SAHRA PALAEOTECHNICAL REPORT
(March 2009)

PALAEONTOLOGICAL HERITAGE OF THE NORTHERN CAPE

John Almond & John Pether

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Giant algal domes (stromatolites) in the Nama Group near Vioolsdrift
(Latest Precambrian period, *c.* 546 million years old)

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1. INTRODUCTION

The core purpose of this SAHRA palaeotechnical report is to briefly but comprehensively document the palaeontological heritage resources in the Northern Cape in an accessible and useful form. The tabular database provided here summarises the known and predicted fossil heritage within all the major fossiliferous stratigraphic units (formations, groups *etc*) that crop out within the province.

When used in conjunction with published geological maps, this report can be used by heritage managers and environmental impact assessors, as well as private developers, to rapidly evaluate the potential impact of proposed developments on fossil heritage. Each rock unit is ranked in terms of its palaeontological sensitivity according to a five-point scale, from which the appropriate action to be taken (if any) before or during development can be inferred (Please note that this scheme is *provisional*, however, and will need to be modified in the light of discussions with heritage managers and palaeontological colleagues). Early assessment of palaeontological sensitivity – preferably at the NID phase - is highly advantageous for developers and heritage managers alike, as well as providing the best safeguard for fossil heritage.

The database provided here explicitly relates palaeontological heritage to well-defined *stratigraphic units* – normally successions of sedimentary rocks – rather than to known *fossil sites*. This is because a site-specific approach is normally inappropriate for assessing the potential impact of new developments on fossil heritage. Large areas of the vast Northern Cape Province have barely been examined for fossils, if at all. Known sites are widely scattered across the landscape, and the most valuable material there may already have been collected. Most fossils are hidden below ground. The best predictors of fossil heritage at any unstudied locality are the stratigraphic units present there. An undue emphasis on fossil sites (*eg* map showing all known localities) would be counter-productive since it would give the misleading impression that areas between known sites are less palaeontologically sensitive than the sites themselves. Furthermore, a site-specific database could not be made freely available since it would undoubtedly endanger localities of scientific importance.

Despite the comparatively good legal protection offered to palaeontological heritage in South Africa by the current legislation, hitherto this aspect of natural heritage has been largely ignored by developers and professional heritage managers alike. In part this stems from pervasive ignorance about the extent of fossil resources in this country, as well as a widespread confusion between palaeontological and archaeological heritage. This report aims to redress some of these misconceptions, for example by making it clear that fossils do *not* only occur in the Great Karoo! A large area of the Northern Cape is underlain by granites and gneisses of the Namaqua Metamorphic Province that are between one and two billion years old and do not contain fossils. However, much of the remaining area features older and younger sedimentary rocks or low grade metasediments (= slightly metamorphosed sediments) that are known to contain fossils or that are are potentially fossiliferous. Even the oldest metasediments in the Northern Cape, within the 2.7 billion year old Ventersdorp Subgroup, contain complex biosedimentary structures known as stromatolites ("algal domes"). Over the past two centuries or so, a wide range of fossils have been recorded from rocks of the Northern Cape, from ancient microbes, trace fossils and invertebrate shells to vascular plants, fish and tetrapods (four-legged vertebrates like reptiles, mammals *etc*). While perhaps the best known fossils are the larger therapsids ("mammal-like reptiles") from the Karoo Basin, these are by no means the only fossils in the province that are of scientific and conservation value.

A short summary of palaeontological heritage in the Northern Cape, with some geological context, is given in Section 2. Section 3 provides a basic introduction to fossils for those without a formal background in geology or palaeontology. Selected highlights of the Northern Cape fossil record are tabulated and illustrated in Section 4. Obviously these particular fossil biotas are worthy of special protection. Section 5 constitutes the core database and *raison d'être* of the report. Here is tabulated the known or expected fossil heritage within all the relevant rock units that are indicated on published geological maps at 1: 1 million and 1: 250 000 scales, together with an assessment of the overall palaeontological sensitivity of each unit. A brief history of palaeontological collection in the Northern Cape is given in Section 6, emphasising early discoveries and pioneers rather than recent work. Section 7 contains a geological history of the Northern Cape over the past 2.7 billion years. This section requires more illustrations. Preparation of Section 8, on palaeontological heritage and the law, is still in progress. Section 9 discusses the growing relevance of fossil resources for ecotourism and public education. A tentative list of potential Palaeosites – *ie* sites of exceptional palaeontological importance and sensitivity that warrant special conservation measures - is given for discussion. In addition, several suggestions are made as to how the SAHRA and HWC palaeotechnical reports can be used to promote wider appreciation of, and protection for, palaeontological heritage across the country. Key references are listed in Section 10 (to be augmented in the final report).

The Northern Cape is the largest province in South Africa, with a surface area of over 360 000 km^2, representing some 30% of the surface area of the RSA. The total population is only around 1.1 million and very sparsely distributed (*c*. 2 people / km^2) outside the few major towns. To our knowledge, there are no professional palaeontologists based in the province at all. Tourism in the Northern Cape has a strong natural history focus (ecotourism), but as yet little advantage has been taken here of the rich fossil heritage of the region. Notable exceptions include educational fossil displays at the Fraserburg Museum and nearby Gansfontein palaeosurface, the SAAO at Sutherland (SAAO), the Victoria West Museum, and the McGregor Museum, Kimberley. A concerted programme to promote the appreciation and understanding of Northern Cape fossil heritage through local museums and other institutions could recoup substantial conservation dividends.

Mining (*eg* for diamonds) is an important component of the Northern Cape economy, and seriously threatens palaeontological heritage along the coast, both on- and offshore, as well as along ancient river systems in the interior. On the other hand, mining and other developments involving major excavations such as roadworks and large building sites have also played a positive role in exposing fresh bedrock containing well-preserved fossils for scientific study. Constructive collaboration between miners, developers, heritage managers and professional palaeontologists for the long-term benefit of fossil heritage and public education remains a real possibility. The first step is to assess the broad nature and distribution of the fossil resources present. That is the aim of this report.

2. SUMMARY OF NORTHERN CAPE FOSSIL HERITAGE

The geological and fossil heritage of the Northern Cape covers over 2.7 billion years of Earth History. Surface exposure of fresh, unweathered rocks – the optimal source of well-preserved fossils - is unusually extensive here because of the prevailing semi-arid to arid climates. Fossil remains, including marine shells and animal burrows, have been noted by travelling European naturalists in the Northern Cape since the late eighteenth century. These were the first formal palaeontological records in South Africa, but of course indigenous peoples would have been well aware of fossil remains, if not their ancient biological origins, for thousands of years previously.

The Northern Cape has important examples of fossils that lived far back in ancient Precambrian times, long before multicellular animals became abundant on Earth around 540 million years ago. Carbonate rocks in the **Ventersdorp Supergroup** in the northeastern part of the province contain what are probably the oldest known fossils in the Northern Cape. These are multi-layered, branching stromatolites constructed by lacustrine cyanobacteria around 2.7 billion years ago (*NB* so far they have only be observed in borehole cores). A much greater variety of stromatolites flourished here in shallow tropical seas between 2.6 and 2.2 billion years ago when tropical, Bahama-like conditions prevailed in the region. Carbonate sediments (limestones, dolomites) of the **Transvaal Supergroup** deposited during this time represent one of the earliest continental shelf successions in Earth history. Stromatolites persisted as the only large biogenic (organically-made) structures during deposition of the following 1.9 billion year old **Olifantshoek Supergroup** (and for the remainder of the Precambrian). Rusty-red river sediments deposited at much the same time show that an oxygen-rich atmosphere had developed by this stage on planet Earth. Lateritic soils may reflect the establishment of the first microbial communities on land.

A range of sedimentary and other rocks were formed in the Northern Cape region between two and one billion years ago. However, they have all been strongly metamorphosed by high temperatures and pressures, deformed by Precambrian continental collision and mountain-building events, intruded by molten magmas, and extensively stripped away by later weathering and erosion. What remains are the resistant crystalline gneisses and granites of the **Namaqua Metamorphic Province**. These are entirely unfossiliferous, so this thousand million year long time interval represents a huge gap in the fossil record of the region.

In contrast, the latest Precambrian time interval (or Neoproterozoic) is represented in the Northern Cape by several successions of deep to shallow marine and near-coastal sediments. These rocks record a fascinating period of dramatically fluctuating environments (including several global glaciations) and rapidly evolving biotas that finally led to the Cambrian explosion of multicellular life around 540 million years ago. Important fossils of early phytoplankton and protozoans, as well the inevitable stromatolites, are recorded from the **Gariep Supergroup** that extends from southern Namibia into the Richtersveld and also occurs in southern Namaqualand. In both geological and palaeontological terms the **Nama Group** is one of the world's most important sedimentary successions that span the palaeobiologically critical Precambrian / Cambrian boundary. Here are found some of the oldest known fossil shells, trace fossils and enigmatic quilted organisms called vendobiontans whose relationships with other organisms remain highly controversial. There is also fossil microplankton and a range of bacterially formed structures such as giant dome-shaped stromatolites, biomats, and "algal strings" or vendotaenids. Most of these fossil groups are best known from Nama outcrops north of the Orange River, but good examples have also been found, or are expected any day, from the Northern Cape as well. The **Vanrhynsdorp Group** of southern Namaqualand contains prolific trace fossil assemblages that reflect the evolution of large body size and complex behavioural patterns among burrowing invertebrates across the Precambrian / Cambrian boundary. Equivocal traces of vendobiontans (tool marks) and shelly fossils have also been recorded here recently.

Small but palaeontologically important outcrops of the **Cape Supergroup** occur on the southwestern margins of the Northern Cape (*eg* Bokkeveld Plateau and Onder Bokkeveld regions). These sediments of Early Ordovician to Early Carboniferous age (*c*. 480 – 375 million years ago) were laid down within a shallow basin on the margins of the southern Supercontinent Gondwana, which at the time was drifting into high southern latitutudes, towards the South Pole. Apart from impoverished trace fossil assemblages (*eg* arthropod trackways and burrows), fossils are sparse throughout the Early Ordovician to Early Devonian **Table Mountain Group** which is dominated by fluvial to occasionally estuarine sandstones. Post-glacial mudrocks of the Late Ordovician Cederberg Formation have yielded an important biota of exceptionally well-preserved primitive jawless fish, water scorpions and other invertebrates in the Western Cape. This unit also extends fractionally into the Northern Cape, where it is probably also highly fossiliferous. Alternating mudrocks and impure sandstones of the Early to Mid Devonian **Bokkeveld Group** contain world-class assemblages of shallow marine trace fossils attributed to trilobites, starfish, molluscs and various unidentified burrowing invertebrates. Moulds of invertebrate shells (trilobites, brachiopods, molluscs *etc*) also found here closely resemble those from similar-aged beds elsewhere in Gondwana, such as present-day South America, Antarctica and the Falklands Islands. These once closely-connected areas all belong to what is known as the Malvinokaffric Faunal Realm or Province. Important remains of primitive fish (*eg* sharks, armour-plated placoderms, bony fish) and early land plants occur in possible deltaic to estuarine beds within the upper Bokkeveld succession. The Mid to Late Devonian **Witteberg Group** sediments are characterised by an abundance of shallow marine trace fossils (notably *Spirophyton*), though fragmentary land plants (*eg* lycopods) and impoverished shelly invertebrates also occur locally. By the time these sediments were deposited, the Cape Basin was situated close to the contemporary South Pole.

During an interval of some 150 million years, from Late Carboniferous through to Early Jurassic times, deposition of a very thick succession of **Karoo Supergroup** sediments took place within a number of intra-continental basins in the Northern Cape. The most extensive of these was the Main Karoo Basin. This basin now occupies the southern half of the province and in ancient Karoo times it was situated within the interior of the Supercontinent Pangaea. The earliest Karoo sediments – massive glacial tillites of the Permocarboniferous **Dwyka Group** – are largely unfossiliferous, although thin intervals of interglacial and post-glacial mudrocks yield sparse fossils of marine invertebrates and fish (*eg* near Douglas) as well a small range of trace fossils generated by arthropods and fish. Reddish sandy and pebbly glacial outwash sediments contain plant fossils (leaves, wood and other debris) of the *Glossopteris* Flora that soon colonised southern Pangaea following the final retreat of the Permocarboniferous ice sheets. Post-glacial flooding of the Karoo Basin established the Mid Permian Ecca Sea, stretching from southern Africa across to, then closely adjacent, South America. This extensive, but for the most part shallow, inland waterway was comparable to the modern Caspian Sea and was likewise brackish to freshwater for most of its existence. Sediments of the **Ecca Group** in the Northern Cape contain a wide range of fossils, from petrified tree trunks, pollen, spores and other *Glossopteris* Flora plant debris that was blown or rafted offshore during storms to moderately diverse trace fossil assemblages. Many of these traces are attributable to fish or non-marine arthropod groups such as crustaceans, king crabs and predatory eurypterids (water scorpions), the last of which reached lengths of two meters or more. There is also a small range of molluscan, crustacean and insect body fossils, primitive bony fish, and – best known of all – well-preserved skeletons of aquatic mesosaurids. Early finds of these small swimming reptiles in both South Africa (N. Cape, near Kimberley) and South America were made in the late nineteenth and early twentieth centuries. They convinced some scientists – notably the famous South African geologist Alex du Toit - of the previous existence of a southern supercontinent, Gondwana, long before the idea of continental drift was accepted by most geologists. Tantalising, water-worn bone fragments and traces attributable to large, crocodile-sized temnospondyl amphibians are also recorded from the uppermost Ecca beds.

Infilling of most of the Ecca Sea by deltaic deposits established dry land across most of the Main Karoo Basin by Late Permian times. The fluvial and lacustrine deposits of the succeeding **Beaufort Group** are internationally famous for their exceptionally rich record of Permotriassic vertebrates. These included various fish groups (notably primitive bony fish called palaeoniscoids), large amphibians which were the dominant aquatic predators, and heavily-armoured, rhino-like herbivorous reptiles called pareiasaurs. The most notable terrestrial animals, however, were a fascinating spectrum of herbivorous and carnivorous mammal-like reptiles or therapsids that dominated terrestrial ecosystems for much of the Permotriassic interval. Their bones and teeth are common enough in the Karoo for them to be used as age-specific zone fossils for subdividing the Beaufort Group succession. As before, Beaufort Group vegetation was dominated by the *Glossopteris* Flora, although environmental circumstances rarely favoured the preservation of abundant plant fossils. These Beaufort sediments and their rich fossil biotas document the establishment of the oldest known complex ecosystems on land. They also provide an unparalleled record of the environmental and biological consequences of two Late Permian mass extinction events around 260 and 251 million years ago. The second of these, the end-Permian event, was the most catastrophic extinction ever recorded in the history of complex life on Earth and defines the end of the Palaeozoic Era. In the Northern Cape post-extinction fossil biotas of Early Triassic age – including various amphibians, therapsids and crocodile-like reptiles - are preserved only in the easternmost parts of the province. Younger Triassic and Jurassic sediments of the Karoo Supergroup, together with their early mammal and dinosaur fossils, have unfortunately been lost to erosion in this region.

Karoo sedimentation was brought to a spectacular end by the eruption of vast volumes of basaltic lavas in the Early Jurassic Period, peaking around 183 million years ago. These volcanic eruptions heralded the approaching fragmentation of Gondwana and were probably the cause of a contemporary global extinction event. While the lavas themselves are not preserved in the Northern Cape, an extensive network of igneous intrusions associated with this period of intense magmatic activity are found here, most of them cross-cutting sediments of the older Karoo Supergroup. Unsurprisingly, these sills and dykes of the **Karoo Dolerite Suite** are unfossiliferous. Scattered, smaller scale igneous activity continued during the succeeding Cretaceous and earliest Neogene Periods. Much of this activity was related to rising plumes of hot mantle rocks beneath southern Africa as well as to incipient rifting of western Gondwana into separate African and South American continental blocks. The explosive intrusion of numerous **kimberlite pipes** in the Northern Cape interior (*eg* Kimberley, Victoria West and Gordonia areas) from Early Jurassic to Late Cretaceous times is of palaeontological as well as economic significance. Crater lake sediments preserved above some younger igneous pipes (*eg* Stompoor, Kangnas and Arnot pipes in Bushmanland, Salpeterkop near Sutherland) contain valuable fossilised remains of aquatic animals (fish, frogs, turtles, crustaceans *etc*) as well of the surrounding vegetation and fauna (*eg* dinosaurs, birds, angiosperm leaves and pollens). These fossil biotas provide a rare glimpse of early African wildlife before and after the major extinction event that brought the Mesozoic Era to a close (65 Ma).

For much of the succeeding Caenozoic Era the southern African interior – in contrast to the continental shelf - has been the site of extensive weathering and erosion of surface rocks, with little long-term deposition of sediments or preservation of fossils. A major exception is the thick **Kalahari Group** succession that blankets much of the northern part of the N. Cape Province and extends northwards to the equator. Late Cretaceous to Paleogene fluvial and lacustrine sediments towards the base of the succession might well be highly fossiliferous, but they are rarely exposed. The onset of West Coast aridity around 15 million years ago (Miocene Epoch) is reflected in sparsely fossiliferous braided stream sediments, cemented soils (pedocretes), and thick, reddish aeolian sands that characterise the Kalahari region today. Arid-adapted fossil biotas include land snails, ostrich eggs, plant root casts as well as pockets of lake sediments with molluscs, diatoms and freshwater stromatolites.

Important late Caenozoic biotas of Miocene age and younger are also recorded from relict bands and patches of sediments (*eg* consolidated gravels) deposited by ancient river networks that drained the subcontinental interior. Thick fluvial gravels are preserved along the Vaal, Orange and Olifants Rivers, as well as the long-extinct Geelvloer-Koa River Valley system south of the Orange. They have yielded fascinating but sparse bones and teeth of large mammals (*eg* proboscideans such as elephants and mastodonts, rhinos, bovids, horses and carnivores), reptiles (crocodiles *etc*), freshwater molluscs and well-preserved petrified wood. The famous **Arrisdrift Formation** terrace gravels along the north bank of the lower Orange in particular have yielded superb vertebrate faunas of Early to Mid Miocene age, some 19 to 17 million years old, when the southern African region experienced warm, non-seasonal subtropical climates. Similar palaeontological treasures may well be represented on the South African side of the river, but Arrisdrift terrace gravels there (*eg* at Bloeddrif, Baken) have yet to be thoroughly investigated for fossils. They are currently being intensively exploited for diamonds.

