Appendix C:
Specialist Palaeontology Baseline Study

PALAEONTOLOGICAL BASELINE STUDY:

Falcon Oil & Gas Ltd Exploration Right – southern Main Karoo Basin, Western, Northern and Eastern Cape Provinces, RSA

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1. EXECUTIVE SUMMARY

The Canadian company Falcon Oil and Gas Ltd is proposing to carry out a seismic survey across a broad stretch of the Great Karoo *sensu stricto*. The survey forms part of an exploration project for shale gas generated from organic-rich mudrocks within the lower part of the Karoo Supergroup. The TCP exploration area is largely situated below the Great Escarpment and covers some 30 000 km^2 and 2500 farms in the Western, Northern and Eastern Cape Provinces, from the Ceres Karoo in the west to the plains of the Kamdeboo in the east. Seismic surveying will involve the drilling of 5m deep shot holes at 50m intervals along a series of corridors across the Great Karoo that total 700-1000km in length.

The network of new seismic survey corridors traverses the outcrop area of continental sediments of the Lower Beaufort Group. This thick succession of fluvial and lacustrine formations forms part of the Karoo Supergroup and underlies the great majority of the exploration area. The Abrahamskraal and Teekloof Formations are mapped in the western part of the study area and the Koonap and Middleton Formations in the east. These sediments are recognized internationally for their rich palaeontological record of terrestrial life in the Middle to Late Permian Periods, some 268 to 251 million years ago. Fossils recorded from these rocks include a wide range of reptiles, therapsids ("mammal-like reptiles"), amphibians and fish as well as petrified wood and other plant material, trace fossils (burrows, trackways *etc*) and microfossils. Many of these fossils are exposed at the surface by natural weathering or in artificial excavations (*e.g.* roadcuts, dams) but the majority remain embedded within the underlying bedrock.

Beaufort Group fossils within the TCP propecting area have been assigned to five successive, time-related biotas known as assemblage zones (AZ), based largely on their distinctively different tetrapod (*i.e.* terrestrial vertebrate) faunas. The survey corridors within the western part of the study area, to the west of Beaufort West and the N12, overlie the three oldest assemblage zones (*Eodicynodon* AZ, *Tapinocephalus* AZ and *Pristerognathus* AZ) that are characterized by low fossil abundance and a limited range of major vertebrate subgroups. A large number of fossil sites are nevertheless recorded here within the upper part of the Abrahamskraal Formation in the Koup region and parts of the Moordenaarskaroo. In contrast, there are very few fossil records from the lower Abrahamskraal Formation in the Klein-Roggeveldberge and Roggeveld Escarpment to the west. To the east of the N12 and Beaufort West the seismic corridors traverse four fossil assemblage zones, the latest two of which (*Tropidostoma* AZ, *Cistecephalus* AZ) have yielded large numbers of specimens representing a wide spectrum of tetrapod subgroups. However, much of this wealth of fossils comes from the Great Escarpment zone outside the propecting area. Due to low levels of bedrock exposure within the eastern portion of the study region itself the density of fossil sites recorded here is generally low, apart from the Sundays River Valley area.

Small outcrops of several formations assigned to the Dwyka and Ecca Groups, the oldest subunits of the Karoo Supergroup, are also represented on the western and southeastern margins of the Falcon prospecting area. They do not crop out within the proposed new seismic survey corridors, With the exception of the thin Whitehill Formation, which contains abundant Early Permian aquatic mesosaurid reptiles, palaeoniscoid fish and crustaceans, these Dwyka and Ecca formations have a sparse palaeontological record dominated by trace fossils and transported plant remains. Early Jurassic dolerites (igneous rocks) intruding Beaufort Group sediments in the northern part of the study area are completely unfossiliferous. Quaternary superficial sediments such as alluvium that mantle the Karoo bedrocks, especially in the eastern part of the study area (Die Vlakte), have a low palaeontological sensitivity. Important vertebrate and other remains (*e.g.* mammal bones and teeth) may occasionally be found here, however.

During the proposed new seismic survey the level of fresh bedrock excavation involved in shot hole drilling within the propecting corridors is minimal. The shot holes will be filled in and rehabilitated soon after use, so there is little opportunity for meaningful palaeontological mitigation. The most likely cause of damage to fossil heritage exposed at the surface in the study area is off-road vehicle use (*e.g.* drilling rig). This will be kept to a practicable minimum, however, and is not considered here to be a serious factor for fossil heritage conservation.

It is concluded that the impact of the proposed seismic survey programme on Karoo fossil heritage is likely to be very low and that no specialist palaeontological mitigation is required for this phase of the project. However, scientifically valuable fossil specimens may be encountered during the field survey. These fossils should be safeguarded – *in situ* as far as possible - and carefully recorded by the ECOs, for example using GPS co-ordinates and digital cameras (with scale). The fossil occurrences should then reported to a professional palaeontologist for possible collection. To this end, the ECOs for the field survey should examine museum displays (*e.g.* at the Albany Museum, Grahamstown, the Bernard Price Institute for Palaeontological Research at Wits University, Johannesburg,, or the Iziko Museum in Cape Town) to familiarize themselves with the typical appearance of Karoo fossil material, especially the bones & teeth of vertebrates, fossil plants, petrified wood, and larger vertebrate burrows.

2. INTRODUCTION & BRIEF

2.1. Outline of the proposed seismic prospecting project

The Canadian energy company Falcon Oil & Gas Ltd ('Falcon') is applying for an Exploration Right in terms of the Mineral and Petroleum Resources Development Act No. 28 of 2002 to conduct natural gas exploration by means of a seismic survey in the southern part of the Great Karoo Basin, Republic of South Africa. The target resource is shale gas sourced from organic-rich mudrocks of the Karoo Supergroup. The main source and reservoir rock for the shale gas is the Early Permian Whitehill Formation within the lower Ecca Group. This formation does not crop out within the study area except at its western and southern edge and elsewhere it is for the most part buried at depths of up to one to four kilometres below the land surface. Further source rocks and reservoirs occur within underlying and overlying formations of the Dwyka, Ecca and Beaufort Groups.

The seismic survey application area, known as the TCP area, comprises approximately 30 000km^2 of the Great Karoo region *sensu stricto* - *i.e.* the comparatively low-lying region between the Cape Fold Mountains and the Great Escarpment. The area overlaps the Magisterial Districts of Ceres, Laingsburg, Prince Albert, Beaufort West, Fraserburg, Sutherland, Aberdeen, Graaff-Reinet, Jansenville and Willowmore in the Western Cape, Northern Cape and Eastern Cape Provinces (Figs. 1 to 3). It includes more than 2 500 farms and farm portions of which some 426 properties are involved in the current seismic survey plan.

The co-ordinates for the TCP seismic survey application area are as follows:

Latitude (S)	Longitude (E)	Length (m)	Angle of Direction
A 32° 25' 0.0"	19° 45' 0.0"	**AB** 470 316.61	90° 00'0.0"
B 32° 25' 0.0"	24° 45' 0.0"	**BC** 64 691.25	180°00'0.0"
C 33° 00'0.0"	24° 45' 0.0"	**CD** 467 266.07	270° 00'0.0"
D 33° 00'0.0"	19° 45' 0.0"	**DA** 64 691.25	0° 00'0.0"

The proposed method to be used during the seismic survey is the shot hole method which will involve the drilling of 5m-deep holes at approximately 50m intervals along selected seismic survey corridors across the Great Karoo (Figs. 2 & 3). The length of these lines will be between 700 and 1000km; their detailed alignment has not yet been specified. The drilling will be carried out by small portable drilling rigs. As far as practicable, seismic data acquisition would take place along existing roads, tracks and trails within the selected corridors. Following controlled detonation of small explosive charges within the shot holes, the holes would be filled in and other necessary environmental rehabilitation measures implemented. It is anticipated that seismic field data acquisition will take place within the second year of a three year exploration programme.

Since the proposed seismic survey may affect fossil heritage exposed at or buried beneath the land surface within the Great Karoo region, a palaeontological baseline study of the entire application area is required as part of an Environmental Management Programme (EMP) in compliance with Mineral and Petroleum Resources Development Act. The present palaeontological impact assessment (PIA) of the prospecting area also fulfils the requirements of the National Heritage Resources Act regarding fossil heritage.

It is noted that Falcon is only planning seismic data acquisition under the Exploration Right. Any subsequent exploration activities would be subject to additional authorization application processes, similar to the current EMP process.

2.2. Potential implications of proposed seismic survey for Karoo fossil heritage

The TCP application area in the southern part of the Main Karoo Basin is almost entirely underlain by Late Palaeozoic bedrocks of the Karoo Supergroup. This *c*. 12km-thick succession of sediments is world famous for its rich fossil heritage recording continental and (non-marine) aquatic wildlife of the ancient southern supercontinent Gondwana during the Carboniferous to Jurassic Periods (Cluver 1978, MacRae 1999, McCarthy & Rubidge 2005). The Karoo Basin fossils – notably a wide range of terrestrial and aquatic vertebrates, as well as land plants, invertebrates and trace fossils – may already be exposed at the land surface but the majority are embedded within the underlying bedrock. The purpose of the present desktop study is to assess whether or not the proposed seismic prospecting project, involving the drilling and detonation of several thousand 5m-deep shot holes across the Karoo *veld*, might have a substantial impact on Karoo fossil heritage, for example by disturbing, damaging or destroying scientifically valuable fossils above or below ground. If so, we would need to know where the impact would be most significant and how it might be effectively mitigated.

2.3. Relevant heritage legislation

A palaeontological baseline study of the TCP prospecting application area is required as part of an Environmental Management Programme (EMP) in compliance with Section 79(4) Mineral and Petroleum Resources Development Act No. 28 of 2002. This palaeontological baseline study for the Falcon Oil Petroleum Exploration Right has been commissioned by SRK Consulting, Cape Town, as part of a comprehensive EMP for the seismic surveying component of the project.

The scale of the proposed seismic prospecting corridors may also fall within the requirements for a Heritage Impact Assessment (HIA) as stipulated by Section 38 (Heritage Resources Management) of the South African 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 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 May 2007.

It may be noted that at this stage the detailed alignment of the proposed seismic survey corridors and the position of the shot holes within these corridors have not yet been finalised. However, these outstanding data would not affect the broader conclusions of the present desktop study.

2.4. Terms of reference for this desktop study

As specified by SRK Consulting, the terms of reference for the present palaeontology baseline study for the Falcon Oil Exploration Right EMP include the following main components:

- A high-level baseline description of known palaeontological resources and areas with a high probability of containing palaeontological resources in the application area, with a specific focus on identification of areas of particular sensitivity;
- The description must include the entire application area, but the discussion should focus on the areas along the proposed seismic line corridors;

- The study to be a literature-based, desktop study (no fieldwork required);
- Identification of information gaps and/or areas where information on palaeontological resources may be lacking;
- Identification of practical mitigation / management measures (if required) that effectively minimise or eliminate negative impacts, enhance beneficial impacts, and assist project design. These measures will be included in the EMP, which will be implemented during the seismic survey activities, in order to ensure that all known and potentially unknown palaeontological resources will be protected during the proposed activities. If relevant, appropriate monitoring measures should also be recommended.

2.5. General approach used for palaeontological impact desktop studies

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 surveys, 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 2008a, b, 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 survey by a professional palaeontologist is usually warranted to identify fossil hotspots as a basis for further specialist mitigation.

2.6. Assumptions and limitations relevant to this palaeontological desktop study

In inferring the palaeontological sensitivity of rock units underlying a development from field and other data obtained outside the study area it is assumed that fossil heritage is fairly uniformly distributed throughout the outcrop area of a given formation. Experience shows that this assumption does not always hold. This is because the original depositional setting across a formation that may extend over hundreds of kilometres may vary significantly, with palaeoecological implications (*e.g,* from a shallow to deeper water environment), while fossils are often patchy in their occurrence. Furthermore, the levels of tectonic deformation (folding, cleavage development *etc*), as well as the intensity and nature of metamorphism and weathering experienced by a given formation may change markedly across its outcrop area. These factors may seriously compromise the preservation of fossil remains present within the original sedimentary rock so that the effective palaeontological sensitivity of a rock unit that is normally highly fossiliferous may be effectively very low in some areas.

Several factors limit and distort our current understanding of fossil distribution within the Karoo rocks, such as collection bias, poor locality details for older fossil collections, and restriction of bedrock exposure mainly due to cover by superficial sediments (*e.g.* alluvium, scree) or vegetation. These factors are discussed further in Section 4.3.7.

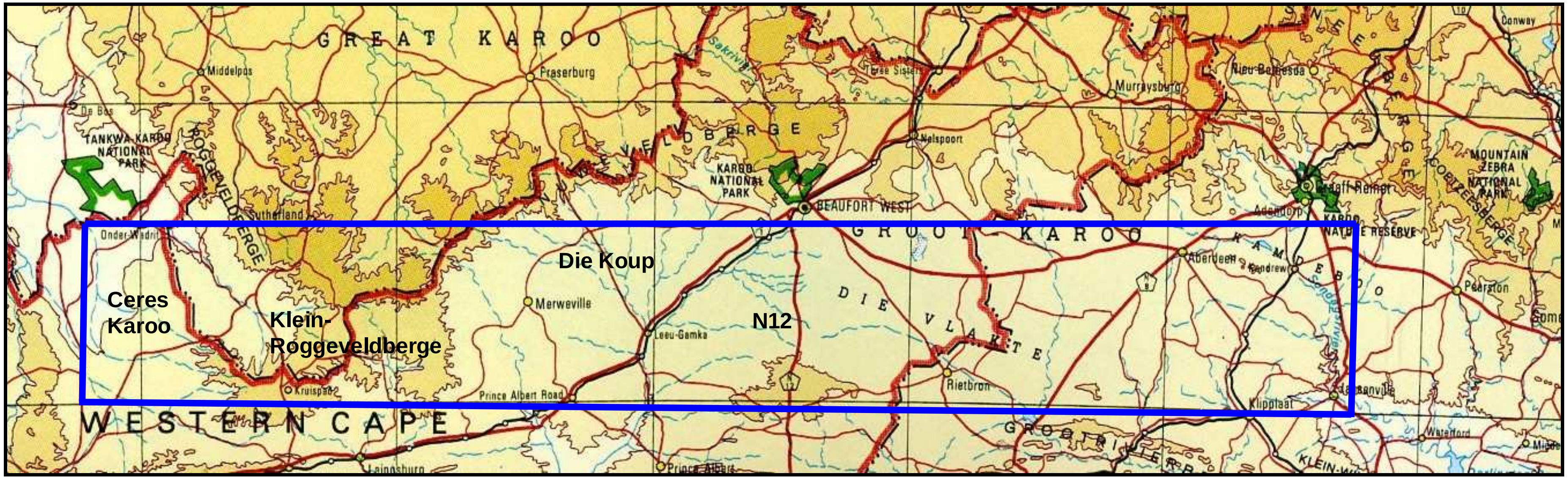

Fig.1. Topographic map of the Great Karoo region, South Africa, showing the approximate extent (blue rectangle) of the TCP exploration area that is mostly situated south of the Great Escarpment. The TCP area extends eastwards from the Ceres Karoo below the Roggeveld Escarpment, across the Klein-Roggeveldberge and Koup region into the flat-lying eastern Karoo regions known as Die Vlakte and the Kamdeboo.

