, herbivorous **sauropodomorph dinosaurs**, several of which were originally regarded as prosauropods and lumped together as the invalid taxon *Euskelesaurus*. The lower Elliot forms include the basal sauropodomorph *Eucnemesaurus* (including *Aliwalia*), the true sauropods *Melanorosaurus*, *Blikanasaurus* and *Antetonitrus* (Fig. 18), and the sauropodomorph *incertae sedis Plateosauravus* (Van Hoepen 1920, Haughton 1924, Van Heerden 1979, Cooper 1980, Cooper 1981, Galton 1985, Galton & Van Heerden 1985, Durand 2002, Yates 2003, Yates & Kitching 2003, Yates 2005, Yates 2007a and 2007b, Yates 2008, Blackbeard 2009). A true, as yet unnamed prosauropod close to *Riojasaurus* from South America has recently been recognised by Yates (2003). Trackways of sauropodomorphs have been identified as the ichnogenus *Tetrasauropus* (Olsen & Galton 1984).
- Possible bipedal **theropod dinosaurs** based on trackways (*Grallator*) and isolated teeth (*e.g.* Olsen & Galton 1984, Ray & Chinsamy 2002).
- The rare primitive **ornithischian dinosaur** *Eocursor* (Butler *et al.* 2007, Butler 2010). This is currently the most complete Triassic ornithischian known.
- Fragmentary material and trackways (*Brachycheirotherium*) of large **rauisuchians**, a group of armoured thecodont archosaurs that were distantly related to crocodiles (crurotarsans) and were among the top predators of the Late Triassic Period (Seeley 1894, Haughton 1924, Kitching & Raath 1984, Olsen & Galton 1984, Gower 2000). Large serrated teeth of this group have been described from Lesotho as *Basutodon* (Von Heune 1932).
- Rare advanced **cynodont therapsids** including the large traversodont *Scalenodontoides* and the tritheledontid *Elliotherium* (Crompton & Ellenberger 1957, Hopson 1984, Gow & Hancox 1993, Abdala & Ribeiro 2003 and 2010, Battail 2006, Sidor & Hancox 2006). These small to medium-sized, rodent-like herbivores have transversely expanded (“gomphodont”) teeth and belong to cynodont subgroups that are considered by many workers as close to the origins of the true mammals (a group that is represented in the upper Elliot Formation).
- Possible large **dicynodont therapsids**, based on trackways (*Pentasauropus*) that are probably attributable to a hippo-sized kannemeyeriid (Olsen & Galton 1984, Anderson *et al.* 1998).
- Local concentrations of large freshwater **conchostracans** (clam shrimps) within fluvial sandstones (Smith *et al.* 2002).
- Sparse, low diversity assemblages of **invertebrate trace fossils** (*e.g.* Smith *et al.* 2002, Bordy *et al.* 2004b).
- Very sparse **plant fossils** including petrified woods (Bamford 2004) and rhizocretions (calcretised root traces). The arid, oxidised settings of the lower Elliot Formation did not favour the preservation of plant material. Given their inferred stratigraphic equivalence, lower Elliot floras would have originally included many elements recorded from the rich plant fossil beds of the Molteno Formation (*cf* Anderson & Anderson 1985, Anderson *et al.* 1998 and numerous references therein).

The taphonomic settings of the lower Elliot Formation fossils are described in some detail by Kitching and Raath (1984). The lowermost few meters of the mudrock succession are palaeontologically barren apart from occasional beds rich in carbonaceous material. In the overlying strata vertebrate remains are uncommon and usually isolated, but occasionally well-preserved, articulated or semi-articulated skeletons are also found. The characteristic haematite (ferruginous) coating of bones seen in the upper Elliot is not found at these lower levels. Lag conglomerates at the base of channel sandsatones contain disarticulated remains (bones, teeth, osteoderms) of capitosaur amphibians. Tetrapod trackways occur on the rippled tops of sandstone beds. The *Euskelesaurus* Assemblage Zone fauna extends up to a widely distributed horizon marked by large calcrete concretions that represents a major arid zone palaeosol. Fossil bones preserved within this palaeosol are typically badly "sun-cracked" and coated with haematite and nodular calcareous growths.