The **offshore fossil record** of the Northern Cape is still comparatively poorly known and heavily dependent on commercial exploration for diamonds and hydrocarbons. Marine fossils dating from the early evolutionary phases of the Atlantic Ocean (Late Jurassic / Cretaceous) are not found onshore in South Africa, although there are isolated Late Cretaceous occurrences in Namibia (ammonites and other molluscs in the Sperrgebiet). Offshore the Cretaceous beds are largely hidden beneath a veneer of younger Caenozoic sediments. They include over six kilometres of Cretaceous sediments within the **Orange Basin** off the coast of Namaqualand that contain economically important hydrocarbon reserves. Abundant fragments of Cretaceous petrified woods have been trawled up off the West Coast and are also incorporated into younger coastal gravels. A recent discovery is a two kilometre square area of Late Cretaceous (*c*. 86 Ma) outcrop featuring abundant tree trunks exposed *in situ* on the seabed of the Namaqualand shelf. At the time temperate forests of podocarps flourished across a wide coastal plain that was periodically flooded by rising sea levels. Caenozoic marine biotas from the West Coast shelf are likewise very poorly known. Sporadic finds of fossils trawled up by fishing vessels or while dredging for submarine diamonds have been recovered, but the majority have not been systematically studied. The best-known examples are spectacularly large (20cm) teeth of the extinct giant shark *Carcharodon* of Miocene / Pliocene age. Bones and teeth of extinct Miocene and Pliocene whales, shelly invertebrates such as bivalves and nautiloids, and an older

Eocene marine fauna of shells and diverse microfossils have also been recorded. These fossil remains are often phosphatised and are associated with hardgrounds, *ie* horizons or patches on the seabed reflecting periods and areas of minimal deposition and secondary mineralisation. Subfossil mollusc faunas of Quaternary age reflect the rapidly changing influence of warm- and cold-water currents around the Cape as the Antarctic ice sheets waxed and waned.

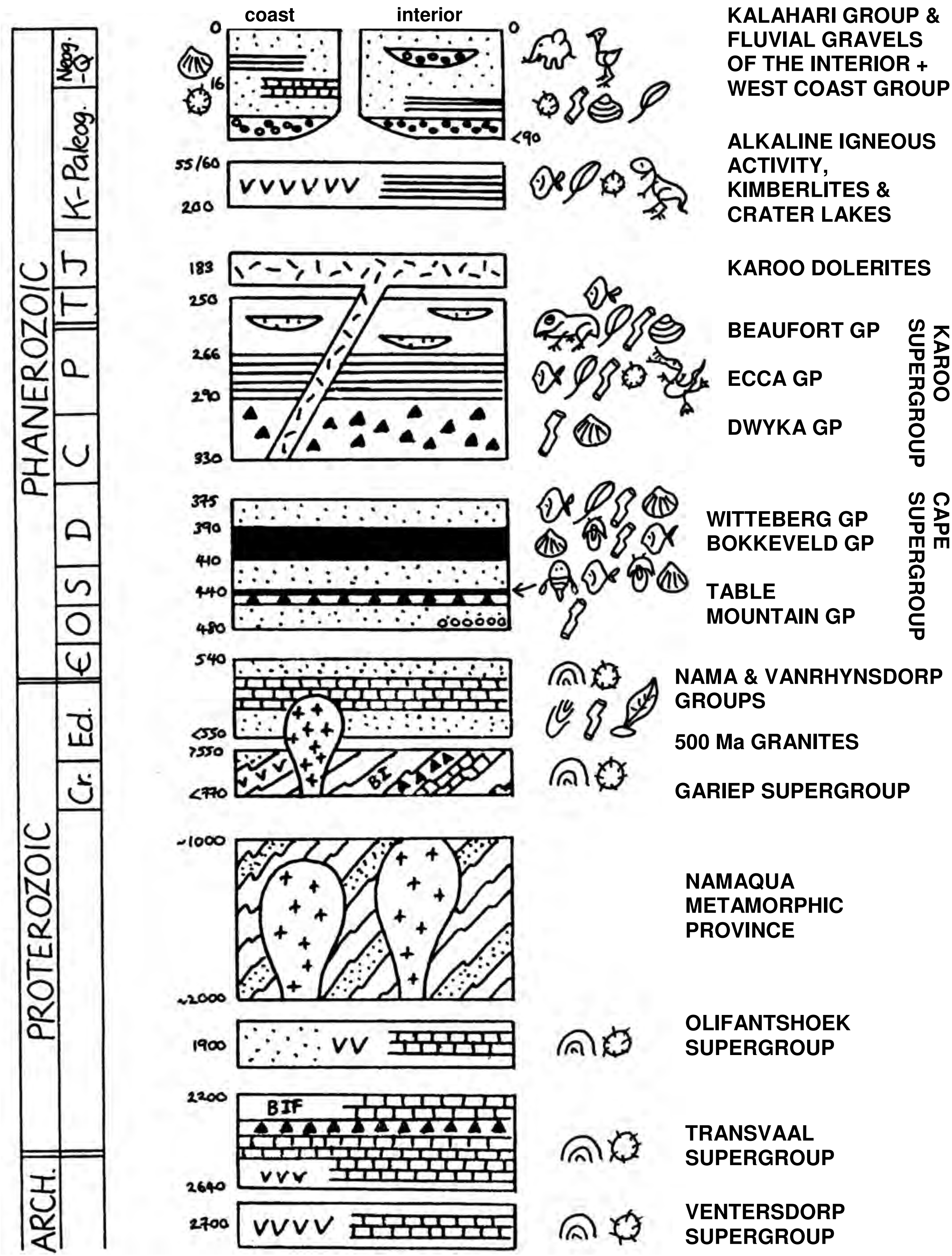
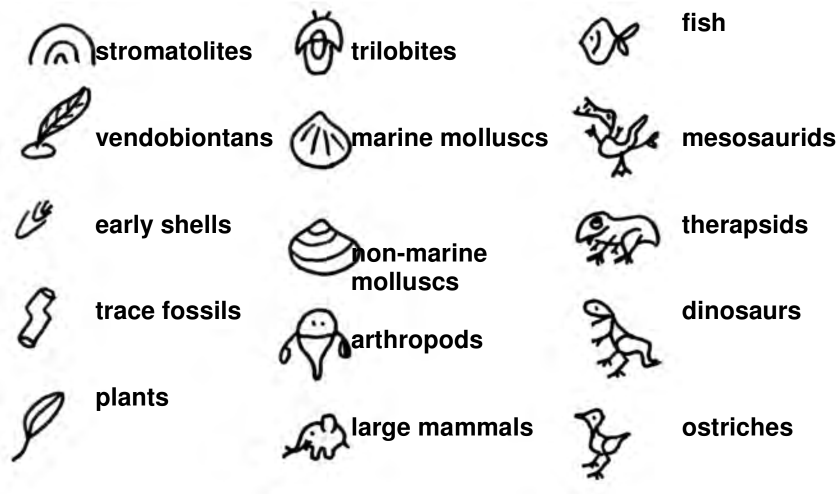


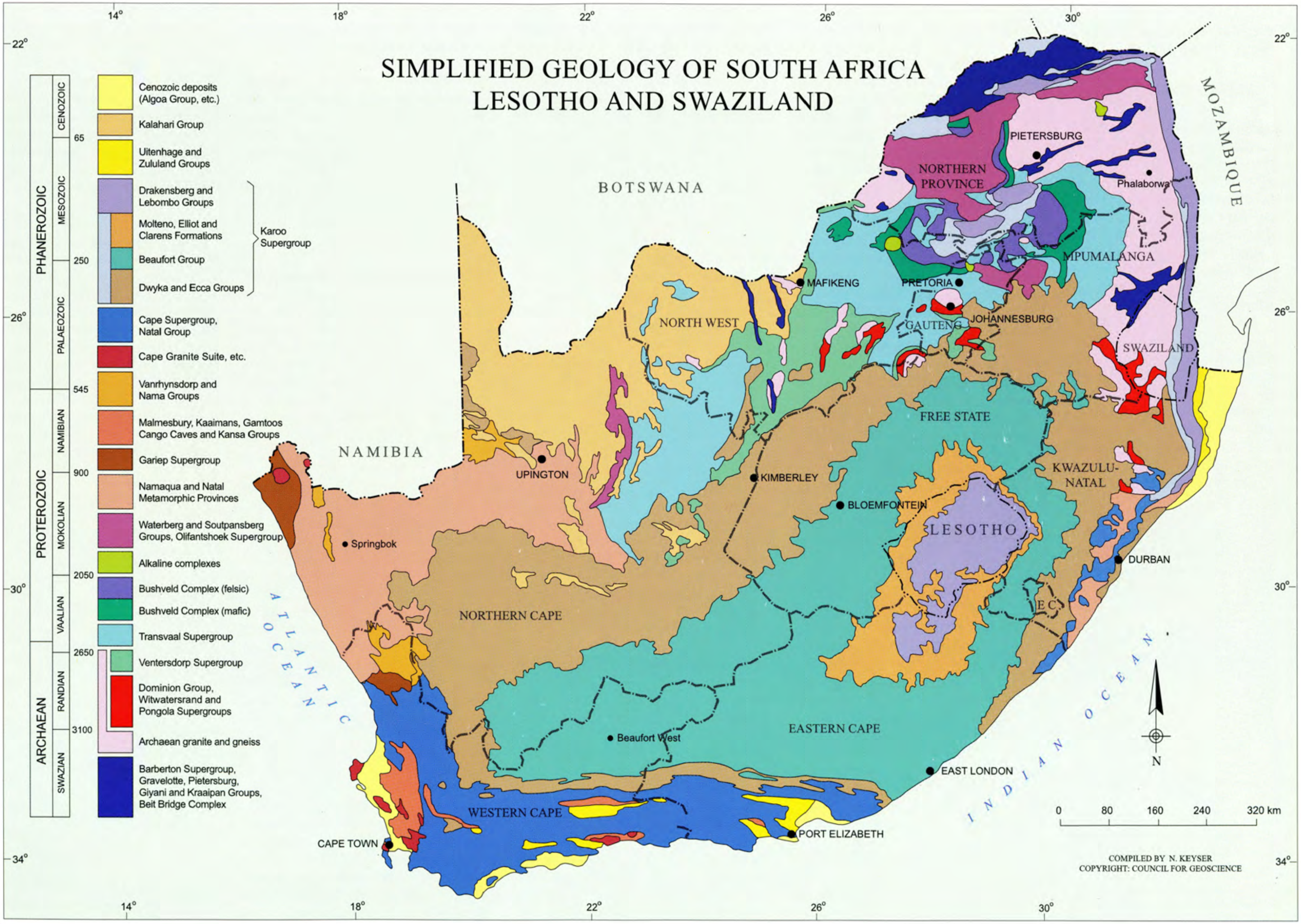
Fig. 2.1. Simplified stratigraphic column for the Northern Cape Province. See below for key to fossil symbols.

Please note that the column is very schematic, showing only the most important stratigraphic units. Some of these rock units overlap in age. The occurrence of selected categories of fossils are indicated for many of the units. The true fossil diversity is much greater than shown.

KEY TO FOSSIL SYMBOLS



SIMPLIFIED GEOLOGY OF SOUTH AFRICA LESOTHO AND SWAZILAND



3. NATURE, PRESERVATION AND SIGNIFICANCE OF FOSSILS

This section aims to provide a basic introduction to fossils in simple terms for those without a formal palaeontological or geological background. For further information, the reader is advised to consult the general palaeontological references listed at the end of the report.

2.1. The nature of fossils - What exactly *are* fossils, and what *sorts* of fossils are there?

Fossils are the more-or-less altered remains of once-living organisms, or traces of their activities, that have been preserved or ***fossilised*** within rocks. Most fossils are thousands of years old at least, and the great majority are many *millions* - sometimes even *billions* - of years old. In fact, there is no agreed minimum age limit for considering ancient organic remains as true fossils - unlike antiques, for example, which by definition must be over one hundred years old.

The scientific study of fossils is known as ***palaeontology***. The related, but largely separate, field of science that deals specifically with the evolution and culture of humankind is called ***archaeology*** (See Section 3.4 below).

Many different groups of plants, animals, fungi, algae and various microbes (*eg* protozoans, bacteria) are represented in the ***fossil record*** or preserved inventory of past life on Earth. Many of these groups, and certainly almost all the species, are now ***extinct***. Examples of extinct groups include the *trilobites* - woodlouse-like marine arthropods whose dorsal exoskeleton was strongly reinforced with the mineral calcium carbonate – and the *ammonites* – marine molluscs with a coiled, many-chambered shell that are distantly related to the living pearly nautilus and squids. Other important fossil groups have surviving members, such as the cyanobacteria, snails, crocodiles, sharks and ferns. Even the *dinosaurs* are represented today by their feathered descendants, the birds.

Most of the fossils found in southern Africa belong to one or other of the following major types or categories (**Figure 3.1**):

1. Fossil shells of marine and freshwater invertebrates – *e.g.* molluscs (bivalves, snails and relatives), arthropods (trilobites, crustaceans and relatives), and echinoderms (starfish, sea lilies and relatives)

2. Fossil bones, scales, teeth and coprolites (excreta) of aquatic and terrestrial vertebrates – *e.g.* various groups of fish (cartilaginous and bony fish, *plus* several extinct groups) and ***tetrapods*** (four-legged, air-breathing animals such as amphibians, reptiles, birds, mammals including humans, and their relatives)

3. Fossil stems, wood, leaves of plants – *e.g.* petrified logs and compressed leaves of the extinct gymnosperm tree *Glossopteris*, cycad leaves from the Mesozoic Era. Even larger algae (seaweeds) are occasionally preserved, although many of these are no longer regarded by biologists as true plants.

4. Microfossils - *i.e.* the skeletons of microscopically small organisms such as unicellular protozoans and algae – *e.g.* silica-shelled diatoms, organic-walled spores and pollen grains (often termed ***palynomorphs***), calcareous-shelled foraminiferans, tiny aquatic crustaceans called ostracods

5. Trace fossils (= ichnofossils), *i.e.* structures preserved in sedimentary rocks which record the *behaviour* or *activity* of extinct organisms (mainly animals) while they were still alive - *e.g.* feeding and dwelling burrows made by marine invertebrates living in the seabed, trackways of mammal-like reptiles and dinosaurs, coprolites (fossil excreta), as well as other **biosedimentary structures** such as laminated microbial mats and mounds (= ***stromatolites***)

6. Chemical fossils – complex but fairly stable organic compounds preserved in sediments which are produced by the decomposition of ancient organisms and sometimes act as "biomarkers" for specific groups – *e.g.* fossil fuels such as oil, breakdown products of bacterial and algal pigments.

Note that:

- the term "trace fossil" has a precise technical meaning in palaeontology and does not apply to all traces (as in faint indications or relics) of past life.
- fossils that preserve parts or impressions of the original body of an organism (1-4 above) are known as **body fossils**, in contradistiction to trace fossils *sensu stricto*.

In contrast to true fossils, **pseudofossils** are structures found in rocks that are of *inorganic* (*i.e. non*-biological) origin but that by chance have shapes which strongly resemble those of plants or animals. Common examples are surface depressions weathered into rocky outcrops that look remarkably like human or other animal footprint. ***Dendrites*** are finely-branching patterns of manganese minerals which have grown in thin water films between beds of rock or over fracture surfaces. They are often misinterpreted as fossil mosses or ferns.

2.2. Fossil preservation - How are fossils formed?

Most fossils have formed from the remains of organisms that have become buried within layers of sediment (***strata*** or ***beds***) such as soil, river alluvium, or mud and sand on the bed of a sea or lake. Over thousands to millions of years, the deposition of additional thick layers of rock above the beds gradually compressed and hardened the sediments together with the organic remains embedded within them. The originally loose sediments gradually bonded together to form solid rocks (*e.g.* sandstone, mudstone, limestone). Various chemical and physical changes, including heating, compression, the solution of some minerals by hot circulating groundwaters and the precipitation of others, altered the organic remains which then became fossils that were completely enclosed within a ***matrix*** of sedimentary rock. When beds of sediment are re-exposed at the Earth's surface due to natural erosion or artificial excavations, the matrix is broken open and fossils are revealed, perhaps millions of years since they were originally entombed.

With very few exceptions, fossils are preserved within ***sedimentary rocks*** (*eg* sandstone, mudstone, limestone, coal). These are rocks that have formed at near-surface temperatures and pressures, that is under similar conditions to those that support life. Fossils are generally not found within ***igneous rocks*** (crystallised from a molten state, *eg* granite, dolerite, basalt) or in ***metamorphic rocks*** that have recrystallised under high temperature and / or pressure conditions (*eg* gneiss, schist). However, gently metamorphosed sediments (= low grade ***metasediments***) may still contain robust fossil remains, although these are often highly deformed. Examples are ***stromatolites*** preserved within even very old Precambrian metasediments, or distorted trilobites from Palaeozoic slates.

Most fossils are still largely embedded within a matrix of sedimentary rock when they are first discovered and collected / excavated. During later fossil ***preparation*** in the laboratory a range of chemical and mechanical techniques – such as acids, abrasives and vibrating steel needles – are used to carefully remove the matrix and reveal the complete specimen. Fossil preparation is highly skilled, delicate and slow work, since the chances of damaging the delicate specimen are very high. Some vertebrate fossils, for example, take several years to prepare and represent very valuable items of our natural heritage, not only because of their intrinsic scientific worth but also because of the huge "added value" invested in their preparation.