Fig. 2. **Satellite image of the Great Karoo region *sensu stricto*, stretching between the Cape Fold Mountains in the south and the Great Escarpment in the north (Image kindly provided by SRK Consulting). The TCP prospecting area is outlined by the white rectangle. The approximate alignments of the proposed new seismic survey corridors are indicated by pink lines.**

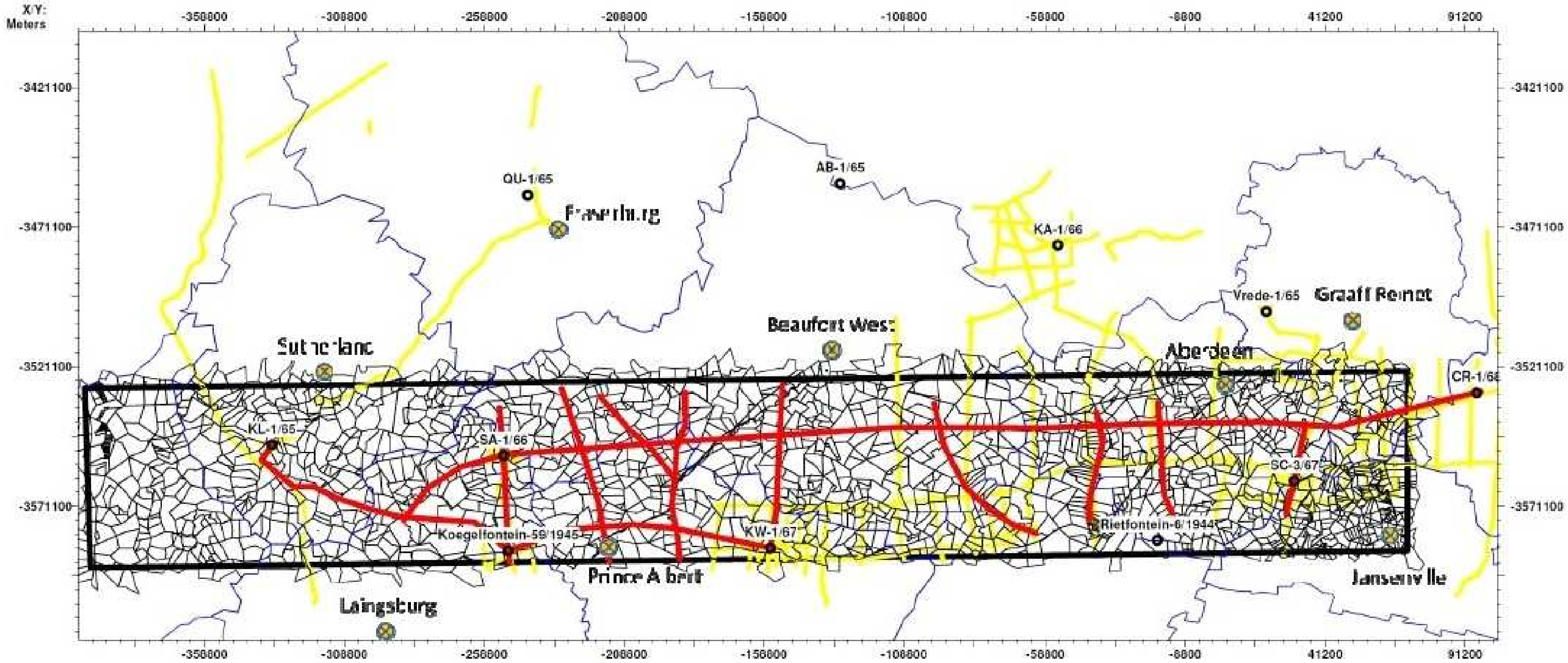

Fig. 3. Outline of the TCP prospecting area (black rectangle) and new seismic corridors (red lines) in the context of the various magisterial districts within the Western, Northern and Eastern Cape Provinces concerned (Image kindly provided by SRK Consulting).

3. GEOLOGICAL SETTING OF THE STUDY AREA

The TCP seismic prospecting application area is located within the southern portion of the Main Karoo Basin of South Africa which is infilled by sediments of Late Carboniferous to Early Jurassic in age. In geographic terms, the study area lies almost entirely within the Great Karoo *sensu stricto*, *i.e*. the comparatively low-lying, flat to hilly region situated between the mountains of the Cape Fold Belt in the south and the Great Escarpment in the north (Figs. 1 & 2). The western edge of the TCP area extends into the arid *vlaktes* (plains) of the Tanqua or Ceres Karoo, a karroid region that lies below the Roggeveld Escarpment and that is separated from the Great Karoo proper by the subdued mountainous uplands of the Klein-Roggeveldberge. The TCP area in the northwest includes a portion of the Great Escarpment - here formed by the Roggeveldberge and Komsberg-Besemgoedberg ranges - and of the southern Roggeveld Plateau to the south of Sutherland. East of the Klein-Roggeveldberge and north of Laingsburg is a deeply-dissected region, the Moordenaarskaroo, that is drained by the Buffels River. This is separated from the equally dissected Koup region, drained by the Dwyka and Gamka Rivers, by a north-south trending mountainous ridge (drainage divide) with s steep, east-facing escarpment. The extensive, low-lying Koup region stretches eastwards to the N12 south of Beaufort West where it merges with an equally extensive, but topographically more subdued, area known as Die Vlakte. This last area, which includes the Aberdeen Flats, is only traversed by minor ephemeral rivers and is extensively blanketed in alluvial deposits. The eastern edge of the prospecting area lies just beyond the Sundays River, flowing southwards from Graaff-Reinet past the small town of Jansenville which is situated in the south-eastern corner of the TCP area. As a result of erosional dissection of the Karoo landscape here, levels of bedrock exposure are much greater than in the *vlaktes* to the west. East of the Sundays River the low-lying area around Pearston, at the foot of the Great Escarpment, is known as the Plains of the Kamdeboo (*cf* Palmer 1990). The main west-east seismic prospecting corridor for the Falkon Oil project extends outside the TCP area here (Fig. 3).

The geology of the TCP prospecting area is shown in outline in the 1: 1 000 000 geological map published by the Council for Geoscience, Pretoria (Figs. 6a to 6c). More detailed geological maps of the TCP area at 1: 250 000 scale include the sheets 3218 (Clanwilliam), 3220 (Sutherland), 3222 (Beaufort West) and 3224 (Graaff-Reinet). These larger scale maps show the different formations within the Lower Beaufort Group but not all the lower Ecca formations are mapped separately. Accompanying sheet explanations with brief accounts of the main rock units have been published by Theron (1983), Johnson and Keyser (1979) and Hill (1993).

With very minor exceptions – such as Early Jurassic intrusions of the Karoo Dolerite Suite (Jd) close to the Great Escarpment and Late Cretaceous carbonatite intrusions of the Sutherland Suite at Salpeterkop (Ksu) – the study area overlies sedimentary bedrocks of the Karoo Supergroup. The stratigraphic subdivision of the Karoo Supergroup is shown in Fig. 4. The great majority of the study area is underlain by continental (fluvial *plus* minor lacustrine) sediments of the Lower Beaufort Group (Adelaide Subgroup, Pa) that are Middle to Late Permian in age. However, small outcrop areas of the glaciogenic Dwyka Group (Late Carboniferous to Early Permian, C-Pd) and Ecca Group (Early to Mid Permian) rocks crop out along the western and southern edge of the TCP area (Fig. 5) and will also be briefly considered from a palaeontological perspective here. Recent reviews of the geology of the Karoo Supergroup in the Main Karoo Basin have been provided by Smith *et al.* (1993), Veevers *et al.* (1994), Johnson *et al.* (1996), Catuneanu *et al*. (2005) and Johnson *et al.* (2006). More accessible accounts with a strong palaeontological emphasis for the general reader are given by MacRae (1999) as well as McCarthy and Rubidge (2005).

It should be noted that not all the formations represented in the study area are differentiated at the 1: 1 million map scale (See key to Figs. 6a-c). For example, several of the Ecca formations are grouped as Ppw in the western Karoo and as Pr along the southern Karoo margins. The four constituent formations of the Lower Beaufort Group in the study area are amalgamated as Pa.

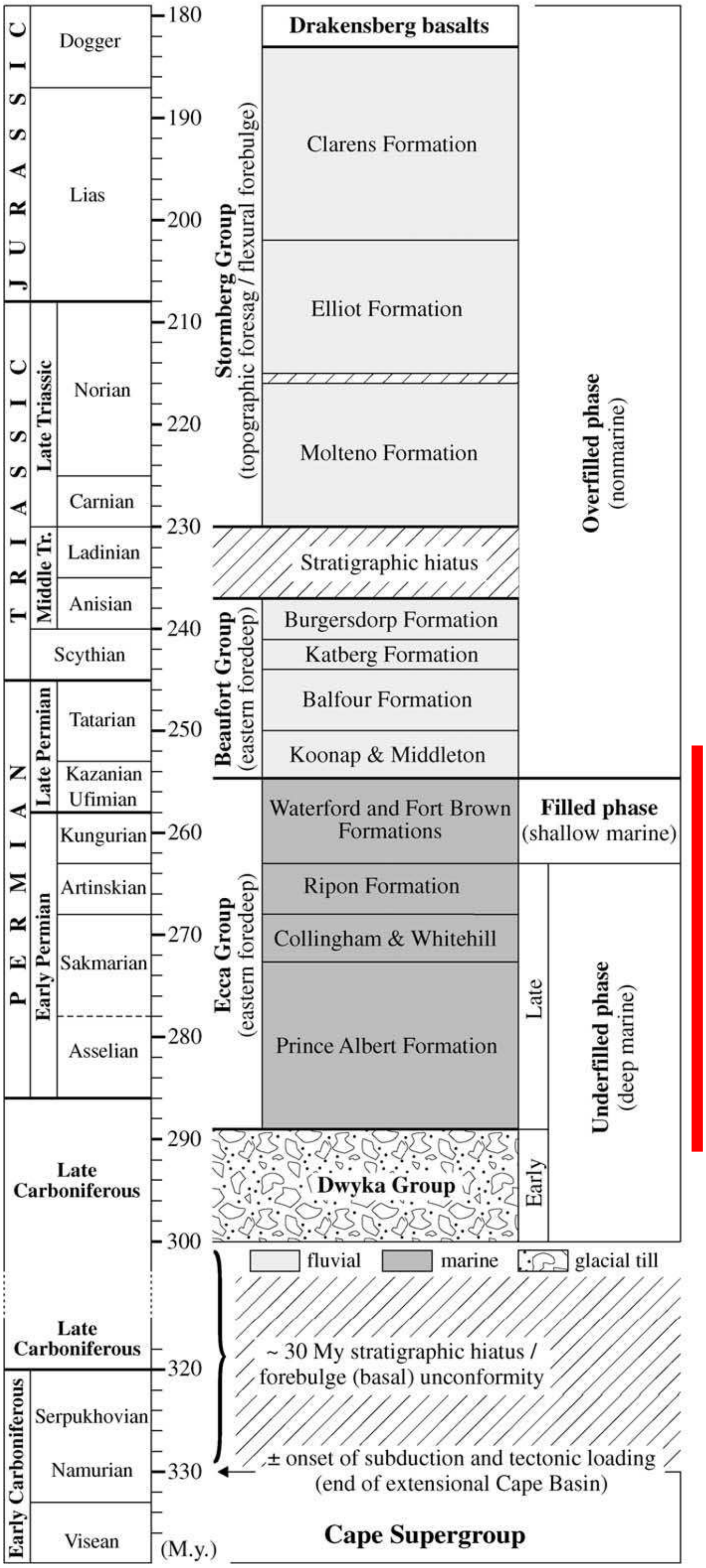

Fig. 4. Stratigraphic subdivision of the *c*. 12km-thick Karoo Supergroup (From Catuneanu *et al.* 2005). The bold red line emphasizes the Late Carboniferous to Late Permian sedimentary units represented in the TCP study area. Not all relevant formations are shown here (See Fig. 5).

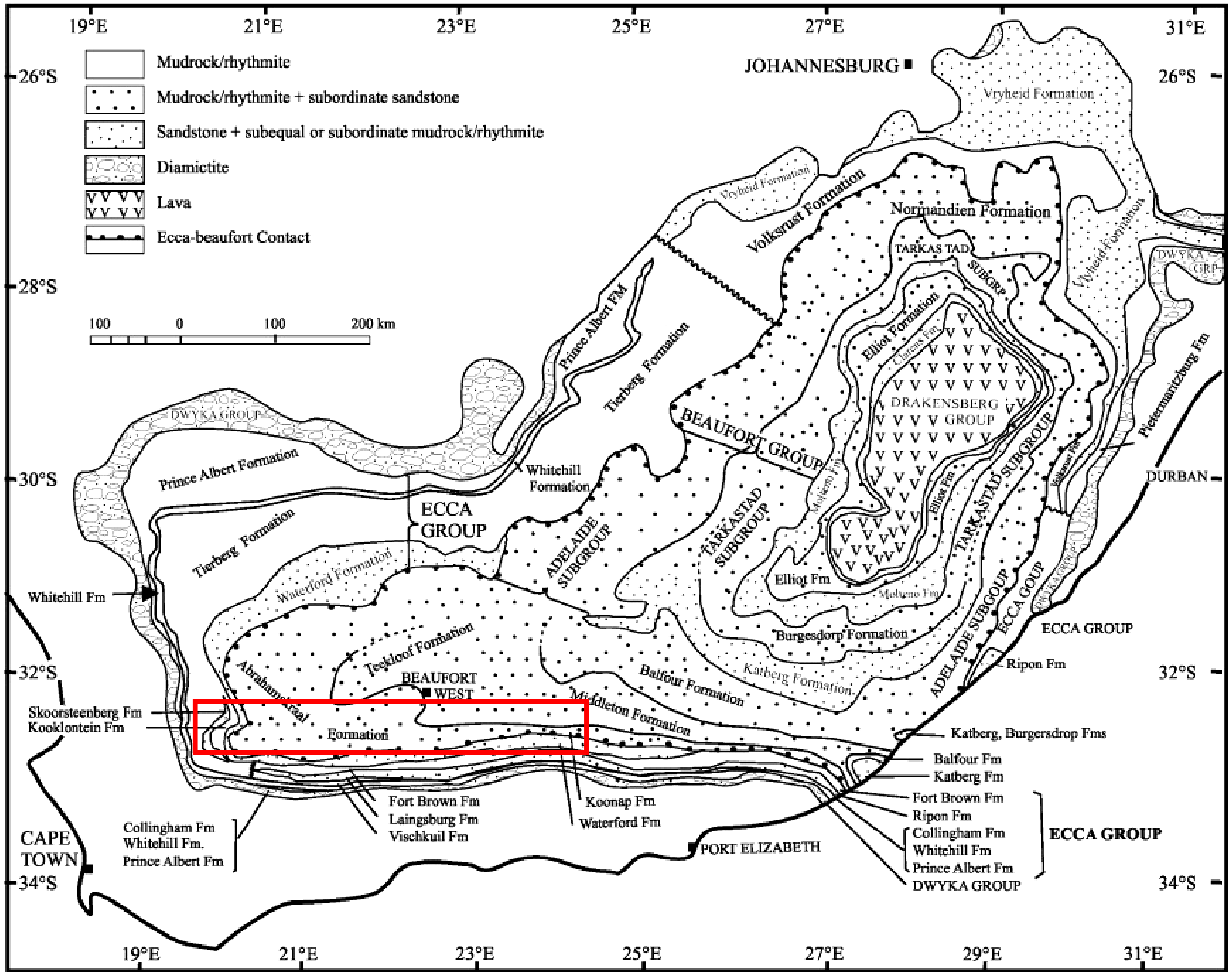

Fig. 5. Distribution and dominant lithologies of sedimentary formations within the Main Karoo Basin, also showing the approximate outline of the TCP study area (Modified from Catuneanu *et al.* 2005).