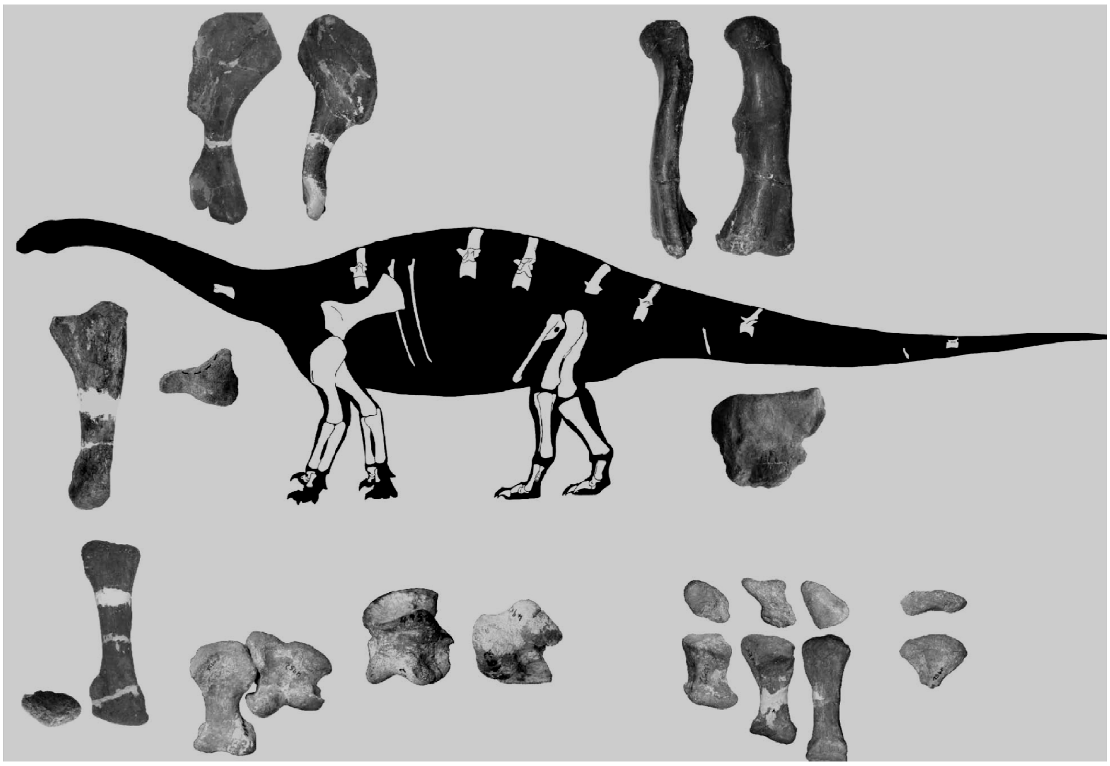

Fig. 18: Skeletal material of the earliest known sauropod dinosaur *Antetonitrus* that was recently described from the Elliot Formation by Yates & Kitching (2003). This early dinosaur is estimated to have been 8 to 10m long.

Numerous fossil sites within the thickly-developed Elliot Formation in its southern outcrop area are noted in the benchmark palaeontological reviews by Haughton (1924) and Kitching and Raath (1984) and doubtless many more sites have been discovered in this key region since. Unfortunately little useful palaeontological data for the Queenstown and Aliwal North 1: 250 000 sheets is provided in the geology sheet explanations by Johnson (1984) and Bruce *et al.* (1983) respectively, although this has been a classic collecting area for Lower Elliot Formation fossils since the time of the famous late nineteenth century amateur fossil collector Alfred (Gogga) Brown – the original discoverer of the dinosaur *Euskelsaurus* (MacRae 1999).

The only fossils observed within the Elliot Formation in the Penhoek Pass area were vague horizontal burrows in some of the sandstone beds (Loc. 543).

3.3. Fossils in the Karoo Dolerite Suite

Dolerite outcrops within the study area are in themselves of no palaeontological significance since these are high temperature igneous rocks emplaced at depth within the Earth's crust. However, as a consequence of their proximity to large dolerite intrusions in the Great Escarpment zone the adjacent Karoo Supergroup sediments have often been thermally metamorphosed or "baked" (*i.e.*

recrystallised, impregnated with secondary minerals). Embedded fossil material of phosphatic composition, such as bones and teeth, was frequently altered by baking. Bones may become blackened and they can be very difficult to extract from the hard matrix by mechanical preparation. Thermal metamorphism by dolerite intrusions therefore tends to *reduce* the palaeontological heritage potential of adjacent Beaufort Group sediments.