2.2.1. Modes of preservation

Fossils can be preserved in a number of different ways, depending on the composition of the original organic remains (*e.g.* phosphatic teeth and bones, calcareous shells, lignified wood, chitinous exoskeletons) as well as the chemical and physical conditions they experienced after burial. Occasionally the original hard parts are preserved essentially unaltered (apart from loss of the soft tissues), as is the case with some fossil teeth or marine shells preserved in limestone or mudstone. Other common modes of fossil preservation are:

- **permineralisation** – microscopic spaces within the original porous tissues are filled in by new minerals (*e.g.* many fossilised mammal bones which are much denser than living bones)

- **replacement** – the mineralised tissues or wood are completely and often very precisely replaced by new minerals such as silica (SiO_2), calcite ($CaCO_3$), pyrite (FeS_2) or clay minerals. Fine details of the original microscopic structure – such as seasonal or even daily growth rings - are sometimes preserved (*e.g.* many Karoo reptile bones, petrified wood)

(The two preservation modes described above are also known as *petrifaction*, which literally means "turning to stone".)

- **compression** – the organic remains are squashed flat and baked so that most of the water and organic compounds are driven off leaving a thin film of carbon in the rock (*e.g.* most fossil leaves and non-woody plants, coals which are essentially fossilised peat)

- **natural moulds and casts** – after sediment surrounding or inside a buried shell, tooth, bone or plant stem has hardened to rock, the original organic remains are dissolved away by circulating groundwater leaving a space, known as a natural ***mould***. If the rock is split open, natural moulds or impressions of the outer and inner surfaces of the original hard parts are seen (*e.g.* many fossil marine shells). When new minerals are precipitated within the empty moulds while they are still buried, natural ***casts*** are formed which replicate or mimic the external form of the original shell *etc*. but naturally lack its internal microstructure

The great majority of fossils represent only incomplete fragments of the original organism – entire plants or animal corpses are very rarely preserved (Famous exceptions are the frozen woolly mammoths from Siberia preserved for thousands of years by permafrost, insects and spiders embedded in amber which is fossilised tree resin, or sabre-toothed cats embedded in Californian tar pits). This is because when an organism dies, most of its delicate living tissues or "soft parts" – muscles, skin, leaves, flowers *etc* - are either eaten by carnivores (predators, scavengers) and herbivores or they are quickly decomposed by microbes (bacteria, fungi). The stem, leaves, roots, flowers and fruits of plants usually become separated after death (and often during life). Only tougher tissues ("hard parts") like bones, teeth, shells, wood and pollen grains that have been strengthened with indigestible, weather-resistant minerals (*e.g.* silica, lime, phosphate) or with complex organic polymers (*e.g.* cellulose, lignin, chitin, sporopollenin) are likely to survive long after death.

While they lie at the sediment surface (bed or sea, lake or river, on the soil *etc*), even these hard parts are usually broken-up, damaged and scattered by scavengers, trampling and burrowing animals as well as by water currents and weathering processes (*e.g.* dissolving in seawater, splitting by frost). Therefore, to have a good chance of being fossilised organic remains must be quickly buried within sediment after death, protecting them from complete destruction. Most fossils are formed on the bed of shallow seas on the submerged continental shelf. Here animal life is generally abundant and rapid burial of their dead remains frequently occurs because sediments are deposited by storms, currents and from suspension faster than they are removed by erosion. On land, where rock erosion generally exceeds deposition, conditions suitable for fossilisation are much more rare. However, rapid, long-term burial may occur, for example, in lakes, in lowlands where rivers deposit alluvial sediment during floods, or where deltas form at the coast.

2.2.2. Fossil treasure troves - exceptional fossil preservation

Rare examples of exceptionally well-preserved fossil biotas – so-called **fossil *Lagerstätte*** ("treasure troves") - give us unique and vivid insights into the appearance, diversity and palaeobiology of long-extinct organisms and communities. These fossil assemblages are often unusually diverse, the highly complex skeletons of animals such as echinoderms (starfish, sea urchins *etc*) are complete and fully articulated as in life, and preservation of soft tissues, or even organisms lacking mineralised hard parts, may also occur.

Such *Lagerstätte* usually reflect natural catastrophes involving the sudden death and burial of living organisms, thereby protecting their remains from destructive weathering processes, currents, decomposers and scavengers. Special physico-chemical conditions at the burial site (*e.g.* anoxia / low temperatures / acidity or heat) ensured slow decomposition and rapid replacement or encasing of fossil remains by new mineral deposits (silica / phosphate / clays / pyrite *etc*). These key fossilisation processes were usually mediated by microbial activity.

Good examples of fossil *Lagerstätte* or otherwise exceptional fossil preservation in southern Africa include:

- post-glacial biotas of the Late Ordovician **Cederberg Formation** (Table Mountain Group, 440 Ma) showing detailed preservation of soft tissues (muscles, gills, guts *etc*) in primitive jawless fish, water scorpions as well as several invertebrate groups without hard skeletons

- diverse invertebrate faunas in **Waboomberg Formation** (Bokkeveld Group, 390 Ma), including dense populations of intact starfish, serpents stars, trilobites, bryozoans and molluscs that were smothered on the Mid Devonian sea floor by a blanket of fine, anoxic mud following major storms

- beds of lake sediments in the Early Carboniferous **Waaipoort Formation** (Witteberg Group, 345 Ma) covered in entire fish corpses following episodic mass mortality events, perhaps triggered by nearby glacial melting or sudden overturn of the lake waters after storms

- complete skeletons of primitive bony fish (palaeoniscoids), aquatic mesosaurid reptiles and crustaceans in the Mid Permian **Whitehill Formation** (Ecca Group, 270 Ma) of the Main Karoo Basin

- beautifully preserved insects, spiders, leaves and even flowers of angiosperms (flowering plants) from Mid Cretaceous (*c*. 90 Ma) **crater lake deposits** at Orapa in central Botswana

- the preservation of an almost complete, well-articulated australopithecine or "ape-man" skeleton ("Little Foot") within late **Pliocene cave deposits** at Sterkfontein in the Cradle of Humankind (perhaps 3 Ma)

Since they comprise a small but unusually informative fraction of the entire fossil record, such palaeontological "treasure troves" are particularly sensitive to development as well as exploitation by unscrupulous fossil collectors. In most cases, these "red flag" units (*eg* geological formations) deserve special heritage protection over their entire outcrop area. Protection should not be site-specific since unusually rich "fossil lodes" may well occur outside known sites (which may already be mined out) and are not always easy to predict.

2.3. The South African fossil record - a rich and ancient common heritage

The palaeontological history or fossil record of southern Africa is one of the longest and most interesting known anywhere in the world, and is also arguably the richest overall on the African continent. The oldest known fossils in southern Africa – and the world - are remains of microbial cells as well as traces of microbial borings from the Barberton Greenstone Belt of South Africa. They are about 3.5 billion years old (3.5 Ga). Some of the highlights of the South African fossil record over the past 600 or so million years – the time period during which multicellular animals and plants have existed on Earth – are shown in Figure 4.21.

2.4. Palaeontology *versus* archaeology - What's the difference?

The scientific study of fossils is known as ***palaeontology*** (the "study of ancient beings"). It combines knowledge from several other fields of science, such as biology, climatology and geology. By global standards Southern Africa has an exceptionally rich archaeological as well as palaeontological heritage, and it important that heritage managers and developers distinguish between these two distinct, but closely related, fields:

1. **Archaeology** is the scientific study of the behaviour, history, culture, evolution and environment of ancient humans (Genus *Homo*) and their close relatives (other bipedal apes or hominins), mainly based on their artefacts (tools, dwellings, food remains *etc*) and sites where they were active. In Africa the archaeological record stretches back some 2.5 *million* years in time, and to around 7-10 Ma if all hominins are included.

2. **Palaeontology** is the scientific study of *all* forms of ancient ("prehistoric") life, from bacteria and biomolecules to bananas and brontosauri, on the basis of their fossil remains and their geological context. This field mainly concerns organisms other than humans, but also includes the scientific study of fossil humans and their primate relatives (***palaeoanthropology***) as well as the study of animal and plant remains at archaeological sites (***archaeozoology***, ***archaeobotany***).

There is obviously considerable overlap, collaboration and cross-fertilisation between palaeontology and archaeology. Both fields share a common scientific methodology and many important concepts (*eg* stratigraphic analysis, geochronology) but their primary focus is different.

Important contrasts to note between the two are:

- Palaeontology deals with the *entire* spectrum of groups of organisms whereas archaeology has a specifically *human* or *anthropocentric emphasis*.

- The palaeontological / fossil record stretches back some 3.5 *billion* years in "deep time" (equivalent to some 75% of Earth history or 30% of cosmic history) and has no modern cut-off point. The archaeological record begins some 2.5 *million* years ago (*c*. 0.02% of Earth history) and may - arbitrarily - be considered to extend until 100 years ago (*eg* National Heritage Resources Act, 1999).

- Archaeological heritage (*eg* artefacts, sites, bones, shells) is largely confined to the surface or shallow depths (*eg* caves, middens, tells), whereas palaeontological heritage is more three-dimensional, often extending for kilometres underground. Importantly, this means that fossil heritage is (a) mostly *hidden* from view and (b) *rarely accessible*. This explains why excavations during development are often a major threat to archaeological heritage but may represent a welcome *opportunity* for palaeontology, *provided that* adequate opportunities for study and sampling of newly exposed fossil heritage are guaranteed.

- The archaeological record is for practical purposes largely site-related, and to a considerable (but by no means complete) extent can be usefully recorded, or at least summarised on a regional scale, using 2d maps. The fossil record - with some important exceptions, such as many smaller Caenozoic deposits of the coast and interior - is much more three-dimensional and related to extensive, voluminous rock units such as sedimentary beds and formations that may be hundreds of metres thick and have outcrops stretching for tens or hundreds of kilometres cross country. Within each formation, fossils may be concentrated within particular thin beds or lenticules, or they may be dispersed widely throughout the unit. In this case, *geographic* (map) data on known fossil sites are usually of limited value on their own as a predictor of true fossil heritage distribution. Geological maps showing the outcrop pattern of sedimentary formations are the best available predictors of fossil distribution when employed in conjunction with palaeontological databases.

2.5. The scientific, cultural and economic importance of fossils – Why is it really important to conserve our unique fossil heritage?

The National Heritage Resources Act protects South Africa's rich and unique fossil heritage not only on behalf of present and future generations of South Africans, but also for the benefit and enrichment of humanity as a whole. Here, in outline, are some of the ways in which fossils are important for science as well as the broader public.

1. Scientific research

In purely scientific terms, fossils are essential for understanding the fascinating history of Life and of changing environments on Planet Earth. In turn, they allow us to place humanity, biological conservation and climate change in a broader evolutionary, "deep time" context.

a. Reconstructing life of the past

Fossils provide the best direct and *concrete* evidence for wildlife in the distant past, showing us how organisms and biological communities have changed enormously through geological time. Fossils show us what extinct animals like trilobites and dinosaurs actually *looked* like. Even trace fossils such as trackways, burrows and droppings allow us to reconstruct the behaviour and biology (*e.g.* locomotion, diet) of extinct animals because they were made by animals *while they were still alive*.

b. Understanding how organisms are related to each other

By comparing the features of living and extinct groups of plants and animals we can begin to work out (a) how they are related to each other by evolution, and (b) when and how one group evolved into another. A good South African example is the excellent fossil record of Karoo tetrapods that clearly shows how true mammals – our own distant ancestors - gradually evolved from reptile-like predecessors over a period of some 50 million years.

c. Assigning sedimentary rocks to particular geological periods

Since particular fossil species or groups only lived at certain times in the past, we can use fossils to "age" or "date" the sedimentary rocks containing them (***biostratigraphy***). Similar fossils indicate similar age. For example, trilobites are only found in Palaeozoic rocks, whereas dinosaurs are restricted to Mesozoic rocks. Some rapidly evolving fossil species, such as many Jurassic ammonites or Caenozoic foraminiferans (shelled protozoans), are estimated to have survived for only a few tens to hundreds of thousand years, giving them great potential for accurate biostratigraphic correlation, even between continents and across oceans. Note that fossils do not give an "absolute date" for the rock in terms of so many million years, just as a particular type of stone tool, coin or pottery does not give a precise numerical age to an archaeological deposit (Absolute ages are found, for example, by radiometric dating). Instead, fossils allow us to assign sedimentary units to specific time slots (*eg* geological eras, periods and epochs – Mesozoic, Cambrian, Permian, Pliocene *etc*) that can be assigned numerical dates by radiometric means.

d. Interpreting the environments and climates of the past

Just like living organisms, those of the past were restricted to particular environments (habitats) and climatic zones; *e.g.* shallow seas, freshwater lakes, or tropical forests. Fossils allow us to recognise these different environments and show how they have changed dramatically in any particular part of the world through geological time. For example, the fossil plants and animals of Langebaanweg (West Coast Fossil Park) show how the habitat was changing from tropical forests to open woodland and grassland around five million years ago. Palaeontological evidence for long-term and short-term climate change plays an important role in climate modelling as we struggle to understand, predict and contain present day global warming.

e. Reconstructing past geography of the Earth

Studying the distribution of fossil animals and plants of the same age helps us to work out which continents and seas were once situated close together (with similar fossils) and which were far apart (with different fossils). An excellent example is the way the distributions of several ancient Karoo reptiles (*eg Mesosaurus, Lystrosaurus*) and plants (*eg Glossopteris*) strongly support the existence of the southern Supercontinent Gondwana 250 million years ago. Indeed, fossil evidence for continental drift and ancient supercontinents was recognised in South Africa long before most geologists accepted the idea at all.

2. Commerce

Some fossils and fossiliferous deposits are of considerable economic importance in their own right and are mined commercially. The most obvious examples are so-called fossil fuels such as peat, coal, oil and gas that have formed from the rotting remains of terrestrial plants and aquatic plankton of the past. Many limestones and phosphate deposits, important for agriculture, cement manufacture as well as smelting are largely composed of fossil remains. Local examples are fossil molluscs ground up for lime and even chicken feed in Cape region, or the incredibly fossiliferous Langebaanweg phosphates (now largely mined out) on the West Coast. Attractive patterns formed by embedded fossils give some building stones their special value. Examples are limestones and dolomites containing spectacular stromatolites (*eg* S. Namibia, China), nautiloids (Morocco / Tunisia?), molluscs, crinoids or corals (UK). Diatomite, a fine-grained, siliceous rock composed of the skeletons of unicellular freshwater algae, from Pleistocene lakes of the Kalahari is exploited as a filler, abrasive, thermal insulator, among other uses.

In some countries, most notably Germany and the United States, there is a thriving commercial market for fossils driven by enthusiastic amateur and professional collectors, some of whom are exceptionally knowledgeable. While this activity does feed important new data and specimens into scientific palaeontology, standards of collection and documentation are often poor - sometimes deliberately so, as in the case of detailed locality and stratigraphic data for specially rich sites which may be kept secret. Collateral damage to fossil heritage may therefore be extensive. Examples are over-preparation or part-forgery of specimens to enhance their sale value, the mining out or dynamiting of fossil-rich beds, and the separate sale of parts (*eg* part and counterpart) of the same specimen. These are all widespread practices in the well-established fossil market for tourists in Morocco, for example – one of the palaeontologically richest regions of Africa. State institutions often cannot compete for exceptional, expensive fossils specimens, which may then end up in private collections, or foreign museums. In some, but far from all, cases they are then inaccessible to scientists and the local public alike. While the collection of fossils without a permit and trade in South Africa fossils are both illegal, it is almost a certainty that both are carried out here on a limited scale. However, as with archaeological heritage, the most serious damage to fossil heritage has been, and is being, inflicted by uncontrolled development and – in the past, certainly - by professional academics themselves.

3. Education and palaeotourism

If appropriately marketed, South Africa's palaeontological heritage can make an important educational as well as (ultimately) commercial contribution to the rapidly growing field of palaeotourism (or geotourism). This may contribute usefully to development in areas that are currently economically depressed (*eg* Great Karoo). Good examples are the Cradle of Humankind project (Gauteng), the Kitching Fossil Exploration Centre at Nieu-Bethesda (Eastern Cape), the Fossil Trail at the Karoo National Park, Beaufort West and the West Coast Fossil Park near Langebaan Weg (both Western Cape). Fossils and evolution are now firmly on the junior (GET) and senior (FET) science syllabus at schools and there is an urgent need to develop many more informative and accessible displays and palaeontological sites for teachers and learners.