Figs. 6a-c (following three pages). Extracts from the 1: 1 000 000 geological map of the RSA (Council for Geoscience, Pretoria) should the geology of the TCP study area (outlined in black). A key to the rocks units is given below. Note that several separate formations may be grouped together on maps of this scale (*e.g.* Lower Ecca units). All four formations of the Lower Beaufort Group represented within the study area are grouped here as Pa (Adelaide Subgroup).

Jd (pink) = Early Jurassic dolerite intrusions of the Karoo Dolerite Suite
Ksu (greenish-yellow) = Late Cretaceous intrusions and volcanics of the Sutherland Suite

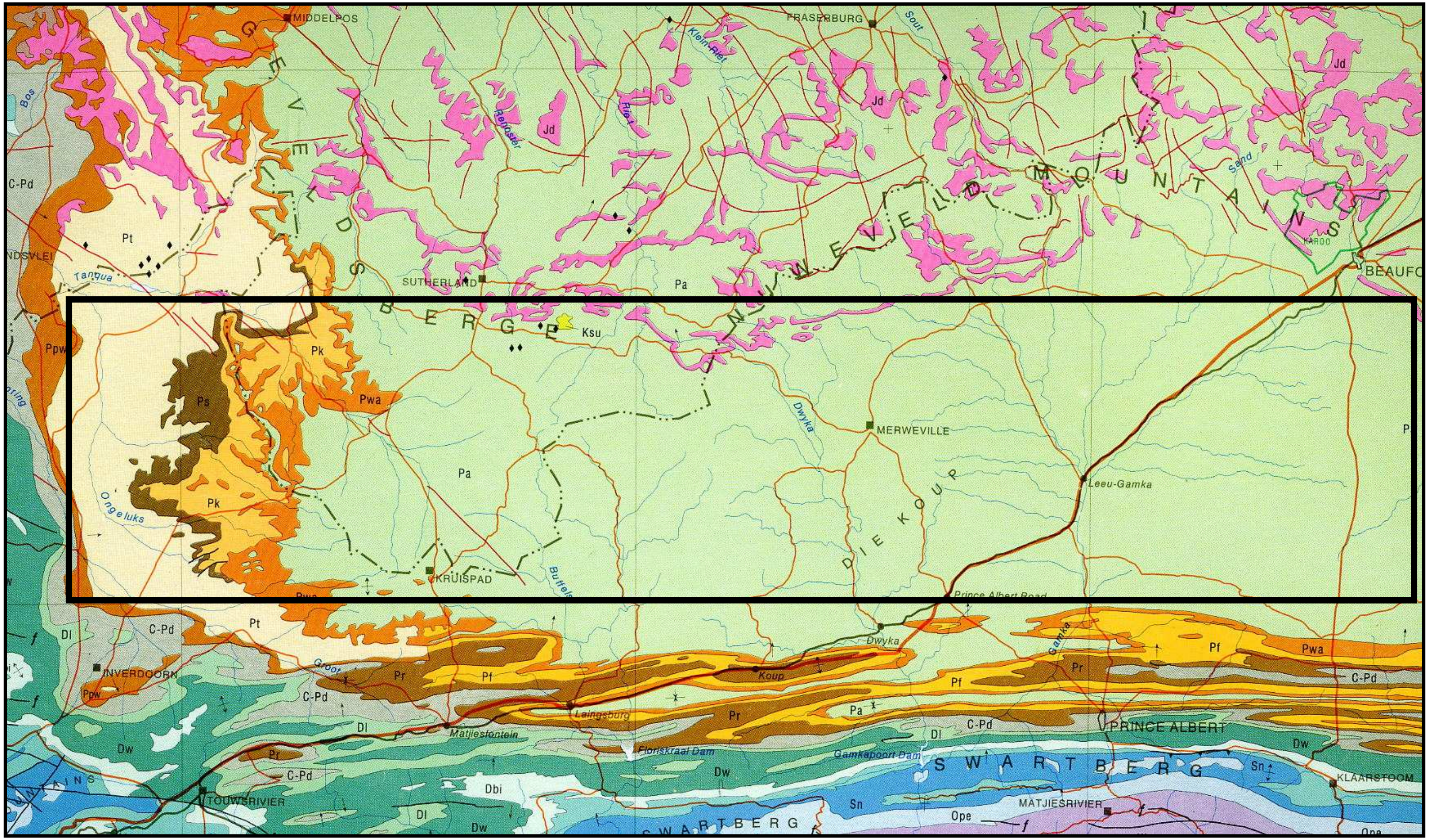

Fig. 6a. Geological map (west). See page 12 for key to geological units.

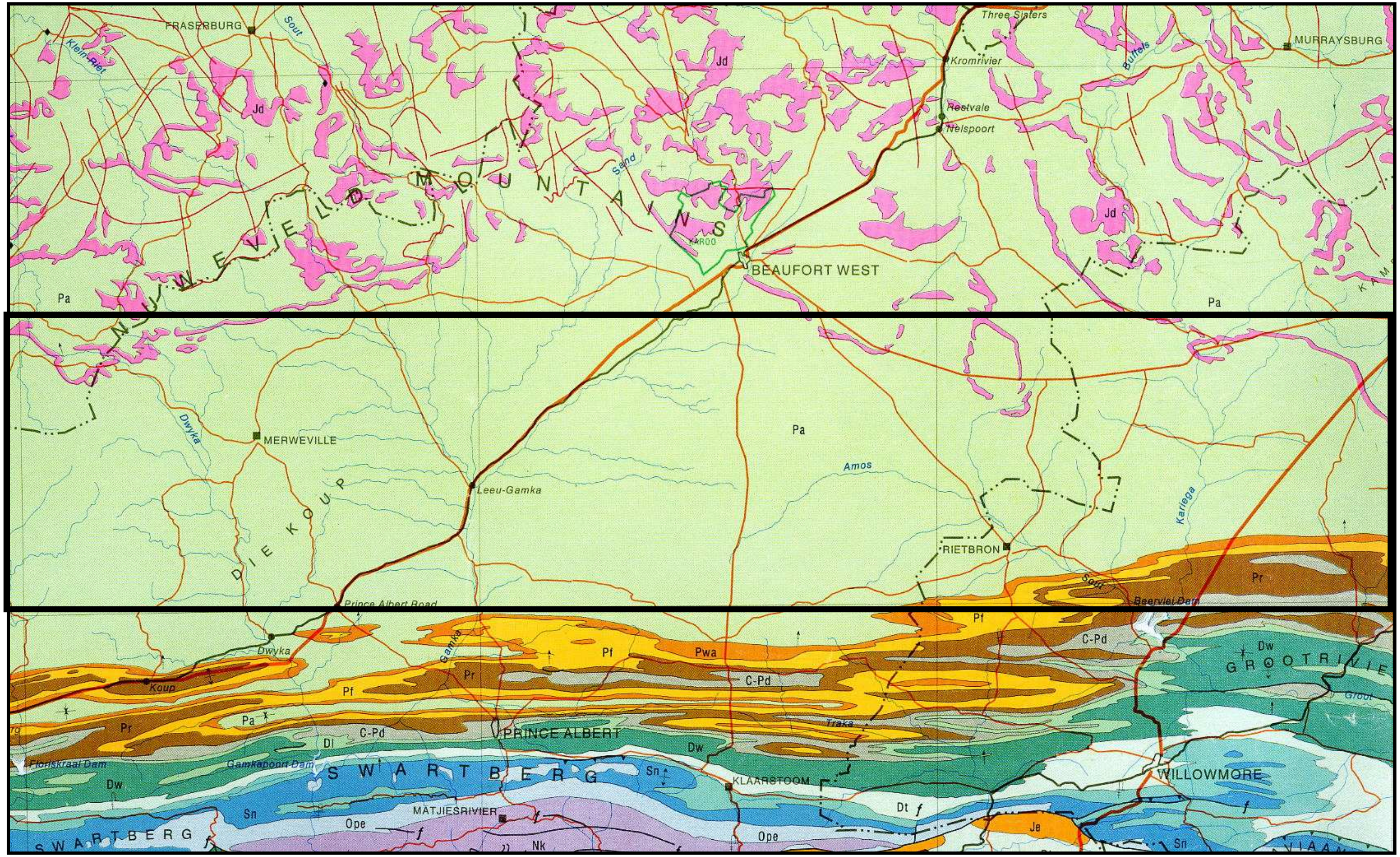

Fig. 6b. Geological map (central). See page 12 for key to geological units.

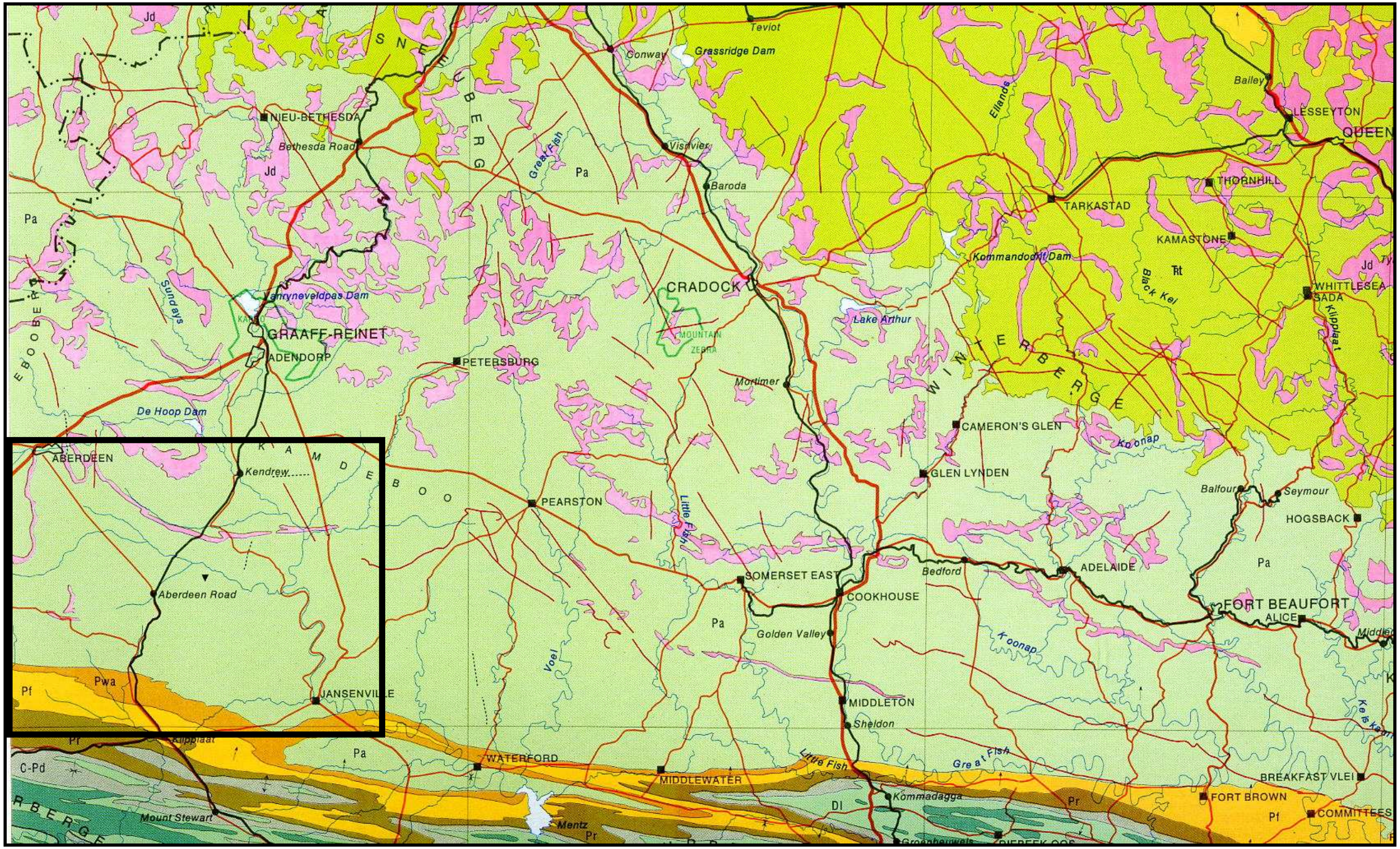

Fig. 6c. Geological map (east). See page 12 for key to geological units.

4. PALAEONTOLOGICAL HERITAGE WITHIN THE TCP PROSPECTING AREA

This section of the report provides an outline of the fossil heritage recorded within all the main geological units represented within the TCP prospecting area. Special emphasis is given here to the fossil record of the Lower Beaufort Group (Adelaide Subgroup) which underlies by far the greater part of the study area and is also the most fossiliferous stratigraphic unit occurring here. Brief accounts are also given of the fossil record of the Dwyka and Ecca Group formations that crop out on the margins of the TCP study area, although these units do not occur within the proposed new seismic corridors shown in Figs. 2 and 3.

4.1. Fossil record of the Dwyka Group

Permocarboniferous sediments of the the Elandsvlei Formation of the Dwyka Group (C-Pd) crop out on the western and southern margins of the TCP study area. This glaciogene succession has a very restricted fossil record (McLachlan & Anderson 1973, Anderson & McLachlan 1976, Visser *et al*., 1990, Visser 2003, Bamford 2004, Almond 2008a, b and refs. therein). This is hardly surprising given that glaciomarine settings prevailed in the Main Karoo Basin during most of the Late Carboniferous to Early Permian interval. However, most Dwyka sediments were deposited during periods of glacial retreat associated with climatic amelioration. Sparse fossil biotas within interglacial or postglacial mudrocks are dominated by low diversity ichnofossil assemblages of the subaqueous, non-marine *Mermia* ichnofacies. The traces mainly consist of arthropod trackways (*e.g. Umfolozia* - probably made by small crustaceans) and fish swimming trails (*Undichna*) that are associated with dropstone laminites and sporadic vascular plant remains – mainly drifted wood and leaves of the *Glossopteris* Flora. Palynomorphs (organic-walled pollens and spores) are present within finer-grained mudrock facies. Glacial diamictites (tillites or “boulder mudstones”) are normally unfossiliferous but do occasionally contain fragmentary transported plant material as well as palynomorphs in the fine-grained matrix. Occasional pale grey limestone glacial erratics from tillites along the southern margins of the Great Karoo contain Cambrian eodiscid trilobites as well as archaeocyathid sponges that have been sourced in Antarctica. Such derived fossils provide important data for reconstructing the movement of Gondwana ice sheets (Cooper & Oosthuizen 1974).

4.2. Fossil Record of the Ecca Group

The Early to Middle Permian sediments of the Ecca Group were deposited in an extensive shallow epicontinental sea that was largely isolated from the world ocean and probably non-marine (brackish to freshwater) for most of its history (Johnson et al. 2006, Johnson 2009). Apart from almost ubiquitous, low diversity trace fossil assemblages that are variously assigned to the *Mermia*, *Nereites*, *Scoyenia* and *Cruziana* ichnofacies and scattered plant remains, including petrified wood, Ecca fossil assemblages are therefore generally impoverished. The Ecca fossil record of the Cape region has recently been reviewed by Almond (2008a, b). It should be noted that there is currently considerable debate in the scientific literature concerning the dating as well as the depositional setting of the Ecca succession, with some recent authors arguing for a marine basin on the basis of geochemical as well as trace fossil evidence (Scheffler *et al.* 2006, Fildani *et al.* 2007, 2010a, b, Higgs 2010 and references therein).