3.4. Fossils in Late Caenozoic superficial sediments

The Karoo "drift" deposits have been comparatively neglected in palaeontological terms for the most part. However, they may occasionally contain important fossil biotas, notably the bones, teeth and horn cores of mammals (*e.g.* Pleistocene mammal faunas at Florisbad, Cornelia and Erfkroon, Free State and elsewhere; Wells & Cooke 1942, Cooke 1974, Skead 1980, Klein 1984, Brink, J.S. 1987, Bousman *et al.* 1988, Bender & Brink 1992, Brink *et al*. 1995, MacRae 1999, Churchill *et al*. 2000 Partridge & Scott 2000) including skeletal remains of early humans (Grine *et al*. 2007). Other late Caenozoic fossil biotas from these superficial deposits include non-marine molluscs (bivalves, gastropods), ostrich egg shells, trace fossils (*e.g.* calcretised termitaria, coprolites), and plant remains such as palynomorphs in organic-rich alluvial horizons (Scott 2000) and diatoms in pan sediments. It is notable that in the Aliwal North sheet area to the north of the Queenstown sheet Bruce *et al.* (1983) report abundant plant material throughout the Quaternary alluvial deposits as well as rounded, transported Earlier Stone Age implements in the Pleistocene basal gravels.

No fossils were recorded within the superficial sediments in the Penhoek Pass study area.

4. CONCLUSIONS & RECOMMENDATIONS

Apart from poorly-preserved, ill-defined trace fossils within sandstones of the Molteno and Elliot Formations (Late Triassic Stormberg Group), no palaeontological material was observed during field assessment within the Karoo Supergroup bedrocks or superficial sediments along Section 4 of the N6, including the BP01 borrow pit site. The HRQ1 hard rock quarry near Jamestown is excavated into unfossiliferous dolerite. Rehabilitation of the southern portion of Section 4 that overlies Molteno Formation beds will not involve substantial new bedrock excavations and is therefore unlikely to have a significant impact on local fossil heritage. Realignment of road sections along the Penhoek Pass will generate fresh cuttings through the Elliot Formation "red beds" which may expose fossil vertebrate remains such as dinosaurs, advanced therapsids and amphibians but these are likely to be scarce. Due to extensive superficial sediment cover and weathering the overall palaeontological sensitivity of the study area is rated as LOW and, pending the discovery of significant fossil material during construction, no further palaeontological heritage studies or mitigation are recommended for this project.

Should substantial fossil remains be exposed during construction, however, such as vertebrate bones and teeth, plant-rich fossil lenses or dense fossil burrow assemblages, the ECO should safeguard these, preferably *in situ*, and alert SAHRA as soon as possible so that appropriate action (*e.g.* recording, sampling or collection) can be taken by a professional palaeontologist.

6. ACKNOWLEDGEMENTS

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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 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
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Appendix: GPS LOCALITY DATA

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

17 and 18 May 2012 – Penhoek Pass project

Loc. No.	South	East	Comments
533	S31 48 21.8	E26 43 42.5	Good Burgersdorp Fm road cuttings N of Queenstown
534, 535	S31 30 18.1	E26 41 30.2	Surface gravels (silcrete / hornfels) overlying Molteno Fm outcrop area
536	S31 29 48.6	E26 41 53.4	Low rocky outcrops of glistening Molteno Fm sandstones
537	S31 29 36.1	E26 42 02.3	Baked Molteno sediments near dolerite intrusion (mainly float blocks); possible vague burrows
538	S31 28 55.5	E26 42 35.5	Borrow Pit BP01
539	S31 27 53.8	E26 42 44.2	Lower Penhoek Pass colluvium, L. Elliot Fm mudrocks and sst
540	S31 27 54.2	E26 42 41.6	Intrusive contact between dolerite dyke & L. Elliot Fm (siliceous nodules)
541	S31 27 54.7	E26 42 39.0	Lower Elliot mudrocks, thin channel sandstones
542	S31 27 53.8	E26 42 24.0	L Elliot medium to thick-bedded channel sandstones
543	S31 27 55.9	E26 42 33.8	Lower Elliot grey & reddish mudrocks, buff sst, vague trace fossils
543a	S31 27 55.8	E26 42 27.7	Doleritic colluvium overlying greyish weathered Elliot mudrocks
544	S31 27 14.7	E26 41 39.3	Exposure of reddish Elliot Fm mudrocks
545	S31 26 58.8	E26 41 34.9	Roadside quarry with dolerite, baked country rocks
546	S31 26 51.1	E26 41 39.3	Elliot Formation at top of pass (old pass road)
547	S31 26 42.7	E26 41 38.5	Elliot Formation channel sandstones and overbank mudrocks, top of Penhoek Pass
548	S31 22 07.0	E26 42 06.0	Elliot Fm purplish-grey sst and mudrocks
549	S31 17 09.5	E26 42 29.7	Elliot Fm road cutting
550	S31 16 13.4	E26 43 51.6	Main Hard Rock Quarry excavated into dolerite sill
551	S31 16 21.7	E26 44 20.6	Good roadside exposure of Elliot Formation sediments and intrusive dolerites