4. Aesthetic and spiritual values

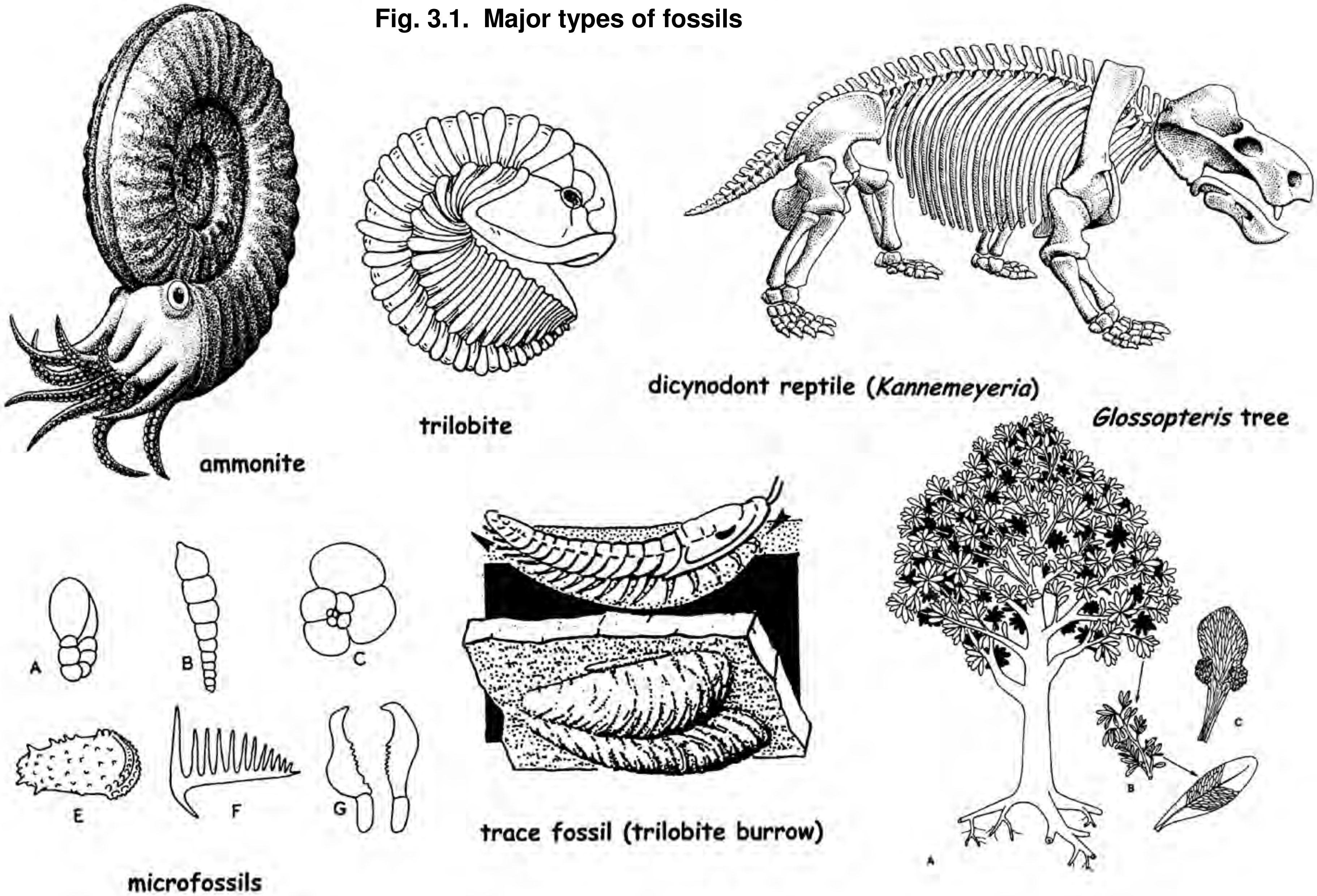
Fossils have been noticed, appreciated and collected as curious, aesthetically attractive and even spiritually significant objects for thousands of years. This occurred long before the late seventeenth century when their significance as relicts of ancient, and probably extinct, life was at last widely accepted. Necklaces of fossil sponges and shells and arrangements of fossil sea urchins are recorded from Bronze and Iron Age sites in Europe, for example. In South Africa a fossil trilobite has been found in association with a collection of attractive quartz crystals and pigment minerals in a Late Stone Age shelter in the Cederberg (W. Cape). This specimen must have been collected, carried at least 10km from the nearest fossil-bearing outcrop, and saved as "something special" – perhaps by a child, or even a shaman (Miller *et al.* 1991). Although we don't know exactly when it was first collected, it points to a history of fossil appreciation in southern Africa stretching back for hundreds of years – and almost certainly much longer.

The ancient San hunter-gatherers of Southern Africa were not only acutely observant, but also very familiar with the rocks (exploited for stone tools), flora, fauna and animal spoor within their own area. Over the millennia they must have often come across fossil remains, such as marine shells embedded in rock at the coast or in the Cape Fold Mountains and vertebrate skeletons and trackways in the Karoo. It would be fascinating to know what these highly skilled naturalists and trackers thought of these remains (perhaps visitors from a spirit world?), since they would have immediately recognised their similarities to, and important differences from, the modern fauna.

The puzzling peculiarity of fossils has encouraged many imaginative beliefs in their medical and magical qualities over the ages. For example, in the seventeenth century fossil sharks' teeth or "tongue stones" were marketed in the Mediterranean as lightening bolts that had fallen to Earth and as effective antidotes against poison and harmful spells. In powdered form they were claimed to be effective against a wide range of medical conditions such as plague, fevers, burns, epilepsy and bad breath. Unlike halitosis, they were also reputed to be an invaluable aid in the courtship of "faire women". In ancient as well as modern China fossil brachiopods (lamp shells), known as "stone swallows", are powdered and baked as a cure against rheumatism, cataracts, anaemia and digestive problems. Similarly tons of vertebrate teeth and bones, from Mesozoic dinosaurs to Pleistocene hominids, have likewise been ground up for folk remedies by apothecaries. African indigenous knowledge concerning fossils, including folk beliefs and alternative medicines, has yet to be investigated.

Quite apart from their scientific interest and inherent beauty, fossils are worthy of our concerted protection and respect. After all, they represent the often vanishingly rare remains of but a tiny fraction of long-lost wildlife from the inconceivably distant past. To wilfully destroy fossils without good reason is therefore as much an act of barbarism as it is to burn down a magnificent building or library, or to destroy pristine vegetation and wildlife. A concern for human welfare and history is integral to any healthy society, but a respect for palaeontological heritage is surely the hallmark of higher civilisation!

Fig. 3.1. Major types of fossils



4. PALAEONTOLOGICAL HIGHLIGHTS OF THE NORTHERN CAPE

A selection of palaeontological highlights in the Northern Cape are listed in **Table 4.1**, together with a brief idea of their age and palaeontological significance.

Some the selected highlights are illustrated in the accompanying colour **Figures 4.1 to 4.20** (This section needs amplifying).

A number of these are placed in the broader context of the South African palaeontological record in **Figure 4.21**.

Some of the palaeontological highlights (*eg*. Soom and Upper Bokkeveld Group biotas) have been recorded so far only outside the N. Cape Province, but are confidently expected on geological grounds to also occur here.

Please note that the absolute dates given (in so many millions or billions of years) are subject to frequent revision, but stratigraphic ages (Devonian *etc*) are fairly stable.

Ga = billion years ago **Ma** = millions of years ago **Ka** = thousands of years ago
BP = before present (1950)

See also the glossary of important technical terms in Appendix 1.

TABLE 4.1. NORTHERN CAPE FOSSIL HERITAGE: PALAEONTOLOGICAL HIGHLIGHTS

FOSSIL BIOTA & AGE	KEY LOCALITIES / AREAS	PALAEONTOLOGICAL SIGNIFICANCE
Later Quaternary aeolian and cave deposits with ESA, MSA and LSA artefacts, associated with exploited prey remains	Widespread fossils in aeolianites, on deflation surfaces and locally in caves (*eg* Spoeg Rivier on coast. interior sites *e.g.* Wonderwerk Cave)	Biological context of early Man. Poorly investigated overall.
West Coast Group, unnamed terrestrial formations. Mainly Pliocene to Quaternary terrestrial mammals, birds & reptiles.	Ephemeral mine exposures of aeolian, fluvial and estuarine deposits of coastal plains. Intersects with archaeological record in Quaternary	Generally sparse, but extremely valuable fossils mainly recording late Caenozoic evolution and distribution of terrestrial mammal fauna of S. Africa, including hominins
West Coast Group marine formations. Mid-Miocene to Quaternary fossil mollusca & other marine invertebrates. Some marine vertebrates fauna (fish, cetaceans, seals, seabirds)	Ephemeral mine exposures of marine deposits of coastal plains. Kleinzee, Avontuur, Hondeklip formations and at least 3 Quaternary "raised beaches" equivalent to Velddrif Fm.	Locally rich shell faunas recording Caenozoic cooling and evolution of modern marine biotas within the Benguela Upwelling System. Rare, valuable fossils of marine vertebrates
Kaolinized "Channel Clays" with lignites (fossil peats), of the West Coast Group	Numerous buried palaeochannels from Vredendal area north to the Orange River *e.g.* Langklip, Koingnaas	Rich fossil pollen spectra, fossil leaves and wood aid reconstruction of earliest Miocene vegetation and climates
Neogene (Late Tertiary) to Pleistocene mammals (*c.* 19 Ma – 10 Ka)	Koa River / Geelvloer Palaeovalley system (Bosluis Pan, Brandvlei, Sak River, Carnarvon Leegte), Orange & Vaal River gravels	Evolution of southern African wildlife (esp. mammals) in west of subcontinent in context of increasing aridity, climatic fluctuations
Late Cretaceous / Palaeocene crater lake biotas, including dinosaurs, frogs, fish, palynomorphs (*c.* 70-60 Ma)	Stompoor, Banke, Kangnas and other volcanic pipes, Bushmanland Plateau	Rare source of information on early post-Gondwana / African biotas & environments in continental interior
Beaufort Group vertebrates (fish, amphibians, reptiles, therapsids) – skeletons, trackways, burrows, coprolites Late Permian – Early Triassic (*c.* 266-250 Ma)	Numerous sites in Upper Karoo *eg* Fraserburg (trackway site) Victoria West (fish)	Rich Permo-Triassic continental tetrapod fauna Evolution of mammal-like features among therapsids Best terrestrial record of two Late Permian mass extinctions

Whitehill Formation (lower Ecca Group) biota - mesosaurid reptiles, palaeoniscoid fish, crustaceans **Mid Permian (*c.* 280 Ma)**	Nieuwoudtville, Kimberley *etc*	Exceptional preservation of intact vertebrate skeletons Historically significant fossil evidence for supercontinent Gondwana & continental drift (late C19 / early C20)
Dwyka & Ecca Group trace fossils **Mid to Late Permian (*c.* 290-266 Ma)**	Widespread Brassefontein / Sakrivier, Calvinia, Carnarvon, Vioolsdrif *etc*	Relatively diverse non-marine trace assemblages. Evolution of non-marine, post-glacial aquatic benthos in Gondwana Among historically earliest fossil finds from RSA ("Eel fish" of Lichtenstein, 1803)
Basal Ecca Group marine biota **Mid Permian (*c.* 290 Ma)**	Douglas, Tanqua Karoo	Earliest post-glacial marine fauna of western Ecca Basin – biostratigraphical and palaeoenvironmental significance
Upper Bokkeveld Group trace fossils, fish, plants **Mid Devonian** **(*c.* 410-390 Ma)**	Onderbokkeveld area, east of Doringbos (Kalkgat, Spaarbos *etc*)	Most diverse shallow marine trace fossil assemblages from Mid Palaeozoic Gondwana
Soom Biota, including early jawless fish, water scorpions **Late Ordovician (*c.* 440 Ma)**	No collection records so far in N Cape (but fossil potential here is high)	Rare Ordovician, post-glacial fauna with exceptional soft tissue preservation (muscles, gills, guts *etc*) Key fossils for understanding early vertebrate (fish) evolution
Vanrhynsdorp Group trace fossils, large columnar stromatolites **Late Proterozoic / Early Cambrian** ***c.* 550-540 Ma**	Namaqualand, SE of Garies (Grootriet / Arondegas area) and Bokkeveld Plateau east of Vanrhynsdorp	Key evidence for evolution of complex behaviour and large body size during Precambrian / Cambrian metazoan "explosion" Global biostratigraphic significance
Nama Group biota, including giant stromatolites, shells, cyanobacterial strings **Late Proterozoic / Early Cambrian** ***c.* 550-540 Ma**	Neint-Nababeep Plateau S of Vioolsdrif, Gordonia	Earliest known shelly invertebrates High likelihood of vendozoan fossils
Transvaal Supergroup shallow marine and lacustrine stromatolites, organic-walled microfossils ***c.* 2.7-2.5 Ga**	Ghaap Plateau *etc*	Record of early microbial-dominated life in shallow seas and lakes of Early / Mid Precambrian

Fig. 4.1. Small-scale, columnar-branching stromatolites within 2.7 billion year old lacustrine sediments of the Ventersdorp Supergroup. Photo shows borehore core, *c.*3cm in diameter, that was drilled in the Free State. Similar late Archaean fossils are expected in the Ventersdorp succession of the Northern Cape (Photo from MacRae 1999).

Fig. 4.2. Spectacular stromatolite domes (algal mounds) in the 2.5 billion year old Transvaal Supergroup at Boetsap, Campbellrand Plateau. This site has recently been seriously vandalised. (Figure abstracted from McCarthy & Rubidge, 2005).

Fig. 4.3. Large domal stromatolites in the late Precambian Nama Group at Swartbas near Vioolsdrif. These examples are about half a billion years old (Ediacaran Period) and are vulnerable to damage, since they are situated close to a busy dust road.

Fig. 4.4. Polished limestone slab from the lower Nama Group at Vioolsdrif, showing sections through the world's oldest known fossil shells (Ediacaran, *c*. 550 Ma).

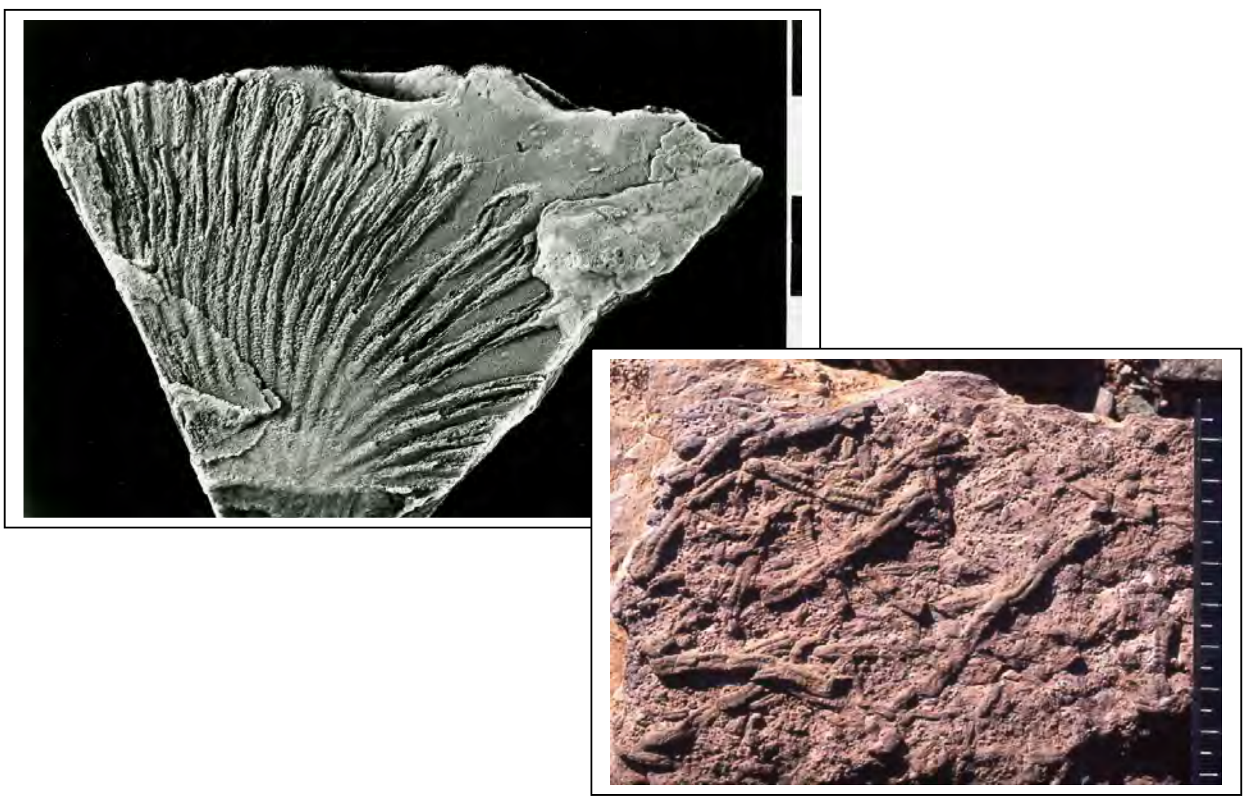


Fig. 4.5. Trace fossils of earliest Cambrian age (*c*. 540 Ma) from the Vanrhynsdorp Group documenting the rapid increase in body size and behavioural complexity among burrowing organisms at the time of the Cambrian Explosion of multicellular life.

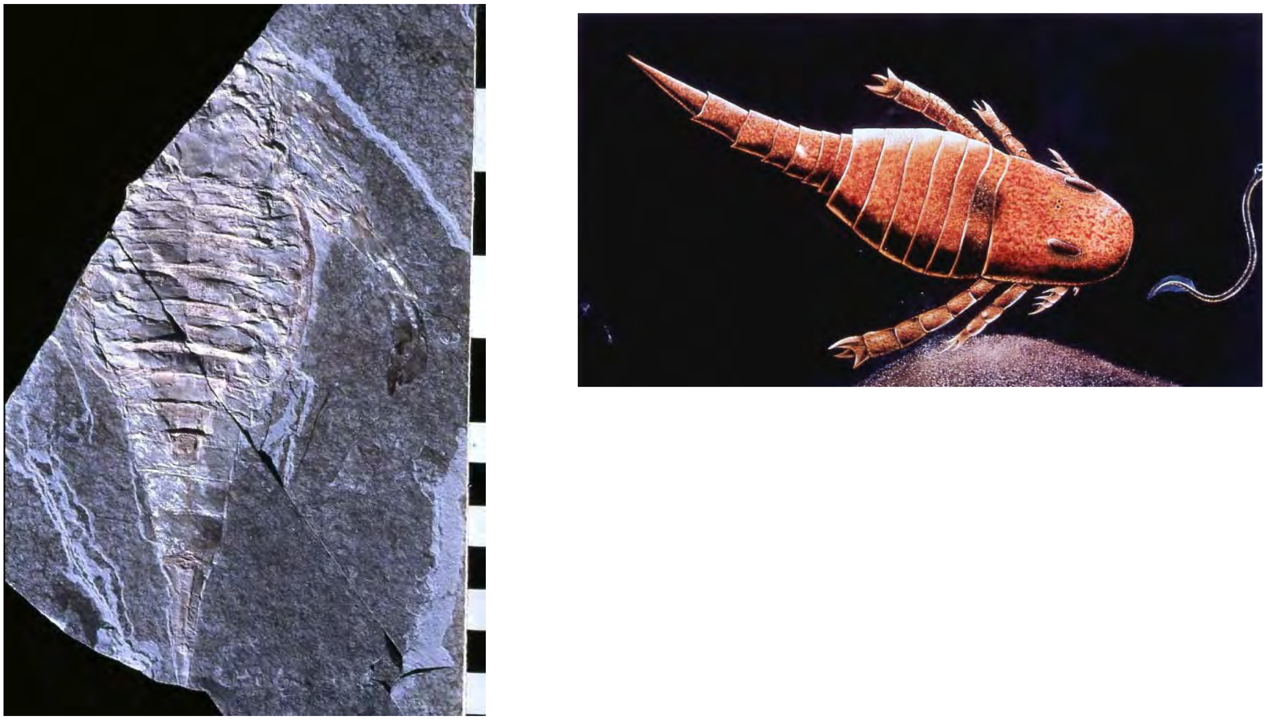


Fig. 4.6. Exceptional fossils of water scorpions (eurypterids) from the post-glacial Cederberg Formation (End Ordovician, *c.* 440 Ma), showing well-preserved respiratory structures, muscles and gut contents. These fossils have so far only been found in the W. Cape, but should occur in the Northern Cape as well.