4.2.1. Prince Albert Formation

The Early Permian fossil biota of the dark, post-glacial mudrocks of the Prince Albert Formation is summarized by Cole (2005). This unit is included within Ppw and Pr on the 1: 1 million scale geological maps and crops out round the entire western and southern margins of the Main Karoo

Basin. Typical trace fossil assemblages of the non-marine *Mermia* ichnofacies are typically dominated by delicate arthropod trackways (especially *Umfolozia*) and scratch burrows or furrows (*Isopodichnus*), arthropod resting traces (*Gluckstadtella*) and undulose fish fin trails (*Undichna*) (Anderson 1974, 1976, 1981, Almond 2008a, b). More complex arthropod trackways, some of them possibly generated by small eurypterids, are known in the Laingsburg District. Diagenetic nodules containing the remains of palaeoniscoids (primitive bony fish), sharks, spiral bromalites (coprolites, gut casts *etc*) and petrified wood have been found in the Ceres Karoo and rare shark remains (*Dwykaselachus*) occur near Prince Albert on the southern margin of the Great Karoo (Oelofsen 1986). Microfossils recorded in this formation include sponge spicules, foraminiferal and radiolarian protozoans, acritarchs and miospores.

4.2.2. Whitehill Formation

This formation is included within Ppw (west) or Pr (south) on the 1: 1 million scale geological maps. In palaeontological terms the Early Permian (Sakmarian) Whitehill Formation is one of the richest and most interesting stratigraphic units within the Ecca Group (Almond 2008a, 2008b and refs. therein). The overall palaeontological sensitivity of this formation has been rated as high (Almond & Pether 2008a). In brief, the main groups of Early Permian fossils found within the Whitehill Formation include:

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

Important material of the fossil groups listed above has mainly been collected in the Western Cape Province during the twentieth century by a series of palaeontologists (See, for example, McLachlan & Anderson 1973, Oelofsen 1981, 1987, Cole & Basson 1991, Almond 1996, 2008a, 2008b, Almond & Pether 2008a, 2008b, Evans & Bender 1999, Evans 2005, and refs. therein). The biostratigraphic distribution of the most prominent fossil groups within the Whitehill Formation – mesosaurid reptiles, palaeoniscoid fishes and notocarid crustaceans – has been documented by several authors, including Oelofsen (1987), Visser (1992, 1994) and Evans (2005).

4.2.3. Collingham Formation

The palaeontology of the Collingham Formation (within Ppw or Pr on the 1: 1 million scale geological maps) has been reviewed by Viljoen (1992, 1994) and Almond (2008a, 2010a, 2010). Extensive unjointed bedding planes are rarely exposed, seriously compromising the recording of fossils from these brittle beds. Transported, water-logged plant debris of the *Glossopteris* Flora and tool marks generated by logs are often associated with thicker turbidite beds, especially within the upper part of the Collingham Formation. Substantial blocks of silicified wood, such as the gymnospermous genus *Australoxylon*, are known from the Laingsburg area and elsewhere (Bamford 1999). The heterolithic character of this succession favours trace fossil preservation, with very high levels of bioturbation recorded locally. The abundance of fossil burrows indicates that oxygenation of bottom waters and the sea bed had improved substantially since Whitehill times. Moderately diverse trace fossil assemblages recorded from the Collingham Formation include horizontal, 2cm-wide epichnial grooves with obscurely segmented levees ("*Scolicia*", possibly generated by gastropods), narrow, bilobate arthropod furrows ("*Isopodichnus*"), reticulate horizontal burrows (perhaps washed out *Megagrapton*-

like systems), densely packed horizontal burrows with a rope-like surface texture covering selected bedding planes (*cf Palaeophycus*), narrow branching burrows, rare arthropod trackways (*Umfolozia*) and fish swimming trails (*Undichna*) (Anderson 1974). The trackway of a large sweep-feeding eurypterid has been identified from the Collingham Formation near Laingsburg, and fragmentary body fossils of similar giant arthropods are known from coeval sediments in South America (Almond 2002). At over two metres long, these bottom-feeding predators are the largest animal so far known from the largely land-locked Ecca Sea.

4.2.4. Tierberg Formation

A wide range of non-marine ichnogenera of the *Mermia* ichnofacies, including fish swimming tails, arthropod trackways and resting traces and as yet unnamed pellet-filled, strap shaped burrows (so called "*Plagiogmus*" *in lit.*), have been collected from the Tierberg Formation (Pt), many of them from the Tanqua Karoo and Roggeveld regions (Viljoen 2005). These basinal ichnoassemblages have been reviewed by Wickens (1996) as well as Almond (2008a, b) who give extensive references. Leaf compressions of the *Glossopteris* Flora and petrified woods have been recorded from these rocks in the Tanqua Karoo region and elsewhere. Rare animal body fossils include disarticulated microvertebrate remains - *e.g.* isolated teeth, scales - from calcareous concretions (Zawada 1992).

4.2.5. Skoorsteenberg Formation

The fossil record of the Skoorsteenberg Formation (Ps) submarine fans has been reviewed by Almond (2008b). Body fossils of animals are very rare, including isolated records of articulated palaeoniscoid fish, disarticulated fish remains and bivalves, generally preserved within diagenetic carbonate nodules. These nodules have also yielded gymnosperm pollens and spores. The commonest fossils are a wide range of traces of the *Mermia* and *Nereites* ichnofacies, often preserved on turbidite soles (Wickens 1996, Scott 1997, Johnson *et al.* 2001). They include various meandering horizontal burrows, arthropod trackways (*e.g. Kouphichnium*, attributed to king crabs and *Umfolozia* of probably crustacean origin) and resting impressions, fish swimming trails (*Undichna*) as well as washed-out graphoglyptid network burrows of the ichnogenus *Megagrapton* ("*Palaeodictyon*") or a related form. Trace fossils in the Skoorsteenberg and correlative Laingsburg Formation have been interpreted as evidence for a marine depositional setting by some recent workers (*e.g.* Johnson *et al.* 2001, Fildani *et al.* 2010b) but this has been contested (Higgs 2010). Thin veneers of fragmentary, transported plant debris of the *Glossopteris* Flora, including glossopterid leaves and segmented roots (*Vertebraria*), are often preserved on the tops of turbidite sandstones (Anderson & McLachlan 1976, Anderson & Anderson 1985). Complex striated tool marks – including prod, groove and skip marks - on the soles of these beds are attributed to logs and branches entrained at the base of turbidity flows. Palynomorphs are apparently scarce (Scott 1997).

4.2.6. Ripon Formation

The Ripon Formation is included on the 1: 1 million scale geological maps under Pr and crops out along the southeastern margin of the Main Karoo Basin from Prince Albert eastwards. Like the correlative units of Early Permian (Artinskian) age towards the west - the Viskuil, Laingsburg, Tierberg and Skoorstenberg Formations - the Ripon is a thick, non-marine submarine fan succession comprising tabular-bedded greywackes, rhythmites and dark mudrocks (Johnson 1976, Kingsley 1977, Kingsley 1981, Johnson & Kingsley 1993, Catuneanu *et al.* 2005, Johnson *et al.* 2006). Within the study area it crops out on the southern edge of the Beaufort West and Graaff-Reinet sheets where it reaches a thickness of 500-800m. The fossil record within the Ripon Formation is rather sparse and has not received much attention from palaeontologists. Fragmentary, compressed plant remains (*e.g.*

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

4.2.7. Kookfontein and Fort Brown Formations

These two geologically similar units are indicated by Pk and Pf on the 1: 1 million scale geological maps. The palaeontological record of these prodeltaic and delta front facies of the western fluvially-dominated Ecca deltas is sparse and poorly known (Wickens 1984, 1996, Rubidge *et al.* 2000, Almond 2008b). Trace fossil assemblages tend to be impoverished due to high sedimentation rates, fluctuating salinities and sediment instability, though levels of bioturbation may be locally very high. They include various horizontal interface burrows and distinctive, transversely-ribbed pellet burrows of an unnamed ichnogenus (so-called "*Plagiogmus*" of authors) as well as large *Teichichnus*, *Undichna*, and *Kouphichnium* (king crab trackways). Plant fragments (finely ground "tea leaves" or "coffee grounds"), disarticulated palaeoniscoid fish scales and silicified wood (Bamford 1999) are also common in Ecca delta front successions. Isolated tetrapod bones, presumably transported offshore by floods, have been recorded from the Fort Brown Formation in the Eastern Cape (Kingsley 1977, Rubidge & Oelofsen 1981).

4.2.8. Waterford Formation

The Waterford Formation (Pw) comprises delta platform sediments that extend round the western and southern margins of the Main Karoo Basin. 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 excellent 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).

4.3. Fossil record of the Lower Beaufort Group

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

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

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

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

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

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

A chronological series of mappable fossil biozones or assemblage zones (AZ), defined mainly on their characteristic tetrapod faunas, has been established for the Main Karoo Basin of South Africa (Rubidge 1995, 2005) (Fig. 7). Maps showing the distribution of the Beaufort assemblage zones within the Main Karoo Basin have been provided by Kitching (1977), Keyser and Smith (1977-78) and Rubidge (1995, 2005). An updated version based on a comprehensive GIS fossil database is currently in press (Van der Walt *et al.*). Five successive Mid to Late Permian assemblage zones are represented within the Abrahamskraal, Teekloof, Koonap and Middleton Formations in the TCP study area. These are the Middle Permian *Eodicynodon*, *Tapinocephalus* and *Pristerognathus* AZ and the Late Permian *Tropidostoma* AZ and *Cistecephalus* AZ. The rather complex relationship between these formations (lithostratigraphic units) and assemblage zones (biostratigraphic units) is shown in Fig. 7. The approximate distribution of the five fossil biozones within the TCP area is shown in Fig. 8. Fig. 9 shows the relative abundance of tetrapod fossil specimens that have been collected from the various biozones and formally curated in museums (*c*. 21 000 specimens in total). This figure gives a very broad overview of changing abundance and diversity of Beaufort Group fossil heritage with time (Nicolas 2007, Nicolas & Rubidge 2010).

It should be noted that on the basis of international faunal correlation, the *Tropidostoma* and *Cistecephalus* Assemblage Zones of the Lower Beaufort Group have until recently been assigned to the Wuchiapingian Stage of the Late Permian Period, with an approximate age range of 260-254 Ma. The underlying *Tapinocephalus* and *Pristerognathus* AZ were referred to the preceding Capitanian Stage (266-260 Ma) of the Middle Permian (Rubidge 2005 and refs. therein). The end-Guadalupian (*i.e.* end – Middle Permian) mass extinction event was inferred to lie at the contact between the *Tapinocephalus* and *Pristerognathus* AZ within the uppermost Abrahamskraal and Koonap Formations (Retallack *et al.* 2006). Recently announced, but as yet unpublished, radiometric dates for the assign a late Guadalupian (Capitanian) age to the *Pristerognathus* AZ (261-260.36 Ma), an early Lopingian

(Wuchiapingian) age to the *Tropidostoma* AZ (259.3 Ma), and a later Wuchiapingian age to the *Cistecephalus* AZ (256.6-255.2Ma) (Rubidge *et al.* 2010). This places the Mid / Late Permian boundary and End Guadalupian mass extinction event, if it is indeed reflected on land, between the *Pristerognathus* and *Tropidostoma* AZs within the Teekloof and Middleton Formations, rather than at the base of the *Pristerognathus* AZ as previously assumed.

4.3.1. The *Eodicynodon* Assemblage Zone

Fossil biotas within the lowermost 800m or so of the Abrahamskraal Formation along the southern margin of the Beaufort Group outcrop near Prince Albert have been assigned to the *Eodicynodon* Assemblage Zone (Rubidge & Oelofsen 1981, Rubidge 1987, 1991, 1995, 2005). This AZ extends along the southern edge of the TCP study area from just south of Prince Albert Road eastwards to the N12 and beyond. The Middle Permian (Wordian) biota is characterized by a limited range of primitive therapsids, notably the small dicynodont *Eodicynodon* (by far the commonest taxon), large-bodied herbivorous and carnivorous dinocephalians such as *Tapinocaninus* and anteosaurids, as well as very rare gorgonopsians and scylacosaurid therocephalians (Rubidge *et al.* 1994, Rubidge 1995, 2005, Abdala *et al.* 2008, Nicolas 2007, Nicolas and Rubidge 2010). The fauna is of considerable biogeographic significance in that it includes some of the earliest and most primitive examples of several therapsid subgroups recorded anywhere in the world. Associated fossils include disarticulated palaeoniscoid fish and amphibians, freshwater bivalves, a small range of ichnogenera such as the arthropod trackway *Umfolozia*, as well as glossopterids and the sphenophyte ferns *Equisetum* and *Schizoneura* (Anderson & Anderson 1985). Vertebrate fossils here are comparatively rare, often tectonically deformed and difficult to extract from the tough rock matrix. They are mainly found within mudrocks in association with pedogenic calcretes or - in the case of the dinocephalians - within or at the base of channel sandstones.

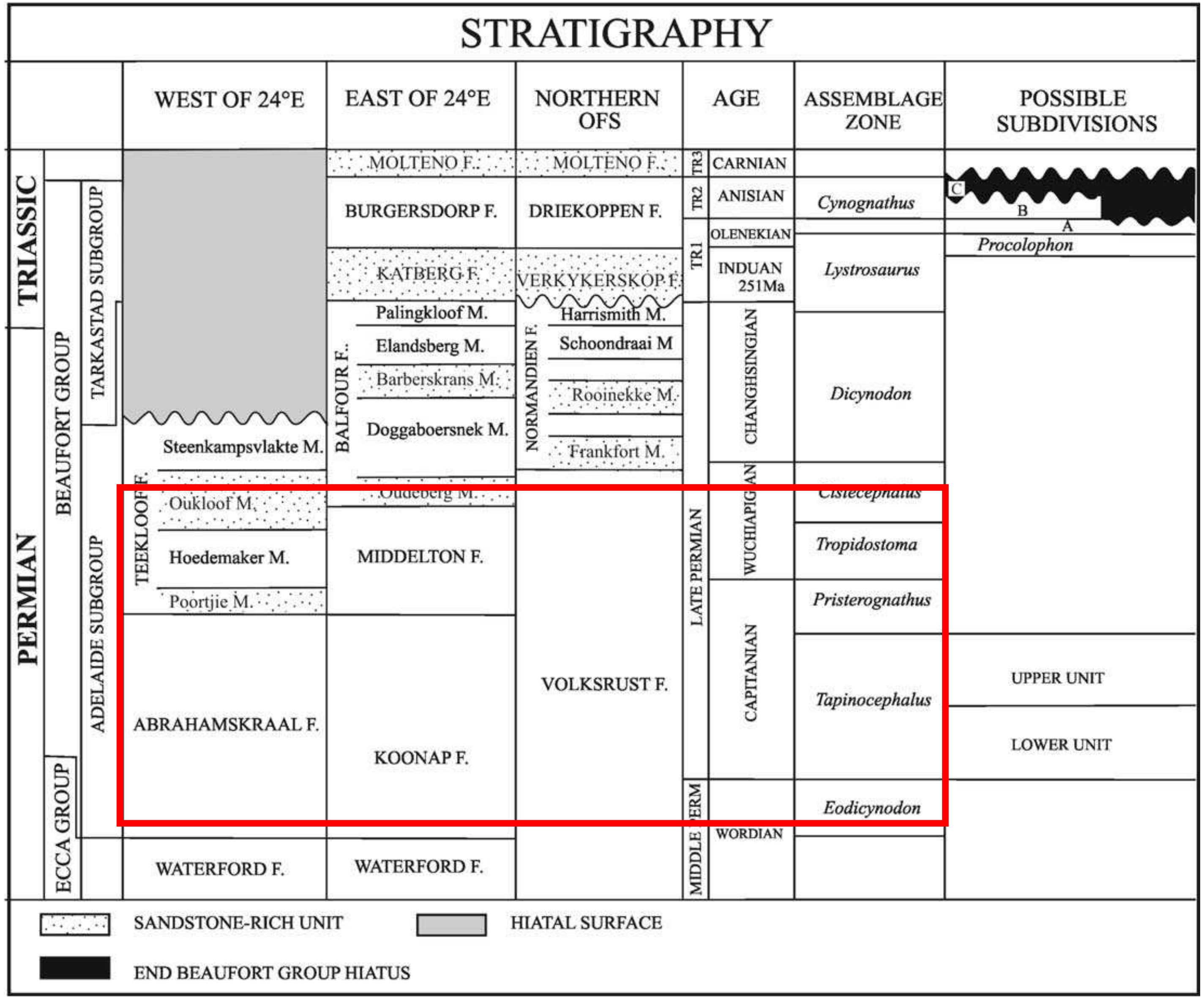

Fig. 7. Beaufort Group stratigraphy showing relationship between fossil assemblage zones and formations represented in the TCP study area (red rectangle) (Catuneanu *et al.* 2005). Note that the dating of these units as shown here has since been modified. For example, the Mid / Late Permian boundary is now placed at the top of the *Pristerognathus* Assemblage Zone.