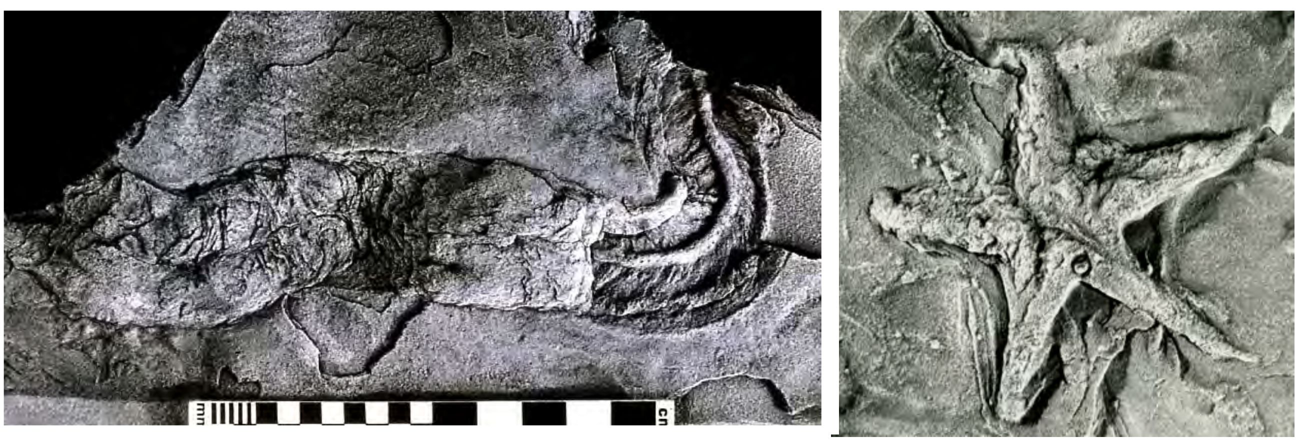


Fig. 4.7. Well-preserved trace fossils of shallow marine invertebrates from the lower Bokkeveld Group (*c.* 400 Ma), attributed to a burrowing snail-like mollusc (left) and a starfish. Over sixty different genera of traces have been recorded from these beds – one of the most diverse marine trace fossils known from the Palaeozoic.

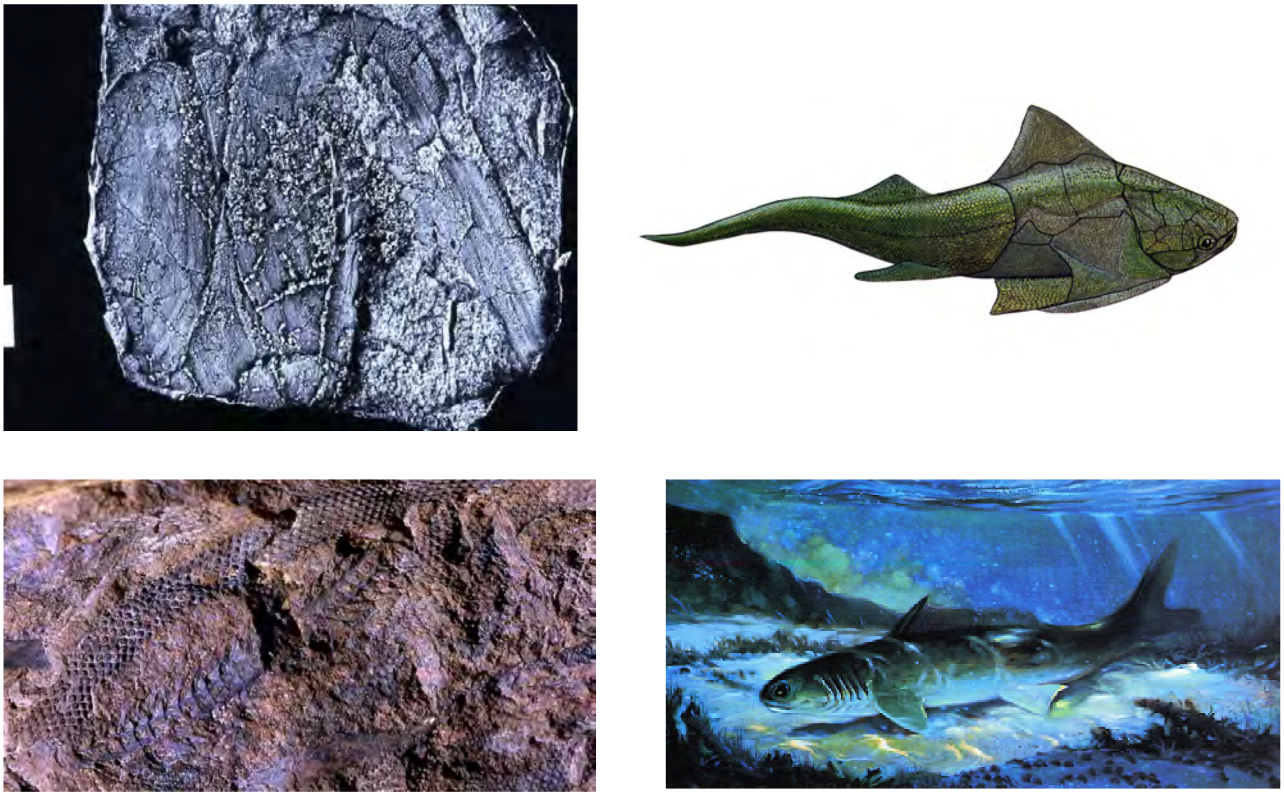


Fig. 4.8. Middle Devonian fish (placoderms, sharks) and land-plant fossils from the upper Bokkeveld Group (*c.* 390 Ma). Similar fossil assemblages are known from the Devonian of Antarctica.

Fig. 4.9. Dwyka Group interglacial / post-glacial mudrock scattered with dropstones that have fallen from floating ice above, showing delicate trackways of bottom living crustaceans (*c.* 290 Ma).

Fig. 4.10. Non-marine trace fossils from the Early Permian Ecca Group (*c*. 270 Ma) attributed to a king crab (left) and a bottom-swimming fish (right). The Ecca Group has one of the richest records of Palaeozoic non-marine traces in the world.

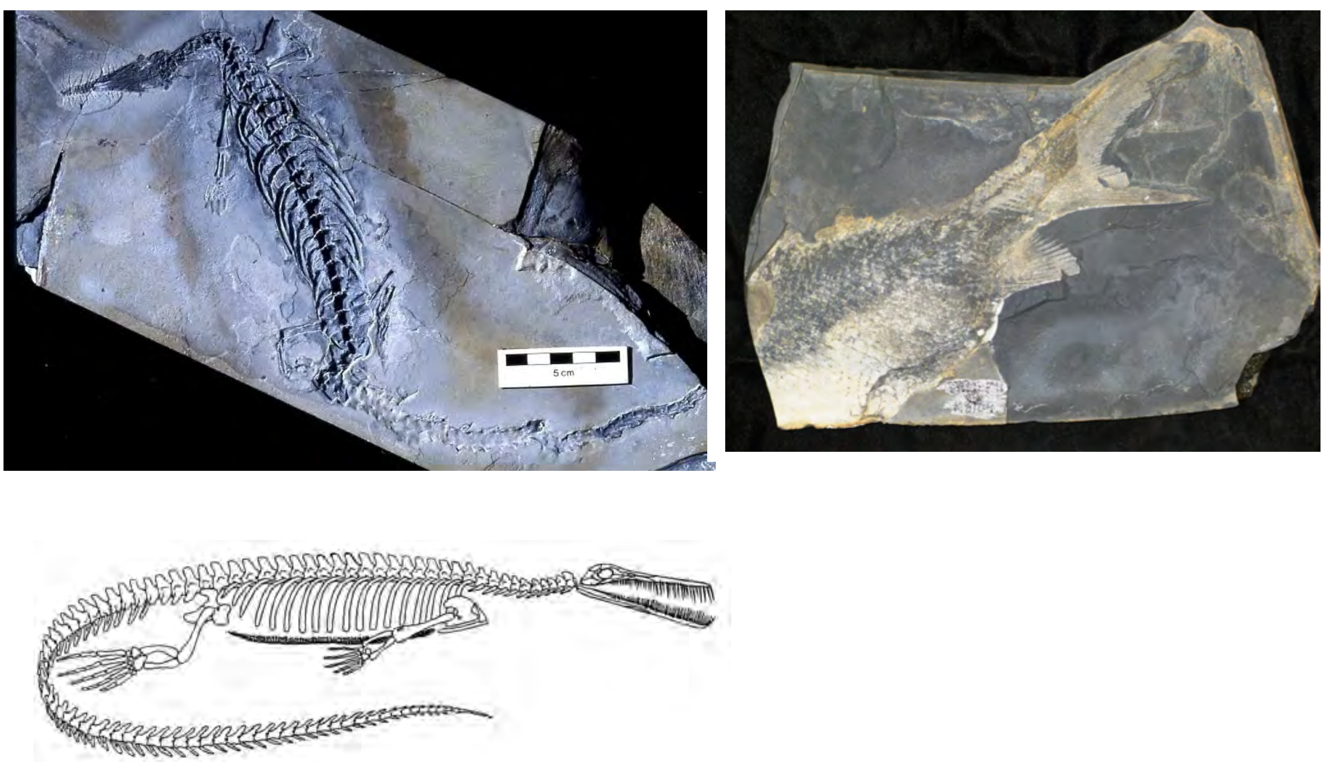


Fig. 4.11. Early aquatic reptile *Mesosaurus* and primitive bony fish from the Whitehill Formation, lower Ecca Group (Mid Permian, c. 280 Ma). Almost identical fossils are known from South America – historically important evidence for the Supercontinent Gondwana.

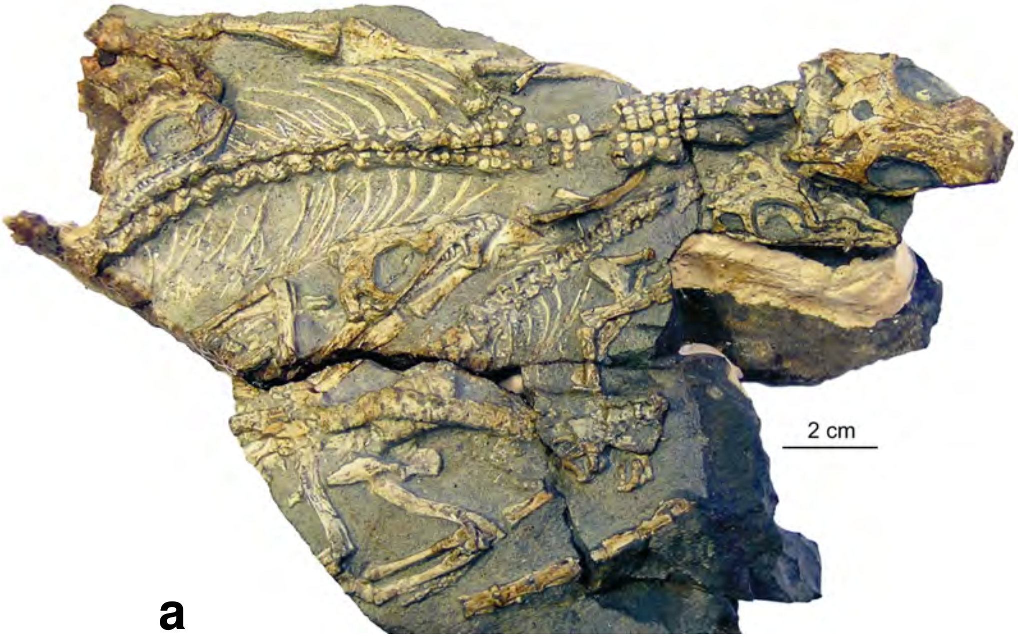


Fig. 4.12. Fossils from the Late Permian lower Beaufort Group (c. 265 Ma):
(a) Tight cluster of several juveniles and an adult varanopid, suggesting parental care among early therapsids (Fraserburg)
(b) Palaeoniscoid fish from Victoria West
(c) Therapsid trackways on the Fraserburg palaeosurface
(d) Arthropod (insect?) tunnels from moist soils (*c.* 1cm diameter)

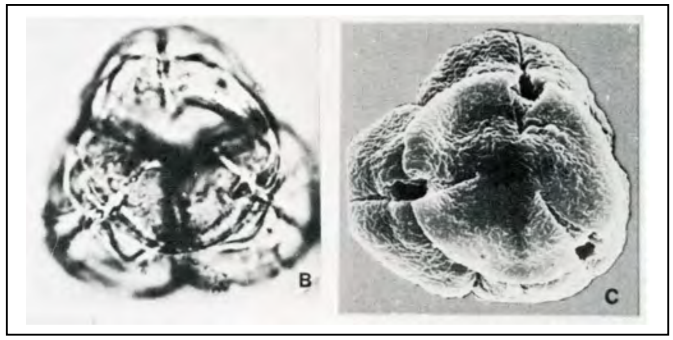
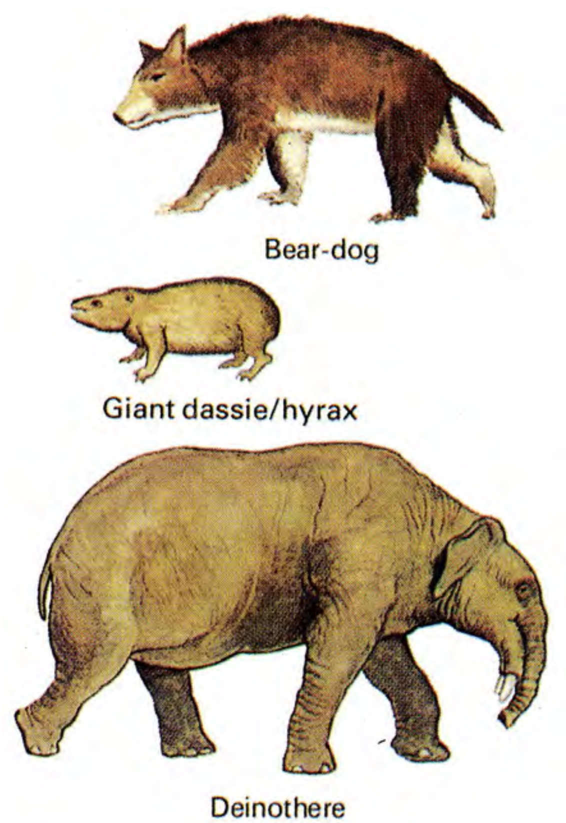


Fig. 4.13. Palaeocene (*c.* 60 Ma) fossils from the crater lake sediments of the Arnot Pipe, Banke, Bushmanland: small pipid frogs, angiosperm pollens. Such fossils allow reconstructions of palaeoenvironments in the African interior shortly after the end-Cretaceous mass extinction.



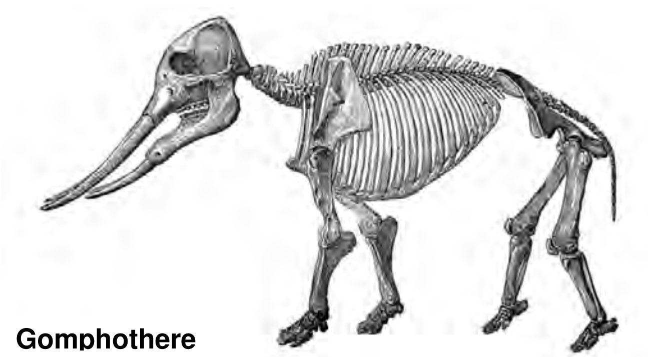


Fig. 4.14. Extinct mammalian genera whose fossils occur in Miocene (*c.* 18-15 Ma) river gravels along the Orange River and its tributaries. This rich mammal fauna thrived when climates in the interior of South Africa were much wetter than they are today.

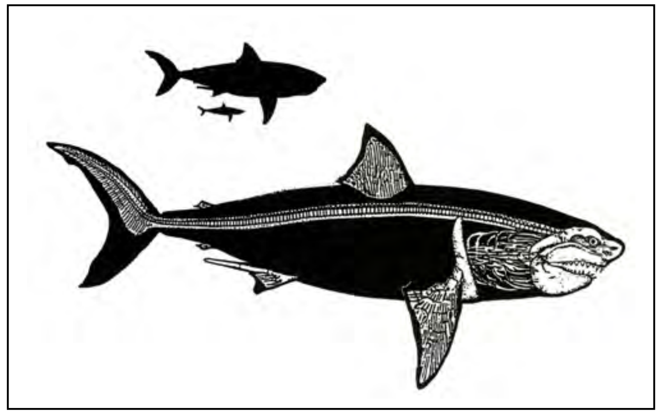


Fig. 4.15. Tooth of the extinct giant shark *Carcharodon*, top predator in the seas around southern Africa and elsewhere from about 16 to 1.6 million years ago. It reached body lengths of 15-20m (see inset, showing comparison with the modern great white shark) and its teeth were up to 15-18cm long. These were shed continuously during life and are not infrequently collected off the West Coast by trawl nets. (Fossil tooth from MacRae, 1999).

Fig. 4.16. Ancient palaeochannel (RHS) incised in bedrock, infilled with organic-rich sediments of Oligocene-earliest Miocene age, when yellowwood forests flourished along the subtropical Northern Cape coast.