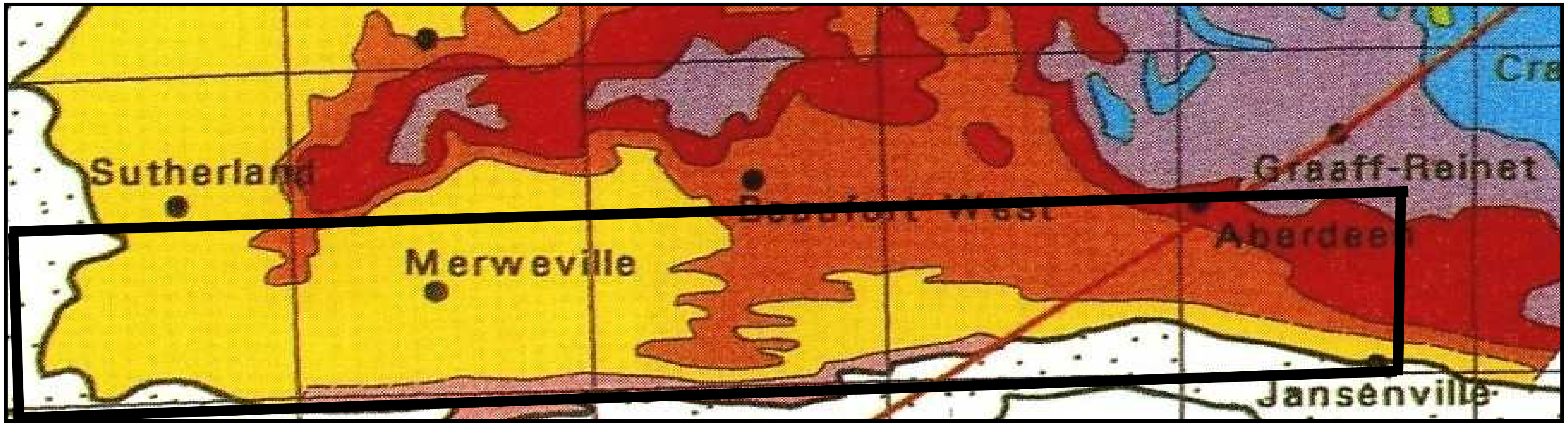

Fig. 8. Extract from the map of fossil assemblage zones (AZ) within the Lower Beaufort Group published by Rubidge (1995). Zones that are represented within the TCP prospecting area (black rectangle) include the *Eodicynodon* AZ (pink), *Tapinocephalus* AZ (yellow), *Pristerognathus* AZ (orange), *Tropidostoma* AZ (red) and *Cistecephalus* AZ (purple). Note that the zone boundaries here were drawn by hand and are only approximate. A revised assemblage zone map based on an extensive GIS fossil database has recently been compiled (Van der Walt *et al.,* in press).

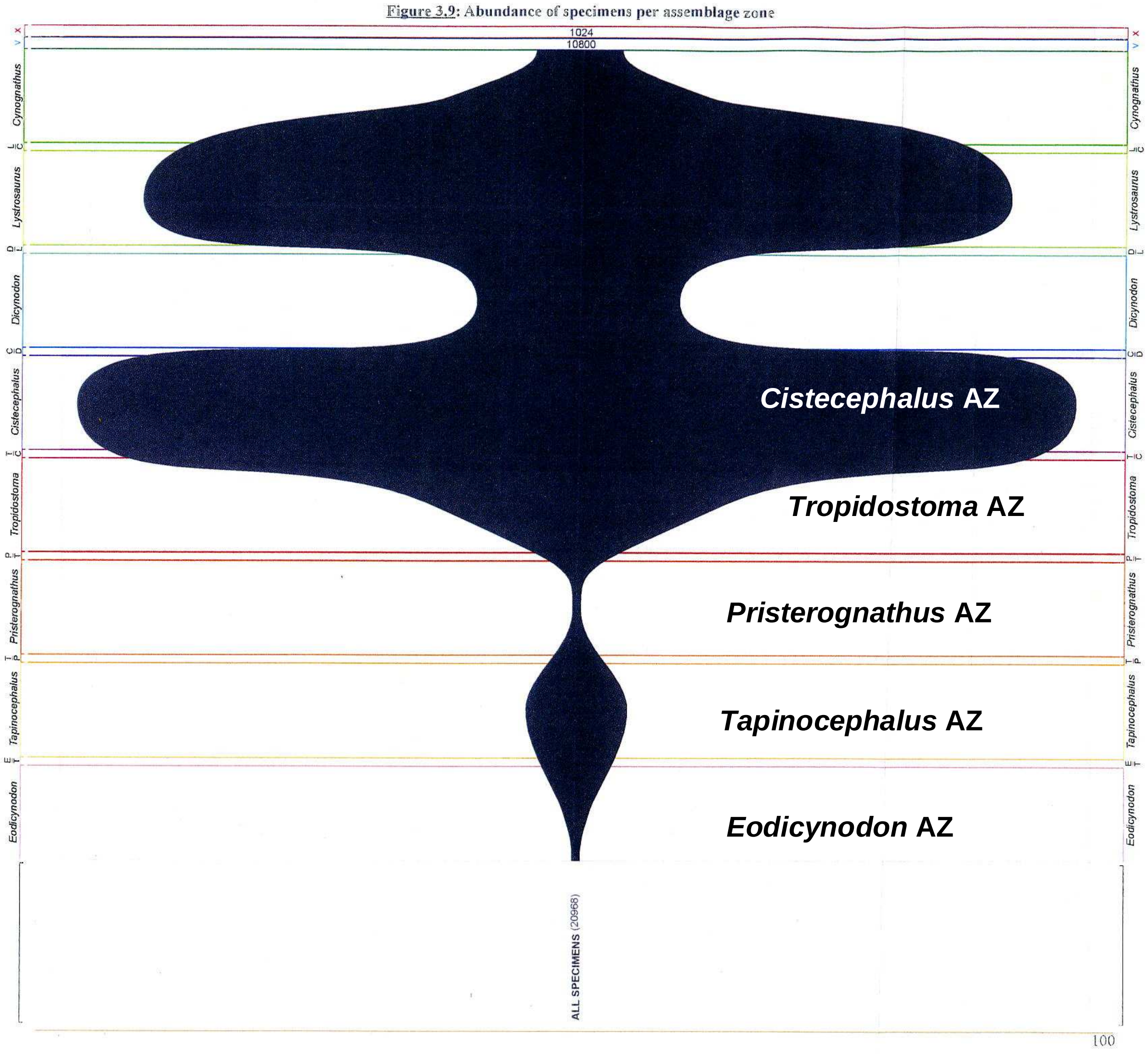

Fig. 9. Chart showing the relative abundance of fossil specimens assigned to the various assemblage zones of the Beaufort Group (Modified from Nicolas 2007). The total sample is c. 21 000 specimens. The five zones represented in the TCP prospecting area are labelled here in large font.

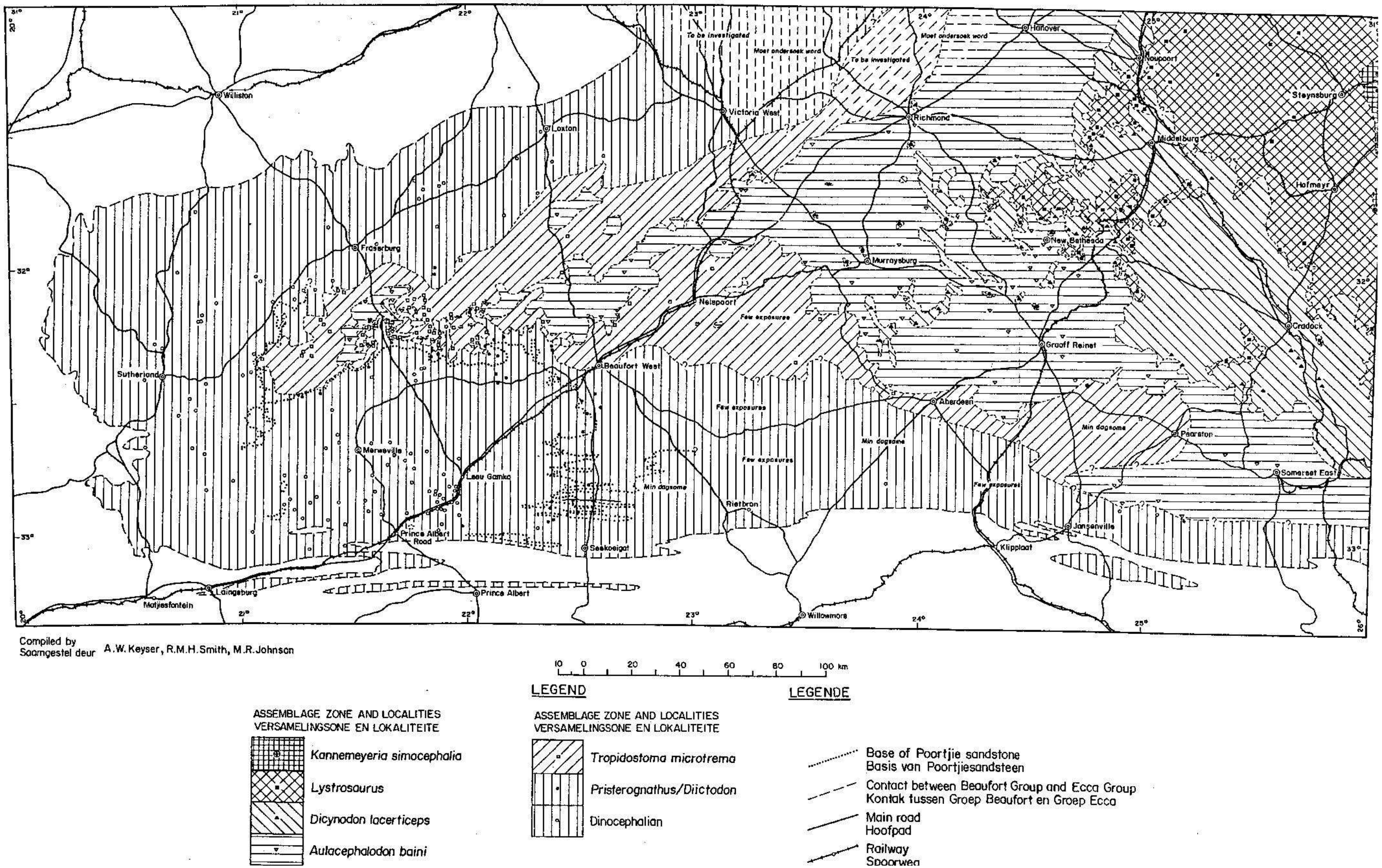

Fig. 10. Early biozanation map of the Beaufort Group outcrop in the western part of the Main Karoo Basin (Keyser & Smith 1997-1998). Many of the fossil occurrences marked on this map are also shown on the 1: 250 000 geological maps of the region. Note the lack of bedrock exposure indicated in the eastern parts of the Great Karoo.

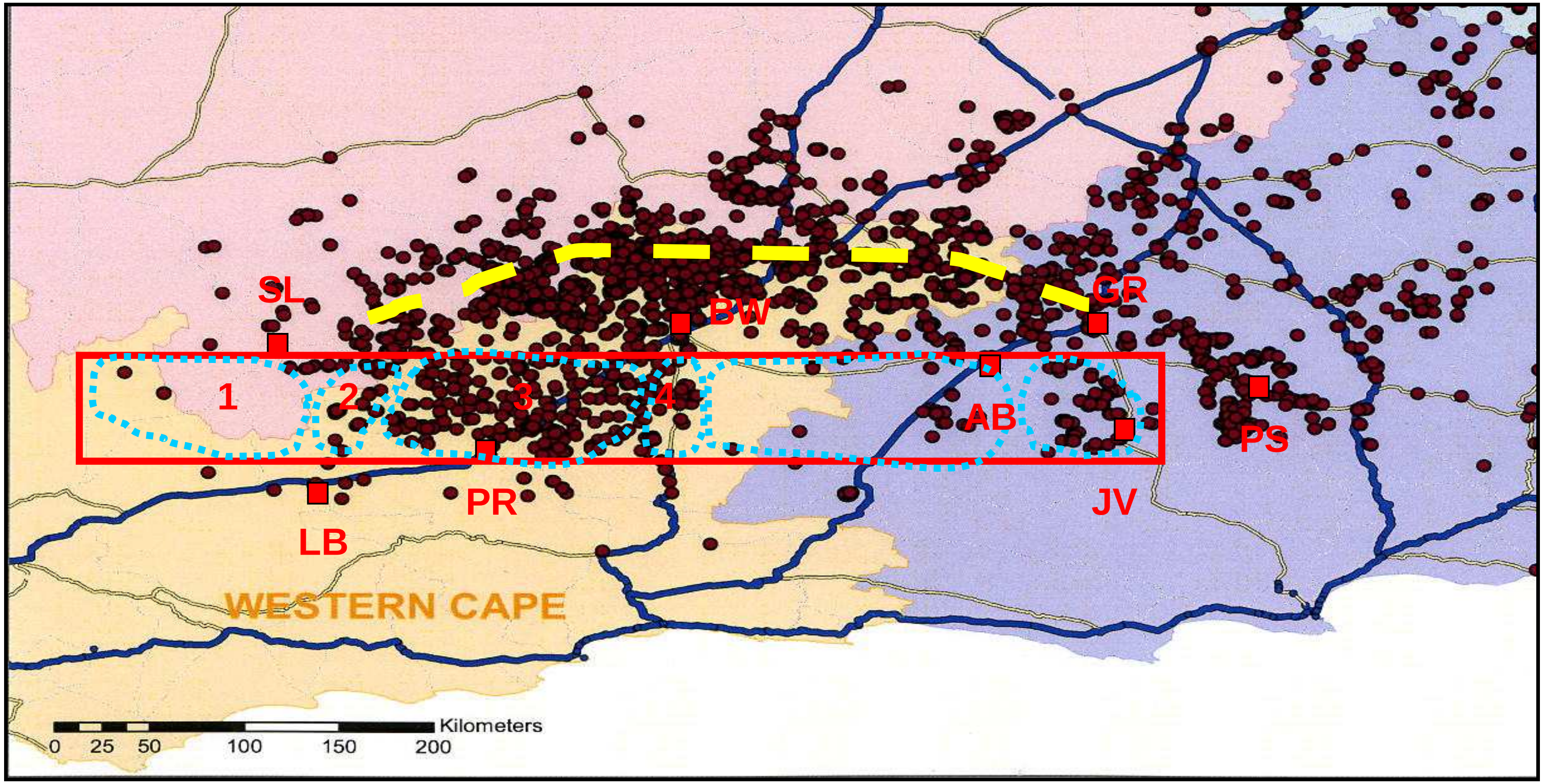

Fig. 11. Distribution map of vertebrate fossil sites (dots) recorded in the TCP study area which is outlined by the red rectangle. (Map modified from Nicolas 2007). The yellow dashed line corresponds to the position of the Great Escarpment where exposure of Lower Beaufort Group bedrocks is unusually good. The six numbered topographic subregions within the TCP prospecting area are discussed further in the text (Section 4.3.8). Note the high density of fossil sites in subregions 2, 3 and 6 and low densities elsewhere.

SL – Sutherland LB – Laingsburg PR – Prince Albert Road BW – Beaufort West AB – Aberdeen GR – Graaff-Reinet JV – Jansenville PS - Pearston

4.3.2. The *Tapinocephalus* Assemblage Zone

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

- isolated petrified bones as well as rare articulated skeletons of tetrapods (*i.e.* air-breathing terrestrial vertebrates) such as true reptiles (notably large herbivorous pareiasaurs like *Bradysaurus*, small insectivorous millerettids), rare pelycosaurs, and diverse therapsids or "mammal-like reptiles". The last group includes numerous genera of large-bodied dinocephalians, smaller herbivorous dicynodonts as well as flesh-eating biarmosuchians, gorgonopsians and therocephalians) (Figs. 12 & 13)

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

- freshwater bivalves (*Palaeomutela*)

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

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

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

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

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

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

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

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

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

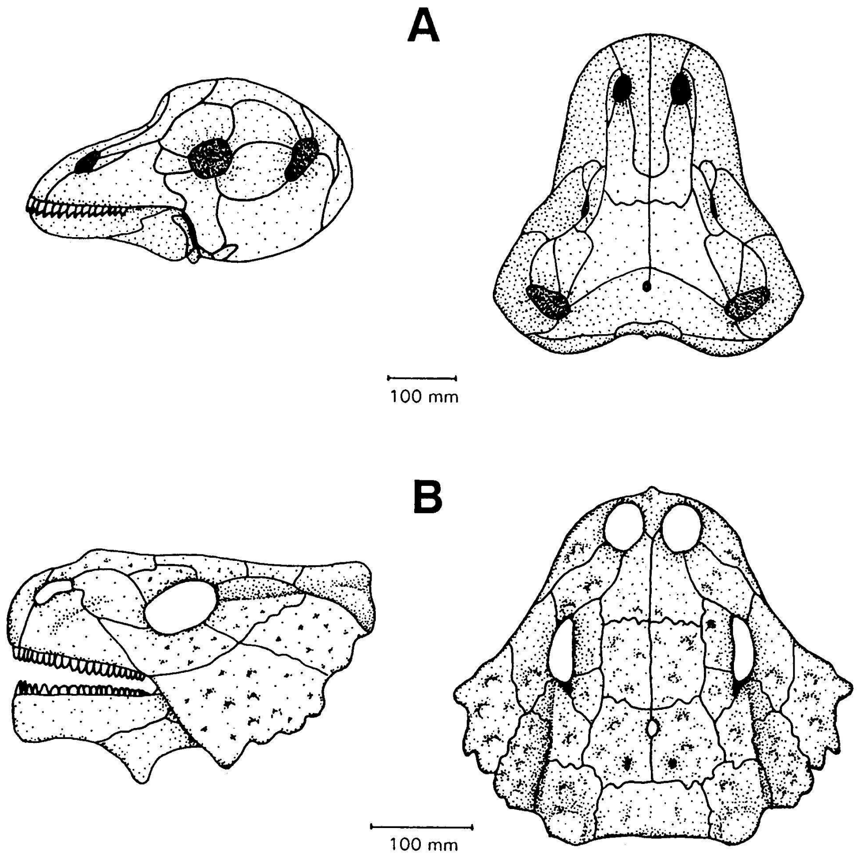

Fig. 12. Skulls of two key herbivorous tetrapods of the *Tapinocephalus* Assemblage Zone: A – the dinocephalian therapsid *Tapinocephalus*; B – the pareiasaur *Bradysaurus* (From Smith & Keyser 1995a).

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

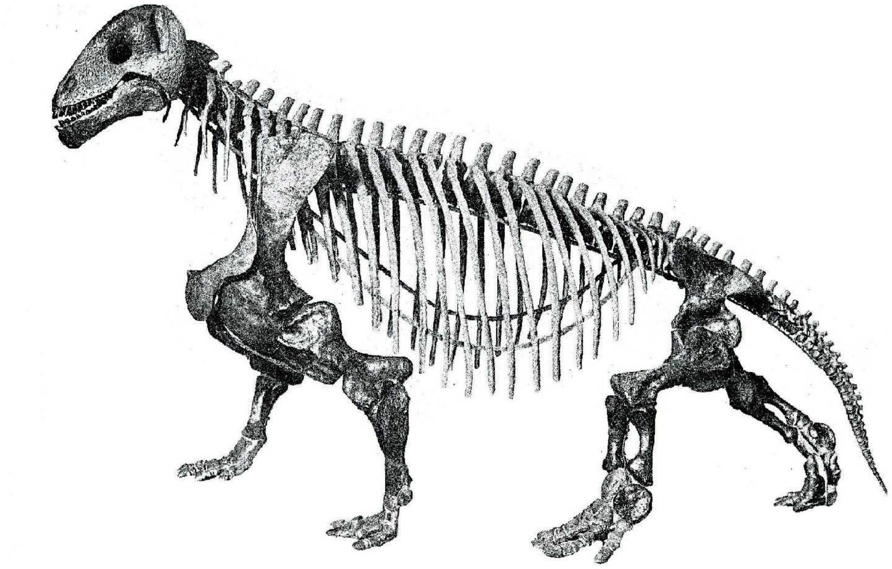

Fig. 13. Skeleton of the tapinocephalid (thick-skulled) dinocephalian *Moschops*, a rhino-sized herbivorous therapsid that reached lengths of 2.5 to 3m and may have lived in small herds.

4.3.3. The *Pristerognathus* Assemblage Zone

Fossils of the *Pristerognathus* Assemblage Zone characterize the arenaceous Poortjie Member as well as the uppermost beds of the underlying Abrahamskraal Formation in the western Main Karoo Basin as well as the beds spanning the Koonap / Middleton Formation boundary in the eastern Karoo (Smith & Keyser 1995b, Fig. 7). This important terrestrial biota is dominated by various therapsids ("mammal-like reptiles") such as the moderate-sized therocephalian carnivore *Pristerognathus* as well as several gorgonopsian predators / scavengers and herbivorous dicynodonts (Fig. 14). The commonest genus by far is the small burrowing dicynodont *Diictodon* (Keyser and Smith 1977-78, Smith & Keyser 1995b, MacRae 1999, Cole *et al*., 2004, Rubidge 2005, Almond 2010, Nicolas 2007, Nicolas & Rubidge 2010). There are also large, rhino-sized herbivorous reptiles (*Bradysaurus* spp.), crocodile-like temnospondyl amphibians (*Rhinesuchus*), palaeoniscoid fish, vascular plant fossils of the *Glossopteris* Flora (fossil wood, leaves *etc*) and various trace fossils, including invertebrate burrows and tetrapod trackways. The comparatively low number of specimens and major taxa represented in fossil collections from this biozone is well seen in Fig. 9 from Nicolas (2007). The fossil biota of the *Pristerognathus* AZ is of special interest because it possibly represents an impoverished post-extinction recovery fauna following a late Mid Permian extinction event that preceded the well-known end-Gualdalupian biotic crisis (*cf* Benton 2003, Retallack *et al.,* 2006, Lucas 2009).

Most fossils in the *Pristerognathus* Assemblage Zone are found in the softer-weathering mudrock facies (floodplain sediments) that are usually only exposed on steeper hill slopes and in stream gullies. Fossils here are often associated with pedogenic limestone nodules or calcretes (Smith 1993a, Smith

& Keyser 1995b). The mudrocks lie between the more resistant-weathering channel sandstones, which in the Poortjie Member display a distinctive "golden yellow" tint. Fossil skeletal remains also occur in the lenticular channel sandstones, especially in intraformational lag conglomerates towards the base, but are usually very fragmentary and water-worn ("rolled bone").

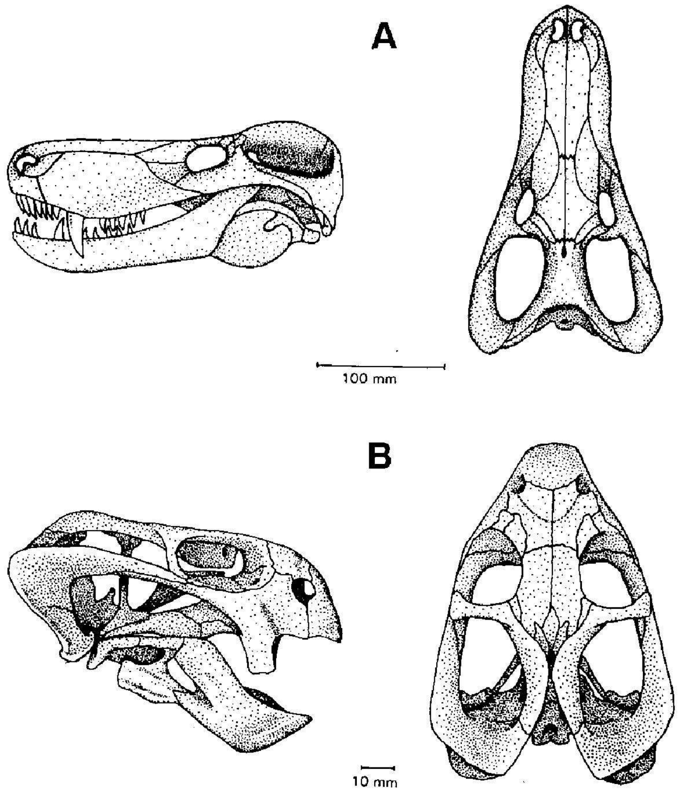

Fig. 14. Skulls of typical therapsids from the *Pristerognathus* Assemblage Zone: A. the dog-sized carnivorous therocephalian *Pristerognathus* and B. the small herbivorous dicynodont *Diictodon* (From Smith & Keyser 1995b).

4.3.4. The *Tropidostoma* Assemblage Zone

The *Tropidostoma* Assemblage Zone (AZ) characterizes the Hoedemaker Member of the Teekloof Formation in the western Karoo and the middle part of the Middleton Formation in the eastern Karoo (Le Roux & Keyser 1988, Smith & Keyser, 1995c) (Fig. 7).

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

- isolated petrified bones as well as rare articulated skeletons of terrestrial vertebrates (tetrapods) such as true reptiles (notably large herbivorous pareiasaurs) and therapsids or "mammal-like reptiles" (*e.g.* diverse herbivorous dicynodonts, flesh-eating gorgonopsians, and insectivorous therocephalians) (Fig. 15)

- aquatic vertebrates such as large temnospondyl amphibians (*Rhinesuchus* spp., usually disarticulated), and palaeoniscoid bony fish (*Atherstonia*, *Namaichthys*, often represented by scattered scales rather than intact fish)
- freshwater bivalves (*e.g. Palaeomutela*)
- trace fossils such as worm, arthropod and tetrapod burrows and trackways, coprolites (fossil droppings), fish swimming trails
- vascular plant remains including leaves, twigs, roots and petrified woods ("*Dadoxylon*") of the *Glossopteris* Flora (usually sparse, fragmentary), especially glossopterid trees and arthrophytes (horsetails).

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

The marked increase in fossil abundance and high level taxonomic diversity within the *Tropidostoma* AZ compared with the underlying impoverished *Pristerognathus* AZ is seen in Fig. 9 (Nicolas 2007). The *Tropidostoma* assemblage may represent a post-extinction recovery fauna following the major end-Guadalupian exctinction event.

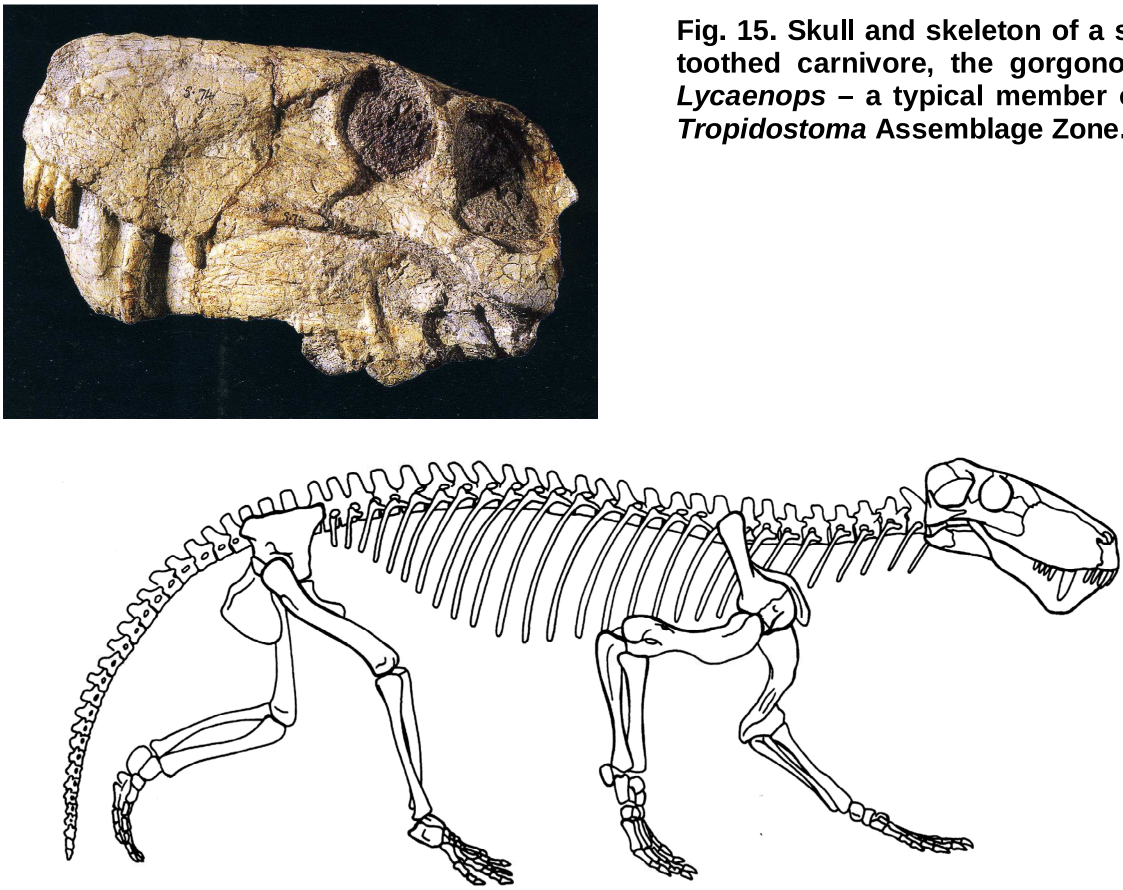

Fig. 15. Skull and skeleton of a saber-toothed carnivore, the gorgonopsian *Lycaenops* – a typical member of the *Tropidostoma* Assemblage Zone.