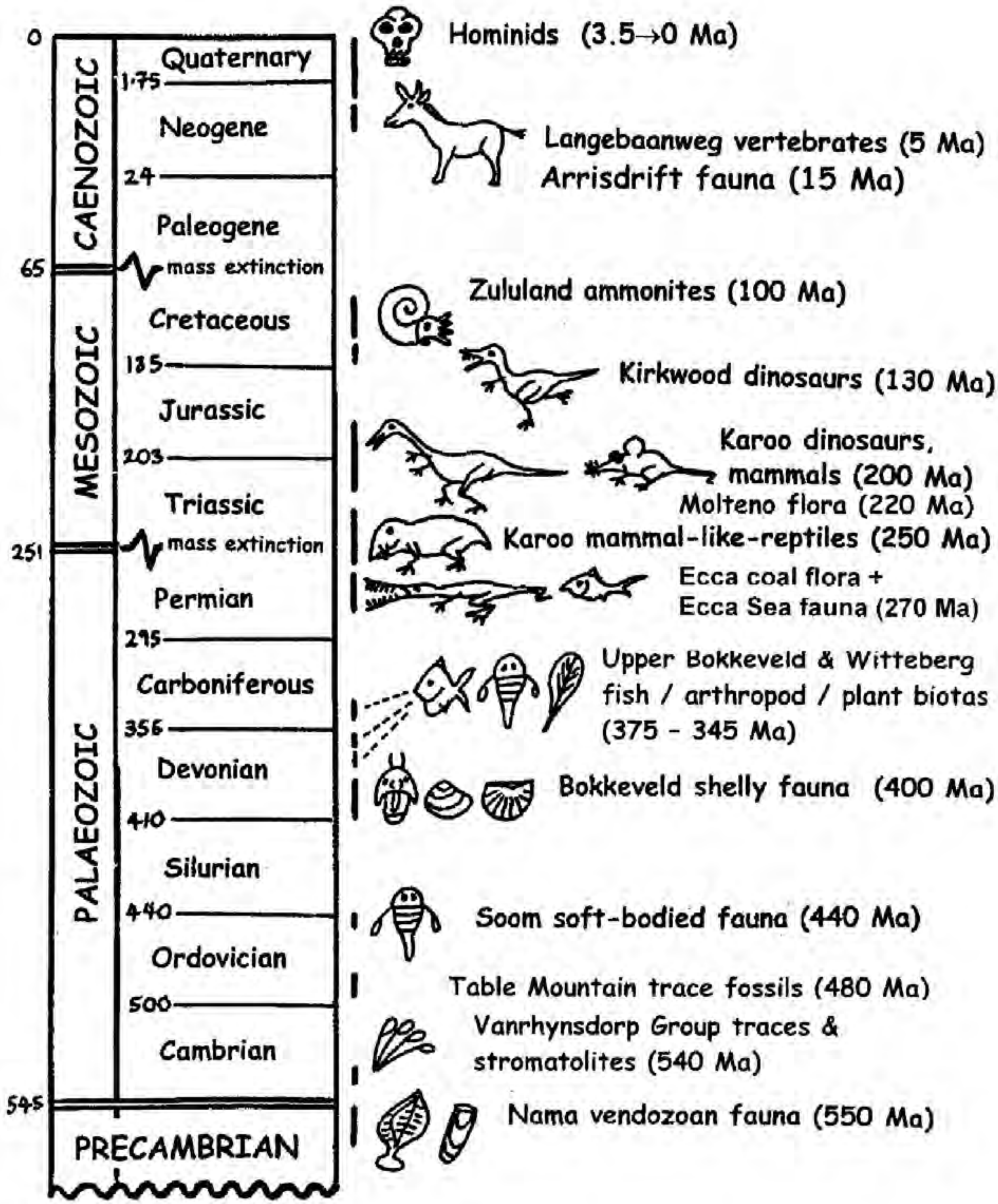
Fig. 4.17. Petrified fossils from the basal gravels of the Early Pliocene Avontuur Formation (West Coast Group). On the LHS are the teeth and ivory of extinct elephantoids. On the RHS are the enormous teeth of extinct, unknown predatory whales. These fossils were eroded from older, Miocene land and marine deposits during the early Pliocene transgression of the sea ~5 Ma. They then lay buried at dhallow depths on the seabed, becoming petrified by phosphatization, whilst some temporarily-exposed fossils were bored by marine organisms (Photo of display at the S. A Museum).

Fig. 4.18. Unusual, very shelly trench exposure of the Early Pliocene Avontuur Formation (5-4 Ma). Fossil shells once occurred throughout the beds, but have been dissolved in the uppermost, reddened layers.

Fig. 4.19. Partial disarticulated skeleton of a small baleen whale that sunk to the bottom of a bay in Avontuur Formation times (Early Pliocene, 5-4 Ma), coming to rest on top of diamondiferous bay-bottom gravels. Sharp grooves on the bones attest to scavenging by sharks.

Fig. 4.20. Bone accumulation collected by hyaenas and stored in a hole excavated into the eroded top of the Early Pliocene Avontuur Formation. The accumulation mainly comprises various antelope bones, but the presence of zebra (*Equus*) indicates that they must postdate ~2.6 Ma, considerably younger than the underlying marine beds.

Fig. 4.21. Selected fossil highlights of southern Africa – the last 550 million years



5. FOSSIL HERITAGE OF THE NORTHERN CAPE: TABULATED DATABASES

The tables presented in this section provide a comprehensive summary of the known and predicted palaeontological heritage of the Northern Cape, arranged according to stratigraphic units.

Table 5.1. is for use with the 1: 1 million scale geological map in four sheets published by the Council for Geoscience, Pretoria. The geological rock record of the Northern Cape is subdivided into fifteen convenient subunits with an outline of the age, depositional environment and fossil record of each subunit. A colour-coding scheme is used to rank the units in terms of their palaeontological sensitivity as outlined at the end of the table. Note that this ranking scheme is *provisional*, however, and will need to be modified in the light of discussions with heritage managers and palaeontological colleagues.

Table 5.2. is for use with the numerous 1: 250 000 scale geological maps covering the Northern Cape that are listed in Appendix 2.

Please note that:

- Many small outcrops of palaeontologically significant sediments (*eg*. coastal and interior units of Caenozoic age) are usually not represented on the maps.

- The table focuses on potentially fossiliferous rock units. There are numerous additional igneous and metamorphic rock units of negligible to no palaeontological significance (*eg* high grade metamorphic rocks and igneous intrusions of the Precambrian basement) that are indicated on the geological maps but are not listed here. These will have to be identified using the keys provided with each map. The user will therefore have to familiarise themselves with the major rock types (granite, gneiss *etc*) mentioned in the map keys. A list of basic geological texts is given in Section 10.

- A glossary of technical terms is provided in Appendix 1 of this report.

TABLE 5.1: FOSSIL HERITAGE OF THE NORTHERN CAPE (For use with 1: 1 000 000 geological map)				
GEOLOGICAL UNIT		**ROCK TYPES & AGE**	**FOSSIL HERITAGE**	**COMMENTS**
16. COASTAL CAENOZOIC DEPOSITS **(Narrow coastal occurrences, mainly subsurface, often not indicated on published maps)**	**WEST COAST GROUP (Q)** **The Northern Cape geological record, as exposed by minining activities, has been crucial to understanding of the history of the S. Afr, coastal plains. Important fossil finds have been rescued by scientifically-conscious mining personnel and during a few research projects.**	Oldest deposits are weathered palaeochannels with earliest Miocene palaeofloras and fossil wood/leaves. Marine record is mainly regressive, prograded shallow-marine sequences comprising basal conglomerates overlain by sandy and gravelly shoreface and sometimes foreshore deposits. Estuarine to fluvial deposits occur in vicinities of rivers and locally also muddier, sheltered embayment and lagoonal deposits. The tops of marine sequences are eroded and overlain by aeolianites. Interbedded and capping calcretes and other soil profiles mark stable palaeosurfaces. The marine deposits have discrete ages associated with high sea-levels and polar-ice melting during globally-warm periods: mid-Miocene ~16 Ma, early Pliocene ~5 Ma, late Pliocene ~3 Ma and later Quaternary <1 Ma. Aeolianites of various intervening ages.	In the marine deposits are fossil molluscan seashells, brachiopods, crustaceans (barnacles, crabs, prawns, ostracods), echinoids, polychaete worm tubes, corals, bryozoans & foraminifera. Shark teeth are common, other fish teeth occur. Bones of whales, dolphins, seals & seabirds. Trace fossils made by prawns, worms, echinoids, anemones, bivalves, fish *etc*, are pervasive. Bones of land mammals appear in estuarine and lagoonal deposits. In the aeolianites are land snails, tortoises, moles, ostrich bones and egg shells, insect traces. Larger animal bones are sparsely scattered on palaeosurfaces (bovids, zebra, rhino, elephant, pigs *etc*). Deposits associated with vleis, pans, springs very rich, especially birds, micromammals,	Unprecedented earlier Tertiary vegetation record, inadequately sampled to date. Marine fossil record is 4 discrete “time slices” or “windows” into the evolution of the coastal biota during Neogene-Quaternary global cooling, from tropical conditions to those today. Fossil bone finds during research on the Northern Cape coast mines have enabled age estimations based on correlations with the African vertebrate biochronology. Much lost to geoheritage due to absence of palaeontological management plans in the past. Fossil data associated with aeolian record overlaps with presence of early humans. Sparse fossils in aeolianites very important for filling gaps in terrestrial faunal record. Potential floral record in vlei deposits.

15. FLUVIAL, LACUSTRINE & TERRESTRIAL DEPOSITS (most too small to be indicated on small scale geological maps) **including *eg* Kwaggaskop Fm** **(Q)**	Fluvial, pan, lake and terrestrial sediments, including diatomite (diatom deposits), pedocretes, tufa, cave deposits Late Cretaceous to Holocene *c*. 65 Ma → 0 Ma	Bones and teeth of mammals (*eg* proboscideans, rhinos, bovids, horses, micromammals), reptiles, fish, freshwater molluscs, petrified wood, trace fossils (*eg* termitaria), rhizoliths, diatom floras	• Scattered records, many poorly studied (*eg* from ancient drainage systems) • Include equivalents of famous Arrisdrift Miocene fauna from S. Namibia • Threatened by alluvial diamond mining (*eg* Gariep, Vaal river gravels) • Orange River Man (100-50 Ka, *H. heidelbergensis*)
14. KALAHARI GROUP **(K-Q)**	Fluvial gravels, sands, lacustrine and pan mudrocks, evaporites, aeolian sands, pedocretes (especially calcrete) Late Cretaceous to Recent <90 Ma → 0 Ma	Palynomorphs, root casts (rhizomorphs) and burrows (eg termitaria), rare vertebrate remains (mammals, fish, ostrich egg shell *etc*), diatom-rich limestones, freshwater stromatolites, freshwater and terrestrial shells (gastropods, bivalves), ostracods, charophytes	Fossils mainly associated with ancient pans, lakes and river systems Palaeontology poorly studied
13. KIMBERLITES AND OTHER POST-KAROO IGNEOUS ROCKS, CRATER LAKE SEDIMENTS *eg* Sutherland Suite (Ksu), Koegel Fontein Complex	Kimberlite pipes and other alkaline intrusions, sometimes associated with lacustrine sediments (deep to shallow crater lakes) Jurassic, Cretaceous to Palaeocene *c*. 200-60 Ma	Bryophytes, vascular plants (leaves, wood), fish, frogs, reptiles, rare dinosaurs, insects, ostracods, palynomorphs in crater lake sediments	Biotas (especially palynomorphs) important for reconstruction of climate and vegetation change during post-Gondwana times
12. KAROO DOLERITE SUITE (Jd)	Intrusive dolerites (dykes, sills), associated diatremes Early Jurassic (*c*. 183 Ma)	NO fossils recorded	Karroo-Ferrar igneous intrusions associated with Early Jurassic mass extinction event

9-11. KAROO SUPERGROUP	**11. BEAUFORT GROUP** **1b. Tarkastad Subgroup (TRt)** **11a. Adelaide Subgroup (Pa)**	Continental (fluvial, lacustrine) siliciclastic sediments, pedocretes (calcretes) Late Permian – Early Triassic *c.* 266 – 250 Ma	Diverse terrestrial and freshwater tetrapods of *Tapinocephalus* to *Lystrosaurus* Biozones (amphibians, true reptiles, synapsids – especially therapsids), palaeoniscoid fish, freshwater bivalves, trace fossils (including tetrapod trackways), sparse vascular plants (*Glossopteris* Flora, including petrified wood)	• Richest Permo-Triassic tetrapod fauna from Pangaea / Gondwana • Key evidence for evolution of mammalian characters among therapsids • Continental record of Late Permian Mass Extinction Events
KAROO SUPERGROUP continued	**10. ECCA GROUP** **(Ppr, Ppw, Pw, Pt, Ps, Pk, Pwa)**	Offshore basin plain (predominantly non-marine) to coastal deltaic sediments, minor volcanic ashes (tuffs) Early – Mid Permian 290 – 266 Ma	**9b. Ecca Group**: non-marine trace fossils, vascular plants (including petrified wood) and palynomorphs of *Glossopteris* flora, mesosaurid reptiles, fish (including microvertebrate remains, coprolites), crustaceans, sparse marine shelly invertebrates (molluscs, brachiopods), microfossils (radiolarians *etc*), insects	• Diverse non-marine trace fossil assemblages from Gondwana • Exceptionally preserved biota of Whitehill Sea (mesosaurid reptiles, fish, crustaceans)
	9. DWYKA GROUP **(C-Pd)**	Glacial, interglacial and post-glacial siliciclastic sediments (*eg* tillites). Late Carboniferous – Early Permian *c.* 320-290 Ma	Trace fossils, organic-walled microfossils, rare marine invertebrates (*eg* molluscs), fish, vascular plants	

8. CAPE SUPERGROUP **8. CAPE SUPERGROUP continued**	**8c. Witteberg Group** **(Dw, ?Dl)**	Shallow marine, lagoonal / lacustrine and minor glacial siliciclastics Mid Devonian – Early Carboniferous	Trace fossils, vascular plants, sparse shelly invertebrates, fish (brachiopods, bivalves *etc*)	• Record of early marine, coastal and estuarine / fluvial life on margins of Gondwana • Cederberg Formation contains soft-bodied, post-glacial biota of Late Ordovician age • Most diverse trace fossil assemblages recorded from Mid-Palaeozoic Gondwana (Bokkeveld Group) • Subpolar Late Devonian biotas
	8b. Bokkeveld Group **(Dbi, Dc)**	Shallow marine siliciclastics Early – Mid Devonian	Rich trace fossil assemblages, also shelly invertebrates (trilobites, brachiopods, echinoderms, molluscs *etc*), microfossils in lower Bokkeveld. Important fish / vascular plant/ trace fossil biotas in upper Bokkeveld.	
	8a. Table Mountain Group **(Ope, Sn)**	Predominantly fluvial sandstones, with subordinate mudrocks, tillites Early Ordovician – Silurian - Early Devonian	Mostly unfossiliferous sandstones with sparse trace fossils, **BUT** also Soom Member post-glacial biota in mudrocks (agnathan fish, eurypterids, brachiopods *etc*)	
7. KUBOOS-BREMEN SUITE (CAPE GRANITE SUITE *etc* on map) **(Cku, Csw,Ct)**		Granites Cambrian *c.* 521-507 Ma	NO FOSSILS RECORDED	
6. NAMA & VANRHYNSDORP GROUPS **6g. Brandkop Subgroup (Cb)** **6f. Knersvlakte Subgroup (Ckn)** **6e. Kwanous Subgroup (Nkw)** **6d. Flaminkberg Fm (Nfl)** **6c. Fish River Subgroup (Cf)** **6b. Schwarzrand Subgroup (N-Csc)** **6a. Kuibis Subgroup (Nku)**		Siliciclastic and carbonate sediments, largely undeformed and with v. low grade metamorphism Latest Proterozoic (Ediacaran) – Early Cambrian *c.* 550 Ma – 540 Ma	Ediacaran shelly invertebrates, trace fossils, calcified algae, agglutinated tubes, early metazoans (possible sponges *etc*), organic-walled microfossils, vendotaenid “algal strings”, stromatolites and other biomat structures Abundant Early Cambrian trace fossils (Fish River, Knersvlakte & Brandkop Subgroups)	• Key successions for body and trace fossils spanning the critical Precambrian (Ediacaran) / Cambrian boundary • Earliest known fossil shells in the world • Classic giant stromatolites, • World-class trace fossils • Vendobiontans expected (but not yet recorded)

5. GARIEP SUPERGROUP(Ng) **5c. Gifberg Group (Ng)** **5b. Port Nolloth Group (Ns, Nh, Nnu, Nho, Ng)** **5a. Marmora Terrane (Nsc, Nc, No)**	Metasediments (marine siliciclastics, carbonates, glacial tillites), igneous rocks Late Proterozoic (Cryogenian – Ediacaran) <770 Ma - >550 Ma	Deformed stromatolites, oolites, pisolites in carbonates, organic-walled microfossils (acritarchs) + agglutinated foraminiferans in siliciclastics	Palaeontology poorly known
4. NAMAQUA METAMORPHIC PROVINCE **large number of subunits (M*….)**	Igneous and metamorphic rocks (including high grade metasediments) Early to Mid Proterozoic (Mokolian) *c.* 2-1 Ga	NO FOSSILS RECORDED	
3. OLIFANTSHOEK SUPERGROUP **(Mlu, Mhr, Mbb, Mm, Mbr, Mkb, Msk, Vga?)**	Predominantly continental "red beds" (fluvial sediments), subordinate shallow marine siliciclastic metasediments (low grade), lavas, carbonates Mid Proterozoic (Mokolian) *c.* 1.9 Ga	Possible stromatolites, microfossils	• Continental "red beds" record development of early oxygen-rich atmosphere • Laterites suggest possible life on land
2. TRANSVAAL SUPERGROUP **2c. Postmasburg Group (Vmk, Vo)** **2b. Ghaap Group (Vsc, Vvs, Vca, Va, Vk)** **2a. Vryburg Fm (Vv)**	Dominantly shallow marine carbonate metasediments (low grade), deeper water BIF (ironstones, chert), subordinate siliclastic sediments, volcanics, tillites L. Archaean / E. Proterozoic (Vaalian) *c.* 2.6-2.2 Ga	Shallow marine and lacustrine stromatolites in carbonates organic-walled microfossils (*eg* cyanobacteria) in siliciclastics / cherts / carbonates Controversial records of 2.2 Ga "trace fossils"	• Classic Early Proterozoic stromatolitic successions (Ghaap & Postmasburg Groups of Griqualand West Basin) • Early continental shelf environments (margins of Kaapvaal Craton)
1. VENTERSDORP SUPERGROUP **(Rk, Rp, Rka, Rgd, Rm, Rri, Rbt, Ral)**	Metasediments (fluvial & lacustrine siliciclastics, chert, dolomite), lavas Neoarchaean (Randian) *c.* 2.7 Ga	Lacustrine stromatolites in carbonates, Possible organic-walled microfossils	• Non-marine stromatolites • LIP (Large Igneous Province) voluminous basaltic eruptions