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

4.3.5. The *Cistecephalus* Assemblage Zone

This assemblage zone is only represented in the northeastern corner In the TCP study area, within the upper part of the Middleton Formation (Figs. 7 & 8). The following fossils groups have been recorded within the Late Permian (Lopingian / Wuchiapingian) *Cistecephalus* AZ (Keyser & Smith 1979, Anderson & Anderson 1985, Hill 1993, Smith & Keyser 1995d, MacRae 1999, Cole *et al*., 2004, Almond *et al*. 2008, Nicolas & Rubidge 2010):

- isolated petrified bones as well as rare articulated skeletons of terrestrial vertebrates such as true reptiles (notably the large herbivorous *Pareiasaurus* and small insectivorous owenettids) and therapsids or "mammal-like reptiles" (*e.g.* diverse herbivorous dicynodonts such as *Cistecephalus*, *Diictodon* and *Oudenodon*, rare flesh-eating gorgonopsians like *Gorgonops* and *Prorubidgea*, and insectivorous therocephalians such as *Ictidosuchoides*) (Fig. 16)
- aquatic vertebrates such as large temnospondyl amphibians (*Rhinesuchus*, usually disarticulated), and palaeoniscoid bony fish (*Atherstonia*, *Namaichthys*, often represented by scattered scales rather than intact fish)
- freshwater bivalves (*Palaeomutela*)
- trace fossils such as worm, arthropod and tetrapod burrows and trackways, coprolites (fossil droppings)
- vascular plant remains including leaves, twigs, roots and petrified woods ("*Dadoxylon*") of the *Glossopteris* Flora (usually sparse, fragmentary), especially glossopterid trees and arthrophytes (horsetails).

This biota is very well represented in fossil collections in South Africa (Fig. 9). Many of the fossil specimens have been found along the Great Escarpment Zone (Nicolas & Rubidge 2009). The best preserved tetrapod fossils are usually found within overbank mudrocks, whereas fossils preserved within channel sandstones tend to be fragmentary and water-worn (Smith & Keyser 1995d). Many fossils are preserved within calcrete nodules in association with ancient soils (palaeosol horizons). The small burrowing dicynodont *Cistecephalus* occurs in great abundance towards the top of the biozone in the southern Karoo.

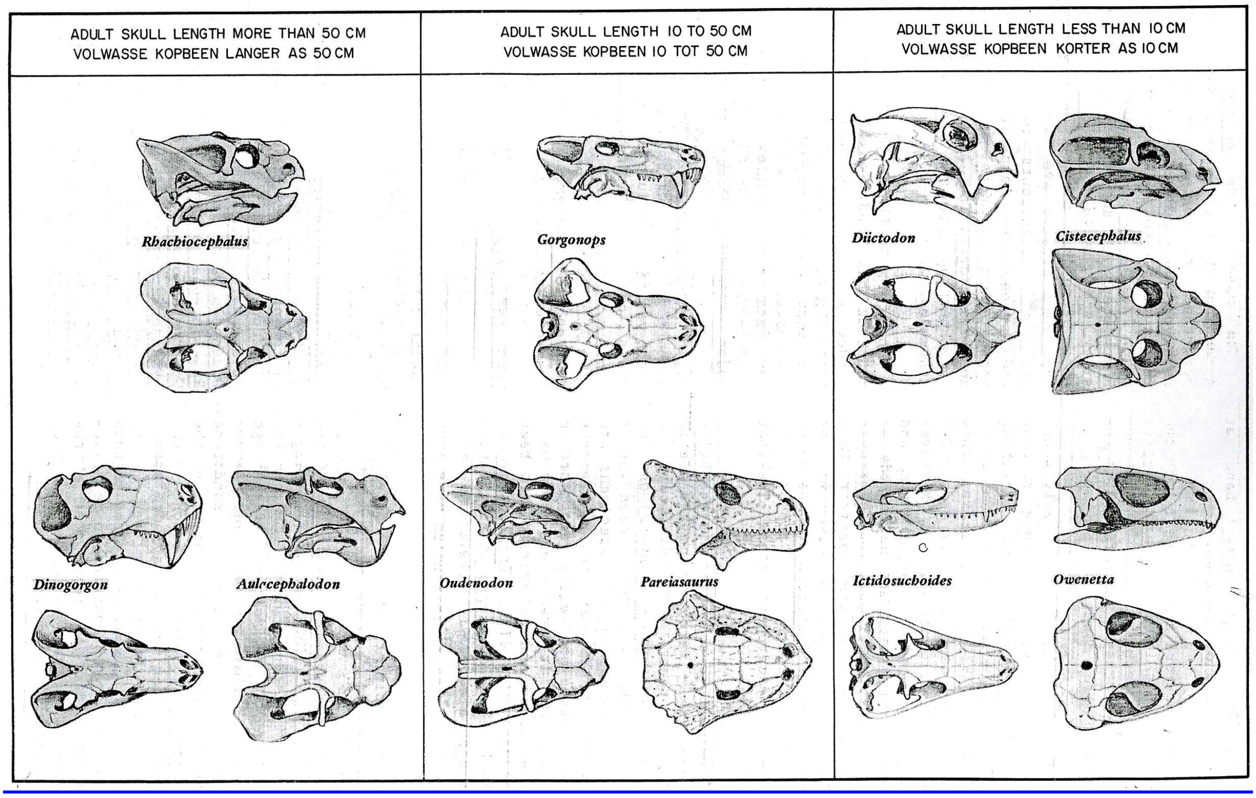

Fig. 16. Skulls of characteristic fossil vertebrates from the *Cistecephalus* Assemblage Zone (From Keyser & Smith 1977-78). *Pareiasaurus,* a large herbivore, and *Owenetta*, a small insectivore, are true reptiles. The remainder are therapsids or "mammal-like reptiles". Of these, *Gorgonops* and *Dinogorgon* are large flesh-eating gorgonopsians, *Ictidosuchoides* is an insectivorous therocephalian, while the remainder are small – to large-bodied herbivorous dicynodonts.

4.3.6. Distribution and density of Beaufort fossil sites in the Great Karoo *sensu stricto*.

Fossils are very widely distributed within the Lower Beaufort Group of the Great Karoo but are often fragmentary and difficult even for the initiated to recognise and collect. At present palaeontologists still have a relatively poor grasp of the real abundance and density of vertebrate and other fossils across the Beaufort Group outcrop area because of the many different biases operating that affect the recording of fossil data (See discussion below). Recently compiled maps of fossil sites and abundance of collected specimens (Nicolas 2007, Nicolas & Rubidge 2009; Figs. 11 & 14 herein) show that there is a relatively high density of both fossils and sites in the Great Karoo region *sensu stricto*, corresponding to the southern part of the Main Karoo Basin. Densities of localities and specimens peak along the Great Escarpment that defines the northern edge of the Great Karoo *ss*. Here bedrock exposure is often very good and intensive fossil collection has taken place over many decades. The analyses of Nicolas (2007) emphasize gaps in the fossil record at both the western and eastern ends of the Great Karoo *s.s.* (Fig. 17), but the significance of these gaps is unclear and need not reflect simply a lower intrinsic fossil abundance here. Fossil abundance and site density maps are not the only measure of "palaeontological heritage sensitivity".

Nicolas (2007) has also generated interesting plots showing the total abundance of fossil tetrapod specimens collected and curated within each Beaufort Group assemblage zone (Fig. 9) as well as the number of specimens assigned to the various major taxonomic groups of vertebrates for each zone. As far as the five zones represented within the TCP study area are concerned, it is worth noting here the comparative scarcity of tetrapod fossils (and the small number of different taxonomic groups) found in the *Eodicynodon* and *Pristerognathus* Assemblage Zones, the low fossil abundance in the *Tapinocephalus* Assemblage Zone, and the rapidly upward-increasing abundance of fossils collected within the *Tropidostoma* and *Cistecephalus* Assemblage Zones. These contrasting abundances are not simply a function of outcrop area because they can be traced along the Great Escarpment where levels of bedrock exposure are comparable. They therefore appear to have real meaning, but the major controls are obscure. However, since the *Tropidostoma*, *Cistecephalus* and *Dicynodon* AZ are best represented along the Great Escarpment, they may have been "over-collected" relative to other assemblage zones (Nicolas & Rubidge 2009).

The low abundance and taxonomic diversity of fossils in the *Pristerognathus* Assemblage Zone have been understood in the past as characterizing a post-extinction recovery fauna following the major end-Mid Permian biotic crisis (*e.g.* Retallack *et al.* 2006). Recent radiometric dating places this extinction event at the *top* of the *Pristerognathus* AZ (Rubidge *et al.* 2010) so we may be seeing the effect of more than one Mid Permian crisis on land in the Great Karoo Basin (A further Mid Permian faunal turnover event probably occurs within the upper part of the *Tapinocephalus* Assemblage Zone, as recognised by Boonstra 1969 and Loock *et al.* 1994). Other environmental factors that may have affected the changing abundance and diversity of ancient Karoo vertebrate faunas and fossils through time include changing climates, the evolution of terrestrial food webs, or changes in the prevailing ecological and depositional environments (*e.g.* rates of deposition, behaviour and density of river channels) and hence also taphonomic circumstances (*cf* Nicolas & Rubidge 2010).

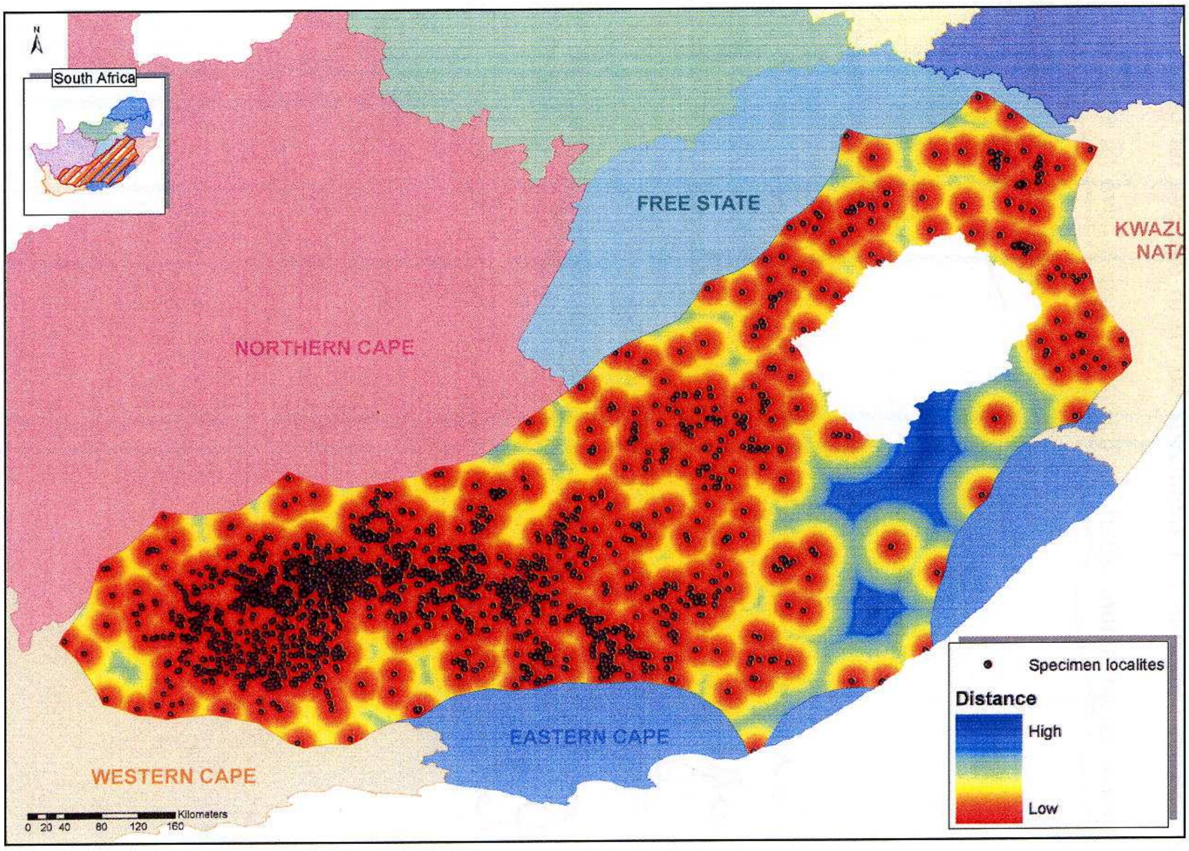

Fig. 17. Map showing distribution of Beaufort Group vertebrate fossil localities in the Karoo region. Sites in the red areas are closely spaced whereas areas shown in blue have a very low density of fossil sites (From Nicolas 2007).

4.3.7. Biases affecting fossil site maps

It should be emphasized that maps of fossil sites in the Beaufort Group are *not* a straight forwards reflection of the abundance of fossils preserved in an area, and certainly do not reflect the original population size or density of extinct organisms! Several interrelated factors, apart from intrinsic fossil abundance, affect the distribution and density of palaeontological sites recorded within the Beaufort Group outcrop area. Among these may be briefly mentioned:

1. The strong and persistent bias towards preferential recording and collection of vertebrate fossils. Recent work has begun to redress the comparative neglect of other fossil categories such as vascular plants (*e.g.* Gastaldo *et al.* 2005), petrified woods (*e.g.* Bamford 1999, 2004), invertebrates, trace fossils including burrows, trackways and coprolites (*e.g.* Smith 1986, 1987, 1993, Botha-Brink 2010) and microfossils.

2. The evolving history, intensity and purpose of fossil recording and collection. Some areas are "over-represented" because they have been selected for specialist studies, for example on biostratigraphy or uranium mineralization, or they lie close to urban centres such as Beaufort West or Graaff-Reinet. In the past, biostratigraphically-focused studies have often led to "head hunting" where less identifiable post-cranial remains of vertebrates may be ignored or under-recorded. Taphonomic and palaeoecological studies (*e.g.* Smith 1993b) as well as field-based palaeontological impact assessments (Almond 2010) may lead to more representative recording of all fossil occurrences in an area while the taxonomic identity of the specimens may be of secondary importance.

3. Early fossil collections were often poorly-localized, both stratigraphically as well as geographically. Misidentification of specimens, especially poorly-preserved or distorted ones, may also be a problem for databases (Nicolas 2007, Nicolas & Rubidge 2009).

4. High and variable levels of fresh bedrock exposure. This is a key control on palaeontological recording. Well-exposed, deeply-incised areas with considerable topographic relief, such as the slopes of the Great Escarpment zone or Die Koup region, are well represented on fossil site maps, while low-relief areas with a pervasive mantle of superficial "drift" like the Aberdeen Flats are under-represented (Fig. 10; Nicolas & Rubidge 2009). Steep slopes may expose lots of fresh rock but are challenging to access and fossils here are often difficult to spot. Gentle slopes traversed by stream beds favour the concentration and collection of fossil remains weathering out from the bedrock.

5. Preservation of near-surface fossil heritage as well as fossil collection itself may be further compromised by weathering processes (generally low-intensity in arid regions like the Great Karoo), intense tectonic deformation (*e.g.* folding, faulting and cleavage development), or dolerite intrusion that thermally metamorphoses the adjacent Beaufort country rocks. On the whole, the level of deformation decreases northwards across the Great Karoo, away from the Cape Fold Belt, while most intrusions of the Karoo Dolerite Suite occur along and north of the Great Escarpment. Deformed fossils are more difficult to recognise and collect in the field and to prepare and reconstruct in the lab.

6. Dolerite intrusions, especially well represented in the Escarpment zone, may have both a negative and a positive influence on fossil recovery. They thermally alter fossils within the adjacent country rock, making them difficult to prepare out from the matrix, and also generate large volumes of doleritic scree that mantles the surrounding bedrock. However, the denudation of areas intruded by resistant dolerites sometimes generates high topographic relief with exposures of thick sections of potentially fossiliferous sediments on hillslopes and scarps.

It should be noted that areas within the Beaufort Group outcrop area with a sparse record of fossil sites are not necessarily "insensitive" in terms of palaeontological heritage resources. They may in fact be of considerable palaeontological interest as far as development impacts are concerned because new fossil finds or bedrock exposures here may well yield scientifically valuable data. In future palaeontological impact assessments (PIAs) can be expected to play an increasingly important role not only in the discovery and conservation of fossil heritage in the Great Karoo region but also in feeding new, well-localised palaeontological data into existing GIS databases (*cf* Nicolas 2007, Groenewald 2010, Van der Walt *et al*., in press).

4.3.8. Variation in recorded fossil abundance within the TCP study area

There is a considerable variation in the density of Lower Beaufort Group fossil sites across the TCP study region in the Great Karoo. A benchmark map showing the location of known vertebrate fossil sites superimposed on the current understanding of the boundaries of the Beaufort Group biozones was published by Keyser and Smith (1977-1978) (Fig. 10). The same map was reproduced by Kitching (1977), who also published extensive faunal lists of vertebrate fossils found at many of these sites. Many of the same fossil sites are also shown on some of the 1: 250 000 series geological maps published by the Council for Geoscience, Pretoria, including sheets 3220 (Sutherland) and 3222 (Beaufort West), but not sheet 3224 (Graaff-Reinet), and on the older 1: 125 000 scale maps such as sheet 198 (Merweville).

A revised fossil locality map incorporating GIS locality data on Beaufort Group vertebrate fossils on the collections of several major South African institutions has recently been produced by Nicolas (2007) (Fig. **). This data forms the basis for the new Karoo assemblage zone map to be published by Van der Walt *et al.* (In press, 2010).

The section of the Nicolas (2007) fossil locality distribution map that is relevant to the TCP study area in the Great Karoo *sensu stricto* is shown here in Fig. 8. Six topographically-based subregions are outlined here within the study area. Aspects of fossil distribution within each subregion are briefly discussed below.

Subregion 1. Roggeveld Escarpment and Klein Roggeveldberge

The Beaufort Group rocks here belong to the *Tapinocephalus* Assemblage Zone, and for the most part to the lower part of this zone that is notoriously unfossiliferous, despite the availability of several excellent bedrock exposures (*e.g.* along Verlatekloof Pass between Matjiesfontein and Sutherland). Based on fieldwork further to the east, Loock *et al.* (1994) describe the Combrinkskraal and lower Leeuvlei Members in the lower part of the Abrahamskraal Formation that are also represented in this region as "almost barren of fossils" and this was also the impression gained during a recent impact study in the area by Almond (2010). Mudrock exposure is often limited by dense shrubby vegetation and soils. A few vertebrate fossils in the Roggeveld Escarpment southwest of Sutherland are recorded on the map of Keyser and Smith (1977-78). Several localities on this map to the southeast of Sutherland are not shown in the 2007 Nicolas map for some reason.

According to Dr R.M.H. Smith (pers. comm., 2010) intensive fieldwork suggests that there are indeed vertebrate skeletal remains as well as trace fossils such as coprolites within the lower part of the Abrahamskraal Formation, but these are very sparse and do not weather out readily from the indurated mudrock matrix. The factors that limit the preservation of vertebrate fossils here remain unresolved. Dr Smith suggests that the paucity of fossils may reflect (a) the predominance of open water - as opposed to exposed, subaerial settings – in this part of the Main Karoo Basin in Middle Permian times (This may be supported by the relative rarity of pedogenic calcrete horizons), and / or

(b) the rapid deposition of fluvial mudrocks that “diluted” fossil remains. However, well-developed horizons of pedogenic calcrete nodules do occur at intervals here. This feature, together with sporadic sun-cracked mudrocks, “star-burst” gypsum pseudomorphs, purplish-brown mudrocks and impressive rippled sandstone palaeosurfaces point towards shallow water conditions with at least intermittent exposure under semi-arid climatic regimes (Almond 2010).

Subregion 2. Moordenaarskaroo area

The density of palaeontological sites mapped here is, at least in part, a reflection of high levels of exposure as well as intensive fossil collection. Excellent exposures of the entire thickness of the Abrahamskraal Formation have been generated by incision of the Buffels River and its tributaries to the north of Laingsburg. An intensive biostratigraphic field study in this region by Loock *et al.* (1994) demonstrated the presence of a wide range of vertebrate fossils within the upper (but *not* the lower) part of the Abrahamskraal succession, *i.e*. the upper Leeuvlei through to Moordenaarskaroo Members. Where exposure is good, moderate to very high densities of vertebrate fossil remains may be found here, as confirmed during a recent impact study by Almond (2010). A north-south trending topographic high, from Gatsberg in the south to the Besemgoedberg along the main escarpment to the north, separates the Mordenaarskaroo in the west from the Koup region to the east. Erosional outliers of basal Teekloof Formation (Poortjie Member) sandstones cap this ridge at intervals. Sparse fossils of the *Pristerognathus* Assemblage Zone are expected here but are not recorded on the available maps.

Subregion 3. The Koup region

This low-lying region, extending from the steep eastern escarpment of the Gatsberg – Besemgoedberg ridge eastwards across the N1 towards Beaufort West, is a classic collecting area for vertebrate fossils in the *Tapinocephalus* Assemblage Zone, as shown by the density of localities marked here on the maps in Figs. 10, 11. Incision by tributaries of the ancient (Cretaceous / Palaeogene) Dwyka and Gamka drainage systems has generated extensive, excellent exposures of both mudrocks and sandstone units here. The sedimentary succession is fairly flat-lying and undeformed – certainly compared to the intense folding seen within the Abrahamskraal Formation rocks towards the southern margin of the Beaufort Group outcrop area – so fossils are not only easier to find but also less deformed by tectonism. The long history of fossil collecting in this area is outlined by Boonstra (1969) and Rossouw and De Villiers (1952), while many localities identified by these authors are marked on the 1: 125 000 Merweville geology sheet as well as the 1: 250 000 Sutherland and Beaufort West sheets.

Recent, ongoing fieldwork in the Koup region by members of the Bernard Price Institute for Palaeontological Research (Wits University) and collaborators is yielding a wealth of important new fossil and stratigraphic data. This work should eventually permit a more refined biostratigraphic subdivision of the *Tapinocephalus* Assemblage Zone (*e.g.* Rubidge & Angielczyk 2009, Day & Rubidge 2010, Jirah & Rubidge 2010) as well as a better understanding of major extinction events in the terrestrial realm towards the end of the Middle Permian Period. Careful re-examination of suitable exposures is also revealing plant fossil assemblages which have been seriously under-represented in previous palaeontological studies (Dr Rose Prevec, Rhodes University, Grahamstown, pers. comm., 2010).

Subregion 4. Beaufort West south to Meiringspoort

The density of fossil sites in this region reflects in part the intensity and long history of palaeontological work here. Careful fossil collection along a north-south transect across the Lower Beaufort succession either side of the N12 between Beaufort West and Meiringspoort has been carried out by Dr R.M.H. Smith in the 1970s. As seen in Figs. 8 and 10 the Beaufort Group here is deformed by numerous east-west folds, producing a complex boundary between the *Pristerognathus* and *Tapinocephalus* Assemblage Zones (and equally between the Abrahamskraal and Teekloof Formations). Very sparse, low diversity but palaeontologically important fossil biotas in the Prince Albert – Klaarstroom area, on the southern margin of the Great Karoo, have been assigned to an *Eodicynodon* Assemblage Zone at the base of the Abrahamskraal Formation (Rubidge 1990, 1995 and Section 4.3.1. above). This biostratigraphic horizon is only marginally represented in the TCP study area, however. A large, triangular-shaped region of the southern Great Karoo lying at over 1000m amsl has been identified as a relict patch of the so-called African Surface of Miocene age by Partridge and Maud (1987), reflecting lower levels of post-Gondwana erosional stripping of the Karoo landscape here (These authors assign most of the central Great Karoo *sensu stricto* to their Post-African II surface of Pliocene or younger age).

Subregion 5. *Die Vlakte* – Aberdeen Flats region

Very few fossil sites have been identified within this topographically subdued region between the N12 south of Beaufort West and the area of Aberdeen (Figs. 10 & 11). Levels of Beaufort Group bedrock exposure here are generally low since the region has not been dissected by any major river systems. Small ephemeral streams transport fine-grained silty alluvium, which is further distributed by winds, mantling the surrounding bedrock. Nevertheless occasional exposures of Beaufort bedrock can be seen in the beds of shallow streams and these have occasionally yielded identifiable vertebrate fossils of the *Pristerognathus* and *Tropidostoma* Assemblage Zones. The concentration of sites along the N9 Aberdeen – Willowmore road reflects intensive collection here related to the mapping of uranium mineralisation (R.M.H. Smith, pers. comm., 2010). Clearly low exposure levels are the major limit on the density of recorded fossil sites in the whole region.

Subregion 6. Sundays River Valley

A concentration of fossil sites from the *Tapinocephalus*, *Pristerognathus* and *Tropidostoma* Assemblage Zones is mapped at the eastern end of the TCP study area, between Graaff-Reinet and Jansenville (Fig. **). This can be ascribed to relatively good levels of bedrock exposure - here due to erosional incision by the ancient Sundays River drainage system. A further factor is the long history of palaeontological collection here, notably by earlier workers like Lex Bremner as well as present-day scientists such as Professor B.S. Rubidge of the BPI (Wits), Dr Billy de Klerk and colleagues who have demonstrated that the lowermost Beaufort Group beds near Jansenville and further east belong to the *Tapinocephalus* Assemblage Zone (Modesto *et al.* 2001). The Kamdeboo area, situated outside the TCP study area but at the eastern end of the main W-E seismic prospecting corridor, has also experienced a long history of fossil collection by several pioneering palaeontologists, including the infamous Dr Robert Broom (*cf* Palmer 1990).

4.4. Karoo Dolerite Suite and Sutherland Suite

Dolerite outcrops in the northern part of the study area, close to the Great Escarpment, 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 Lower Beaufort Group 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, as seen near Bedford to the east of the study area, and they can be very difficult to extract from the hard matrix by mechanical preparation (Smith & Keyser 1995d). Thermal metamorphism by dolerite intrusions therefore tends to reduce the palaeontological heritage potential of adjacent Beaufort Group sediments.
Fossiliferous crater lake sediments are recorded on the southern slopes of Salpeterkop within the eroded remnants of the Late Cretaceous carbonatite volcano, located within the Lower Beaufort outcrop area some 20km southeast of Sutherland (Verwoerd *et al.* 1995, Verwoerd & De Beer 2006). Fossils recorded here include unidentified tree trunks and vertebrate remains, presumably also Cretaceous in age. There are also reports of Caenozoic fossil mammal remains within caves in the Salpterkop area, including those of lions, eland and brown hyaena. Unidentified large mammal remains were collected from Salpeterkop by the author in the 1990s. To the author's knowledge, none of these fossil occurrences have been fully published.

4,5. Late Caenozoic superficial sediments

Various types of superficial deposits ("drift") of Late Caenozoic (Miocene / Pliocene to Recent) age occur in the Great Karoo region *sensu lato*. They include pedocretes (*e.g.* calcretes), colluvial slope deposits (sandstone and dolerite scree *etc*), gravelly to silty river alluvium, as well as spring and pan sediments (Keyser 1993, with more extensive discussion in Holmes & Marker 1995, Cole *et al.* 2004, Partridge *et al*. 2006). These 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.

A small (640m wide) meteorite impact crater known as Kalkkop is situated about 30km northwest of Jansenville within the Lower Beaufort Group outcrop area. It is largely infilled with pale calcrete limestone and there are unconfirmed reports of freshwater shelly invertebrate fossils as well as possible "stromatolites" here (R.D.F. Oosthuizen, pers. comm., 1990s). The age of the impact study is poorly constrained, with guesstimates ranging from 250 000 to 50 000 years, *i.e.* Late Pleistocene (Reimold *et al.* 1998, Reimold 2006).

5. CONCLUSIONS & RECOMMENDATIONS

The following broad conclusions can be drawn from a comparison of (a) the proposed alignment of the seismic prospecting corridors (Figs. 2 & 3), (b) geological maps of the TCP prospecting area (Figs. 6a to 6c), (c) the distribution and density of Beaufort Group fossil sites (Figs. 10, 11), (d) the map of Beaufort Group fossil assemblage zones (Fig. 8), and (e) the comparative abundance of fossils collected within each biozone (Fig. 9):

1. The proposed new prospecting corridors only transect the outcrop area of the Lower Beaufort Group and not older units within the Karoo Supergroup (Dwyka and Ecca Groups).

2. The prospecting corridors in the western portion of the TCP area, west of the N12 and Beaufort West, overlie fossil assemblage zones (*Eodicynodon* AZ, *Tapinocephalus* AZ, *Pristerognathus* AZ) which have hitherto yielded important but comparatively small, low-diversity fossil collections. Most of

these fossils have been collected from a large number of closely-spaced sites in the Koup region. Fossils here are clearly sparse but widely and fairly evenly scattered across the landscape. The westernmost prospecting corridor sectors overlie lower Abrahamskraal Formation bedrocks of the Klein-Roggeveldberge and Roggeveld Escarpment that have hitherto yielded only a few fossil specimens.

3. The propecting corridors in the eastern portion of the TCP area, east of the N12 and Beaufort West, overlie a spectrum of five fossil assemblage zones. However, only those short corridor sectors within the northeastern corner of the TCP area as well as the corridor extension towards Pearston intersect biozones that have yielded a large number and wide diversity of fossil remains (*Tropidostoma* and *Cistecephalus* AZ). The density of recorded fossil sites over much, but not all, of this eastern region is generally low, mainly due to poor bedrock exposure.

4. Superficial deposits (*e.g.* alluvium) within the Great Karoo region are generally of low palaeontological sensitivity, although some valuable fossils such as mammalian bones and teeth do occasionally occur here.

The level of fresh bedrock excavation involved in shot hole drilling at each site within the seismic prospecting corridors is minimal. The shot holes will be infilled and rehabilitated soon after use, so there is little opportunity for meaningful palaeontological mitigation. The most likely cause of damage to fossil heritage exposed at the surface is off-road vehicle use (*e.g.* drilling rig. However, this will be kept to a practicable minimum and is not considered here to be a serious factor.

It is concluded that the impact of the proposed seismic survey programme on Karoo fossil heritage is likely to be very low and that no specialist palaeontological mitigation is required for this phase of the shale gas project. However, scientifically valuable fossil specimens may be encountered during the field survey. These fossils should be safeguarded, preferably *in situ*, and carefully recorded by the ECOs, for example using GPS co-ordinates and digital cameras (with scale). They should then be reported to a professional palaeontologist for possible collection. To this end, the ECOs for the field survey should examine museum displays (*e.g.* at the Albany Museum, Grahamstown, the Bernard Price Institute for Palaeontological Research at Wits University, Johannesburg, or the Iziko Museum in Cape Town) to familiarize themselves with the typical appearance of Karoo fossil material, especially the bones & teeth of vertebrates, fossil plants, petrified wood, and larger vertebrate burrows.

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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 APHAP (Association of Professional Heritage Assessment 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 prospecting project, application or appeal in respect of which I was appointed other than fair remuneration for work performed in connection with the activity, application or appeal. There are no circumstances that compromise the objectivity of my performing such work.

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