KEY & GLOSSARY:

Ma = millions of years old **Ga** = billions of years old
metasediments = metamorphosed sediments (*eg* quartzite = metamorphosed sandstone).
high grade metasediments = sedimentary rocks that have been strongly metamorphosed, and therefore not fossiliferous (*eg* schist, gneiss), as opposed to **low grade metasediments** that have only been slightly metamorphosed, and may therefore still contain fossils (*eg* quartzites, slates).
siliciclastics = sediments mainly composed of silicate minerals (*eg* quartz, feldspar, clays), as opposed to **carbonates** = sediments composed of carbonate minerals (*eg* limestone, dolomite, calcrete).
fluvial sediments = deposited by rivers (alluvium) **lacustrine sediments** = deposited in lakes **aeolian sediments** = deposited by wind
tillites = glacial sediments **tuffs** = volcanic ashes
pedocretes = secondarily cemented soils (*eg* lime-cemented calcretes, silica-cemented silcretes)
BIF = banded ironstone formations **laterite** = red, iron-rich soils formed from highly weathered bedrock
palynomorphs = organic-walled microfossils of plant, or plant-like origin (*eg* spores, pollens)
vendozoans = problematic macroscopic fossils of late Precambrian (mainly Ediacaran) age with a peculiar quilted or tubular substructure, controversial biological affinities

PALAEONTOLOGICAL SIGNIFICANCE OF ROCK UNITS

COLOUR OF ROCK UNIT	PALAEONTOLOGICAL SIGNIFICANCE / VULNERABILITY	RECOMMENDED ACTION
RED	very high	field scoping study recommended before excavation takes place
PURPLE	high	desk top study + scoping study may be necessary
GREEN	moderate	desk top study
BLUE	low	no action required (any fossil finds to be reported by developer)
BLACK	insignificant or zero	no action required

NB.1. These significance / vulnerability ratings are *provisional*
NB.2. Some rock units are largely unfossiliferous, but have thin subunits of high palaeontological significance (*eg* Table Mountain Group).

TABLE 5.2: FOSSIL HERITAGE OF NORTHERN CAPE (For use with 1: 250 000 geological maps)				
GEOLOGICAL UNIT & AGE		**ROCK TYPES, PALAEOENVIRONMENTS**	**FOSSIL HERITAGE**	**COMMENTS**
21. WEST COAST GROUP The West Coast Group stratigraphic formations and members are still "under construction" and thus informal. The schema below is based on the author's own view (J. Pether) and unpublished inputs by D. Roberts and C. de Beer of the Council for Geoscience. Please note that these units do not yet appear on published geological maps, and in many cases outcrop width is too small to be shown at 1: 250 000 scale.				
Swartlintjies Fm	Late Quaternary to Holocene	Dune plumes extending from the mouths of rivers	Rare scattered bones, especially assoc. with interdune areas, ephemeral vleis	Spatial variation in colours from white to pale hues of yellow & red show various additions, remobilizations.
Hardevlei Fm	Late Quaternary	Surficial pale red aeolian sands, locally as reticulate dune fields	Rare scattered bones	Bones usually on basal contact and assoc with MSA and LSA
Koekenaap Fm	Late Quaternary	Red aeolian sands mantling current surface locally	Rare scattered bones assoc. with LSA artefacts on aeolian palaeosurfaces, Land snails & terrestrial trace fossils	
Olifants River Fm	Mid to late Quaternary	Aeolian sands and palaeosols with local colluvial and sheetwash deposits	Scattered bones assoc. with aeolian palaeosurfaces, blowouts, interdunal areas & pans. Terrestrial trace fossils abundant. Land snails	Some ESA, but mainly MSA artefacts
Curlew Strand Fm Mid-Quaternary? to Holocene beaches	6-4 ka	Marine: mainly beach deposits, but shoreface deposits locally preserved	Modern, cool-water shell faunas, some extinct species and warm-water extralimitals in sheltered bays	Mid-Holocene, 2-3 m asl.
	~125 ka			Last Interglacia,l ~4-5 m asl.
	~400 ka?			MIS 11? 8-12, m asl.

Kalkvlei Fm	Pliocene to early Quaternary	Aeolian sands and palaeosols with local colluvial and sheetwash deposits	Scattered bones assoc. with aeolian palaeosurfaces, blowouts, interdunal areas & pans. Terrestrial trace fossils abundant. Land snails	Broadly equivalent to Graauw Duinen Fm, but as condensed terrestrial sequences formed in places lacking significant dune buildup
Graauw Duinen Fm, "Part 3"	Early Quaternary, <2.6 Ma (*Equus* datum)	Aeolian sands and palaeosols with local colluvial deposits	Scattered bones assoc. with aeolian palaeosurfaces, blowouts, interdunal areas & pans. Terrestrial trace fossils abundant. Land snails	*Equus* in lower part, large Achuelian artefacts (ESA) in uppermost part.
Graauw Duinen Fm, "Part 2"	Late Pliocene, 3.0-2.6 Ma	Terrestrial erosion followed by aeolian sands and palaeosols with local colluvial deposits	Scattered bones assoc. with aeolian palaeosurfaces, blowouts, interdunal areas & pans. Terrestrial trace fossils abundant. Land snails	Overlies Hondeklip Fm close to coast and laps onto earlier Graauw Duinen "Part 1" inland
Hondeklip *Fm* (30 m Package) Alexander Bay *Subgroup*	Mid-Pliocene, 3.0-3.4 Ma?	Marine: locally conglomeratic beaches, but mainly coarse-sandy shoreface deposits.	Relatively poor preservation of fossil shells due to extensive leaching and reddening of coarse, porous sands	Last subtropical shell fauna. Most shell fauna preserved in lowermost, fine-sandy, lower shoreface. No associated fossil bones for age constraints yet found. Important to improve sampling overall
Graauw Duinen Fm, "Part 1"	Mid-Pliocene, 4.0-3.4 Ma?	Terrestrial erosion followed by aeolian sands and palaeosols with local colluvial deposits	Scattered bones assoc. with aeolian palaeosurfaces, blowouts, interdunal areas & pans. Terrestrial trace fossils abundant. Land snails	Undescribed fossil tortoises and moles most common. Bones of antelopes, small carnivores, hares, rodents and birds assoc with water seepage out of dunes
Avontuur *Fm* (50 m Package) Alexander Bay *Subgroup*	Early Pliocene 5-4 Ma	Marine: locally beaches and upper shoreface, but mainly lower-shoreface and inner-shelf deposits preserved	Petrified, reworked fossils from 7-5 Ma earlier terrestrial deposits in gravels. Contemporaneous fish teeth and rare marine mammals, seabirds. Locally rich fossil shell faunas. Abundant trace fossils.	Best-preserved West Coast sub-tropical shell fauna. Important to improve sampling of poorly-preserved shelf facies
Unnamed Fm Could be coastal equivalent in part of inland De Toren Fm (see below)	Later Miocene	Terrestrial erosion followed by aeolian sands and palaeosols with local colluvial deposits	No fossils yet recovered, but 13-9 Ma rolled teeth reworked into Avontuur Fm (*Amphicyon*, *Tetralophodon*)	Seldom-exposed, cryptic. Featureless, pale leached sands, or later reddened. Silicified equivalent in drainages.

Kleinzee *Fm* (90 M Package) Alexander Bay *Subgroup*	Late middle Miocene, 16-14 Ma	Marine: beach & shoreface deposits preserved >60 m asl. Limited patches of shoreface & shelf deposits at lower elevations	Rare, petrified, reworked fossils from earlier ~18 Ma terrestrial deposits in gravels. Contemporaneous fish teeth etc. Only very rarely shells preserved.	Unique tropical shell faunas very occasionally exposed below younger formations, fragilely preserved in shelf muds. Very poorly sampled.
Coastal River Valleys Equiv. of Meso-Orange III River Gravels	Mid-Pliocene, 3.7-3.4 Ma	Fluvial terraces and abandoned channels on valley flanks of major rivers	Very poorly known, largely unstudied	Fluvial agradation with rising sea level of transgression to ~30 m asl. Equivalents in other coastal rivers poorly known
Coastal River Valleys Equiv. of Meso-Orange II River Gravels	Latest Miocene, 7-5 Ma	Fluvial terraces and abandoned channels on valley flanks of major rivers	Very poorly known, largely unstudied	Fluvial agradation with rising sea level of transgression to ~50 m asl. Equivalents in other coastal rivers poorly known
Coastal River Valleys Equiv. of Proto-Orange River Gravels aka Arris Drift Gravel Fm	Miocene, 19-17 Ma	Fluvial terraces and abandoned channels on valley flanks of major rivers	Fossil content best known from lower Orange River, vertebrates, fossil wood and some invertebrates	Fluvial agradation with rising sea level of transgression to ~90 m asl. Equivalents in other coastal rivers poorly known
De Toren Fm	Miocene?	Silicified angular gravels and sandstones overlying kaolinized bedrock on high ground (>200 m asl.) inland of coast. Colluvial scree & run-off stream deposits.	Not well studied wrt. fossils, but likely to be very rare in such deposits (thus very valuable).	Sandy stream facies need more detailed examination.
Koingnaas Fm	Oligocene to early Miocene, 34-22 Ma	Deeply-weathered (kaolinized) fluvial arkosic sands and diamondiferous gravels in incised palaeo-channels (aka "Channel Clays"), with silcrete.	Locally peat beds very rich in plant macrofossils and pollen. Well-preserved fossil wood. Possible very rare silicified bones recently seen.	From time when yellowwood forest dominated the West Coast. Also ironwood and mahogany. Earliest daisy pollen. Macrofossil potential unrealized.

TABLE 5.2: FOSSIL HERITAGE OF THE NORTHERN CAPE: GEOLOGICAL UNITS ON 1: 250 000 MAPS			
GEOLOGICAL UNIT	**ROCK TYPES & AGE**	**FOSSIL HERITAGE**	**COMMENTS**
20. WEST COAST & INTERIOR SILCRETES **(K-si or unmarked)** Mesozoic (?Jurassic / Cretaceous) to Oligocene / Miocene	silicified gravels to fine-grained silcretes overlying weathered bedrock or within incised channels	No fossils recorded (but silicified plants, traces *etc* might be present)	Coastal silcretes above +90m amsl probably Palaeogene and not Cretaceous Hondeklipbaai silcretes Oligocene / Miocene Platbakkies silcretes above Escarpment possibly extend back to Late Jurassic
19. OTHER CAENOZOIC FLUVIAL, LACUSTRINE & TERRESTRIAL DEPOSITS OF INTERIOR **(Most too small to be indicated on 1: 250 000 geological maps)** ***eg* Kwaggaskop, Dasdap, Vaalputs, Arries Drift, Windsorton, Rietputs, Riverton Fms**	Fluvial, pan, lake and terrestrial sediments, including diatomite (diatom deposits), pedocretes, spring tufa / travertine, cave deposits, peats, colluvium Late Cretaceous /Palaeocene to Holocene	Bones and teeth of wide range of mammals, including mammals (*eg* teeth & bones of mastodont proboscideans, rhinos, bovids, horses, micromammals), reptiles (crocodiles, tortoises), ostrich egg shells, fish, freshwater and terrestrial molluscs (unionid bivalves, gastropods), crabs, trace fossils (*eg* termitaria, horizontal invertebrate burrows, stone artefacts), petrified wood, leaves, rhizoliths, diatom floras, peats and palynomorphs. Calcareous tufas at edge of Ghaap Escarpment might be highly fossiliferous (*cf* Taung in NW Province – abundant Makapanian Mammal Age vertebrate remains, including australopithecines)	Scattered records, many poorly studied and of uncertain age Reflect ancient drainage systems of subcontinental interior (eg Geelvloer – Koa River Valley system, Palaeo-Orange and Vaal systems) Include fossil equivalents of famous Arriesdrift Mid Miocene fauna from S. Namibia (*eg* at Bosluispan, Proto-Orange Terrace Gravels of lower Orange River) Fossils threatened by alluvial diamond mining (Vaal & Mid to Lower Orange River gravels) Orange River Man (100-50 Ka, *H. heidelbergensis*) See archaeological literature for fossil & subfossil remains from archaeological sites (eg Wonderwerk Cave nr Kuruman, Kathu Pan near Sishen)

18. KALAHARI GROUP **Wessels (Tw), Budin (Tb), Eden (Te), Mokalanen (T-Qm), Obobogorop, Gordonia (Qg) and Lonely Formations**	Fluvial gravels, sands, lacustrine and pan mudrocks, diatomites and diatomaceous limestones, evaporites, consolidated to unconsolidated aeolian sands, pedocretes (especially calcrete) Late Cretaceous to Recent <90 Ma → 0 Ma	Palynomorphs, root casts (rhizomorphs / rhizoliths) and burrows (*eg* termitaria), rare vertebrate remains (mammals, fish, ostrich egg shell *etc*), diatoms, freshwater stromatolites, freshwater and terrestrial shells (gastropods, bivalves), ostracods, charophytes	Fossils mainly associated with ancient pans, lakes and river systems Palaeontology poorly studied. Basal Late Cretaceous gravels and lacustrine clays probably fossiliferous (bones, teeth, petrified wood, palynomorphs?) but v. rarely exposed.
17. COASTAL CRETACEOUS SEDIMENTS **Not marked on map (no surface exposure)**	fluvial and lacustrine deposits of limited extent, not exposed at surface (*eg* incised channel fills, Kleinzee area) ?Early to Late Cretaceous	palynomorphs (pollens, spores), marine microfossils, macroplant remains reworked silicified podocarp wood occurs within Caenozoic raised beach deposits	In some cases conflicting age data from different fossil groups Extensive occurrences of Early to Late Cretaceous petrified wood, logs offshore of Kleinzee-Port Nolloth coast
16. KIMBERLITES AND OTHER POST-KAROO IGNEOUS ROCKS, ASSOCIATED CRATER LAKE SEDIMENTS ***eg* Sutherland Suite (Ksu), Gamoep & Garies volcanic pipe swarms of Bushmanland / Namaqualand Province, Koegel fontein Complex**	Kimberlite / olivine melilitite / carbonatite volcanic pipes and related intrusions, sometimes associated with lacustrine sediments (deep to shallow crater lakes), granite plutons and related intrusions (Koegel Fontein complex, Early Cretaceous) Jurassic, Cretaceous to Palaeocene *c.* 200-60 Ma	Bryophytes, vascular plants (leaves, wood, fruit), fish, pipid frogs (adults, tadpoles), reptiles (tortoises, lizards), rare dinosaurs, birds (ratites), insects, ostracods, palynomorphs (bryophytes, ferns, gymnosperms, angiosperms) within crater lake sediments	Biotas (especially palynomorphs) important for reconstruction of climate and vegetation change during post-Gondwana times Key crater lake fossil localities at Stompoor, Kangnas (Late Cretaceous) and Banke (Palaeocene?), Bushmanland Plateau). Fossiliferous crater sediments also at Salpeterkop, Sutherland (Late Cretaceous).
15. KAROO DOLERITE SUITE **(Jd)** Early Jurassic (182-183 Ma)	Intrusive dolerites (dykes, sills), associated diatremes	NO fossils recorded	Massive igneous activity (dolerite intrusion, basaltic volcanism) of Karoo-Ferrar Large Igneous Province preceded break-up of Gondwana and may have caused Early Jurassic extinction event (183Ma)

KAROO SUPERGROUP (UNITS 12 TO 14 BELOW)				
14. BEAUFORT GROUP Late Permian – Early Triassic *c.* 266 – 250 Ma	**14b. Tarkastad Subgroup (Trt)** **Katberg Fm (Trk)** Early Triassic	Fluvial, as below, with higher abundance of channel sandstones (braided rivers) and reddish mudrocks	As below, but post-extinction fauna features greater variety of amphibians, diapsid reptiles, cynodonts whereas most other tetrapod groups are less diverse (*eg* no gorgonopians, dinocephalians, pareiasaurs). Tetrapod burrows common. *Glossopteris* Flora replaced by abundant horsetails, *Dicroidium* Flora.	Biota in N. Cape assigned to single Early Triassic assemblage zone. Documents post-mass extinction recovery fauna of early Triassic Period.
	14a. Adelaide Subgroup **Abrahamskraal Fm (Pa)** **Teekloof Fm (Pt, Ptp, Pth, Pto)** **Balfour Fm (Pb)** Late Permian – Early Triassic	Fluvial sediments with channel sandstones (meandering rivers), thin mudflake conglomerates interbedded with floodplain mudrocks (grey-green, purplish), pedogenic calcretes, playa lake and pond deposits, occasional reworked volcanic ashes	Diverse continental biota dominated by a variety of therapsids (*eg* dinocephalians, dicynodonts, gorgonopsians, therocephalians, cynodonts) and primitive reptiles (*eg* pareiasaurs), sparse *Glossopteris* Flora (petrified wood, rarer leaves of *Glossopteris*, horsetail stems), tetrapod trackways, burrows & coprolites. Freshwater assemblages include temnospondyl amphibians, palaeoniscoid fish, non-marine bivalves, phyllopod crustaceans and trace fossils (esp. arthropod trackways and burrows, "worm" burrows, fish fin trails plant rootlet horizons).	Richest Permo-Triassic tetrapod fauna from Pangaea / Gondwana. Key evidence for evolution of mammalian characters among therapsids. Best continental fossil record documenting two Late Permian Mass Extinction Events (260Ma, 252 Ma). Biota assigned to six successive assemblage zones, each with specific temporal range and of value for interbasinal correlation.

13. ECCA GROUP Early – Mid Permian (290 – 266 Ma)	**13g. Waterford Fm (Pwa/Pw=Pko, Pc in part)**	Prodelta to delta plain sediments	Low diversity non-marine trace assemblages (especially arthropod scratch burrow *Scoyenia*), common petrified logs (silicified/ calcified), twigs and other remains of *Glossopteris* Flora (*eg* horsetails), palaeoniscoid fish scales, rare rolled fragments of tetrapod bone (probably from large temnospondyl amphibians)	Now includes previously named Koedoesberg (Pko) & Carnarvon Fms (Pc) Several genera of non-marine bivalves recorded from the W.Cape
	13f. Kookfontein Fm (Pk)	Offshore non-marine mudrocks with distal deltaic sediments	Impoverished trace fossil assemblages, disarticulated fish scales, silicified wood, comminuted plant debris	
	13e. Skoorsteenberg Fm (Ps)	Turbidite (submarine fan) deposits – fine sandstones greywackes and mudrocks	Localy abundant plant debris (petrified logs, twigs, leaves, rooting and fruiting structures of *Glossopteris* Flora), rare palaeoniscoid fish, disarticulated microvertebrates (scales, teeth, bones), palynomorphs (spores, gymnosperm pollens), rare bivalves, non-marine trace fossils (as below).	These sediments are of considerable research interest as model for oil-bearing sucessions elsewhere in world.
	13d. Tierberg Fm (Pt)	Offshore non-marine mudrocks with distal turbidite beds, prodeltaic sediments	Disarticulated microvertebrate remains (*eg* fish teeth, scales), sponge spicules, spare vascular plants (leaves, petrified wood), moderate diversity trace fossil assemblages (as below *plus* variety of additional taxa such as large ribbed pellet burrows, arthropod scratch burrows, *Siphonichnus etc*)	Ecca Sea traces are among most diverse and best preserved non-marine ichnofaunas from Gondwana. Doubtful stromatolites also recorded.

	13c. Collingham Fm (Pc)	Offshore non-marine mudrocks with numerous volcanic ashes, subordinate turbidites	Low diversiy but locally abundant ichnofaunas (horizontal “worm” burrows, arthropod trackways), vascular plant remains (petrified and compressed wood, twigs, leaves *etc*).	Trackways of giant water scorpions over 2m long recorded from W. Cape.
	13b. Whitehill Fm (Pw)	Carbonaceous offshore non-marine mudrocks within minor volcanic ashes, dolomite nodules	Mesosaurid reptiles, rare cephalochordates, variety of palaeoniscoid fish, small eocarid crustaceans, insects, low diversity of trace fossils (*eg* king crab trackways, possible shark coprolites), palynomorphs, petrified wood and other sparse vascular plant remains (*Glossopteris* leaves, lycopods *etc*)	High carbon content of mudrocks probably derived from phytoplankton blooms. Anoxic quiet-water bottom conditions promoted frequent preservation of intact skeletons of animal life. Distinctive Ecca Sea fauna also found in S.America – early historical evidence for Gondwana supercontinent. Coeval with Ecca Coal Measures of Gauteng, KZN (Vryheid Fm).
	13a. Prince Albert Fm (Ppr)	Marine to hyposaline basin plain mudrocks, minor volcanic ashes, phosphates and ironstones, post-glacial mudrocks at base	Low diversity marine invertebrates (bivalves, nautiloids, brachiopods), palaeoniscoid fish, sharks, fish coprolites, protozoans (foraminiferans, radiolarians), petrified wood, palynomorphs (spores, acritarchs), non-marine trace fossils (especially arthropods, fish, also various “worm” burrows), possible stromatolites, oolites	Transition from marine to brackish salinities early in history of epicontinental Ecca Sea. Marine body fossils rare (*eg* Douglas area) Biogenic origin of “stromatolites” within carbonate rocks needs confirmation.

12. DWYKA GROUP (C-Pd) Late Carboniferous – Early Permian *c*. 320-290 Ma	**12c. Mbizane Fm** Early Permian	Varied glacially-related sediments, including valley glacier deposits (tillites, conglomerates, sandstones mudrocks)	Low diversity non-marine trace fossil assemblages (predominantly fish, arthropod traces, *Rhizocorallium*) scattered vascular plant remains (*eg Glossopteris* leaves, petrified wood)	Restricted to N. margin of Main Karoo Basin. Overlies basement (N)or Elandsvlei Fm (S). Reports of stromatolites, oolites in limestone lenses require confirmation.
	12b. Elandsvlei Fm Late Carboniferous – Early Permian	Predominantly massive tillites, with interglacial mudrocks at intervals	Interglacial mudrocks occasionally with low diversity marine fauna of invertebrates (molluscs, starfish, brachiopods, coprolites *etc*), palaeoniscoid fish, petrified wood, leaves (rare) and palynomorphs of *Glossopteris* Flora. Well-preserved non-marine ichnofauna (traces of fish, arthropods) in laminated mudrocks. Possible stromatolites, oolites at top of succession.	Main Dwyka subunit within south and central portion of Main Karoo Basin. Body fossils v. rare. Richer interglacial & postglacial biotas recorded from southern Namibia (*eg Eurydesma* fauna) and may eventually be traced into N. Cape. Reports of stromatolites require confirmation.
	12a. "Red Dwyka" Late Carboniferous (>300Ma)	Glacial tillites, proglacial outwash sandstones & conglomerates, glaciolacustrine mudrocks *etc*.	Well-preserved, non-marine trace fossil assemblages (mainly of fish, arthropods), sparse *Glossopteris* Flora plant remains (wood, twigs, leaves)	This unit occurs just south of Orange River, extending into S. Namibia. Underlies Elandsvlei Fm.
CAPE SUPERGROUP (UNITS 9-11 BELOW)				
11. WITTEBERG GROUP (Weltevrede Subgroup)	**11c. Swartruggens Fm (Ds)**	Shallow, storm-dominated shelf siliciclastics, principally sandstones in Dbl but with abundant mudrock interbeds in Dwa and Ds	Low diversity trace fossils (esp. *Spirophyton*)	Restricted, v. high palaeolatitude biotas shortly preceding Late Devonian Gondwana glaciations and extinctions
	11b. Blinkberg Fm (Dbl)		Transported lycopod stems common. Low diversity trace fossils.	

	11a. Wagen Drift Fm (Dwa)	Mid to Late Devonian	Sparse shelly invertebrate faunas (brachiopods, molluscs *etc*), rare fish remains (acanthodians, placoderms, sharks, ?bony fish), transported vascular plants (lycopods), low diversity ichnoassemblages (esp. *Spirophyton*), probable microfossils (*eg* palynomorphs)	Shelly biotas and fish so far only recorded to south of N. Cape Province.
10. BOKKEVELD GROUP	**10b. Bidouw Subgroup** **(Dwb, Dwu, Dkl,Do, Dka)** Mid Devonian	Alternating mudrock- and sandstone- dominated packages reflecting offshore shelf to restricted coastal sedimentation (deltaic / estuarine?)	Shelly marine invertebrates only abundant in basal beds (Waboomberg Fm, Dwb), and locally in Karoopoort Fm (Dka). Important low diversity, non-marine fish fauna in Klipbokkop Fm (Dkl) – acanthodians, placoderms, sharks, crossopterygians, with non-marine bivalves. Ubiquitous, low-diversity trace fossil assemblages (*eg Spirophyton*). Vascular plants common (lycopods, possible psilopsids and progymnosperms).	Diverse mud-smothered invertebrate communities in Waboomberg Fm. Mid Devonian Klipbokkop ichthyofauna of bostratigraphic and palaeogeographic significance (high palaeolatitudes). Most fish records so far from W. Cape, but similar faunas expected in N. Cape as well.
	10a. Ceres Subgroup **(Dg, Dga, Dv, Dh, Dt/Dtr, Dbo)** Early to Mid Devonian	Alternating mudrock- and sandstone- dominated packages reflecting offshore and nearshore shelf sedimentation along a storm-influenced coastline.	Rich shelly invertebrate assemblages (especially in Dg, Dv) dominated by trilobites, brachiopods, mollusc and echinoderms, with many other minor groups (*eg* rare fish remains) microfossils (*eg* ostracods). Sparse transported plant remains (mainly lycopods possible psilopsids). Rich variety of trace fossils	Typical Malvinokaffric cold water biotas of Gondwana. Southern outcrops, especially of mudrock units, are richer in shelly remains. Include exceptionally well-preserved beds of mud-smothered invertebrates (especially intact echinoderms) Northern outcrops are dominated by trace fossils – including some of the most diverse trace assemblages from Gondwana.

9. TABLE MOUNTAIN GROUP	**9f. Rietvlei Fm (Dr)** Early Devonian	**Nardouw Subgroup** Braided fluvial pebbly sandstones with rare mudrocks in thin, shallow marine- /estuarine-influenced parts of succession	Sparse marine / estuarine /?fluvial trace fossil assemblages (trilobite burrows, *Skolithos* "pipe rock", horizontal burrows) within more mudrock-rich part of succession	Low diversity, brachiopod-dominated shelly faunas recorded from eastern outcrop area (outside N. Cape)
	9e. Skurweberg Fm (Ss) Silurian			
	9d. Goudini Fm (Sg) Early Silurian			Limited outcrops in N. Cape
	9c. Cederberg Fm (Ow) Late Ordovician	Post-glacial mudrocks (**Soom Member**) grading up into shallow marine sandstones(**Disa Member**)	**Soom Member** with moderately diverse marine biota of various microfossils, "algae", soft-bodied and shelly invertebrates (eurypterids, trilobites, nautiloids, brachiopods *etc*), primitive jawless fish, some showing exceptional soft tissue preservation. **Disa Member** with low-diversity shelly invertebrate dominated by brachiopods, also rare molluscs, trilobites, shallow marine trace fossil assemblages	World-famous post-glacial Cederberg biota not recorded yet in N. Cape – but almost certainly only due to insufficient exposure.
	9b. Pakhuis Fm (Ow) Late Ordovician	Sandy and muddy glacial diamictites (tillites)	V. rare interglacial / post-glacial trace fossils	Global mass extinctions correlated with two short end Ordovician glaciations on Gondwana
	9a. Peninsula Fm (Op) Early – Late Ordovician	Fluvial sandstones, quartzites, subordinate mudrocks within thin marine / estuarine intercalations	Sparse shallow marine / coastal /estuarine to freshwater trace fossils, including eurypterid trackways, trilobite burrows	N. Cape outcrop v. limited (Bokkeveld Plateau)
8. KUBOOS-BREMEN SUITE (CAPE GRANITE SUITE *etc* on map) (Cku, Csw,Ct)		Granites Cambrian *c.* 500 Ma	NO FOSSILS RECORDED	Igneous intrusions related to birth of supercontinent Gondwana through continental collisions

7. VANRHYNSDORP GROUP	**7d. Brandkop Subgroup (Cvz, Cst, Ckl)** Early Cambrian	Shallow marine, nearshore and fluvial silicicastics typically reddish in colour	Abundant, low-diversity trace fossil assemblages dominated by *Trichophycus* / *Treptichnus* ispp. Arthropod (trilobite?) scratch traces (*eg Monomorphichnus*) controversially present.	Key successions for body and trace fossils spanning the critical Precambrian (Ediacaran) / Cambrian boundary Stratigraphic position of lenticular carbonate units (Besonderheid Formation?) with large columnar stromatolites not clearly established. Top of succession probably does not extend into trilobitic Early Cambrian (controversial)
	7c. Knersvlakte Subgroup (Ngb, Nbs, Nkg, Ndo, Nas) Ediacaran to Early Cambrian	Shallow to offshore marine siliciclastics, with rare carbonates	Abundant but low diversity trace fossil assemblages *eg* large horizontal burrows, *Oldhamia*, *Treptichnus*, ?*Monomorphichnus*. Large columnar stromatolites, possible vendobiontan tool marks, microbial mats	
	7b. Kwanous Subgroup (Nar) Ediacaran	Shelf limestones and mudrocks	Oncolites, simple horizontal burrows, possible tubular shells (*Cloudina*?), microbial mats, vendotaenid cyanobacterial strings	
	7a. Flaminkberg Formation (Nfl) Ediacaran	Coarse sandy and pebbly river sediments	Possible trace fossils (rare, unconfirmed)	

6. NAMA GROUP Siliciclastic and carbonate sediments, largely undeformed and with v. low grade metamorphism Latest Proterozoic (Ediacaran) to Early Cambrian <550 Ma – c. 540 Ma	**6c. Fish River Subgroup**	braided river and shallow marine / intertidal siliclastics (no limestones) of Stockdale, Breckhorn (**Nb**) and Nababis (**Nn**) formations, typically reddish-brown in colour	Abundant but very low diversity trace fossils assemblages dominated by *Treptichnus,* simple horizontal burrows; unambiguous arthropod traces not recorded.	Classic early Cambrian (pre-trilobitic) trace fossil assemblages, possibly coeval with Brandkop Subgroup of Vanrhynsdorp Group succession.
	6b. Schwarzrand Subgroup (Nnd, Nna, Nhn) Nudaus & Urusis Formations	coastal, shallow marine and offshore siliciclastics, carbonate shelf sediments (stromatolitic reefs)	Shelly invertebrates (*Cloudina*), large domical and small columnar stromatolites, thrombolites, vendotaenids (cyanobacterial strings), rare trace fossils, cyanobacterial wrinkle structures (*Arumberia etc*), microbially-bound intraclasts ("sand buttons" / *Vendella* / *Beltanelliformis*, "sand chips" *etc*)	Spectacular large stromatolites in Huns Member (Urusis Fm) Vendobiontans expected in marine units (as found in Nama Group of S. Namibia, Cango Caves group of Little Karoo) but not yet recorded from Nama succession of RSA Also expect range of other Edicaran fossil groups such as acritarchs, agglutinated tubules (*Archaeichnium*) , calcified metaphytes (algae), sponges, colonial tubular organisms *etc*
	6a. Kuibis Subgroup (Nui, Nng, Npl, Nz) Dabis & Zaris Formations	shallow marine to braided fluvial siliciclastic sediments (Dabis Fm) and shallow marine to coastal limestones siliclastics (Zaris Formation) low levels of deformation and metamorphism	Primitive shells (*Cloudina*, *Namacalathus*), conical stromatolites (*Conophyton*) in limestones, cyanobacterial mat wrinkle structures (*Arumberia etc*) in intertidal quartzites	Among first records of shelly invertebrates in the world Vendobiontans possibly present in marine units, but not yet recorded

5. GARIEP SUPERGROUP Late Proterozoic (Cryogenian – Ediacaran) <770 Ma - >550 Ma	**5c. Gifberg Group (Vredendal Inlier) (Nkr, Nwi, Nat, Nbp)**	low grade metasediments (marine carbonates, siliciclastics, tilites, iron formation), volcanics	Domical stromatolites in Bloupoort Formation (Nbp)	Southern equivalent of Port Nolloth Group Palaeontology poorly known Two Snowball Earth major glaciation events Probable origins of first Metazoa (multicellular animals) in this period
	5b. Marmora Terrane	low grade metasediments (marine siliciclastics, carbonates), metavolcanics	Deformed stromatolites, oolites, pisolites in Gais member of Grootderm Formation	Displaced fragment of oceanic crust Carbonates formed in oceanic atoll setting
	5a. Port Nolloth Group (Nkk, Nl, Nka, Nvr, Nho)	low grade metasediments (marine shelf carbonates, siliciclastics, tilites, iron formation), volcanics	Hilda Subgroup: deformed stromatolites, oolites in Dabie River Formation, acritarchs in Wallekraal & Pickelhaube Formations Holgat Formation: acritarchs & agglutinated foraminiferans	Two Snowball Earth major glaciation events Probable origins of first Metazoa (multicellular animals) in this period – *eg* early sponge fossils from Namibia Most recorded fossil localities in Southern Namibia but similar biotas expected in N. Cape
4. NAMAQUA METAMORPHIC PROVINCE large number of subunits (M*….)		Igneous and metamorphic rocks (including high grade metasediments) Early to Mid Proterozoic (Mokolian) *c.* 2-1 Ga	NO FOSSILS RECORDED	Check map keys to identify metamorphic and igneous rocks
3. OLIFANTSHOEK SUPERGROUP (Ml, Mb, Mf, Mel, Mgl, Mve, Mt) Early Proterozoic (Mokolian) *c.* 1.9 Ga		Predominantly continental "red beds" (fluvial sediments), subordinate shallow marine siliciclastic metasediments (low grade), lavas, carbonates	Possible stromatolites, microfossils in marine units *eg* Lucknow Formation carbonates (Ml), Top Dog Formation shales (Mt)	• Continental "red beds" record development of early oxygen-rich atmosphere • Laterites (Gamagara Formation) suggest possible biological activity on land

2. TRANSVAAL SUPERGROUP Dominantly shallow marine carbonate metasediments (low grade), deeper water BIF (ironstones, chert), subordinate siliclastic sediments, volcanics, tillites Late Archaean / Early Proterozoic (Vaalian) *c.* 2.6-2.2 Ga	**2c. Postmasburg Group (Vm, Vo)**	Glacial diamictites (tillites), volcanic lavas, dolomites, ironstones Early Proterozoic c. 2.2 Ga	Stromatolites in Mooidraai Formation carbonates	Controversial records of 2.2 Ga “trace fossils” in equivalent beds of Transvaal Supergroup (Transvaal Basin) Makganyene Formation records major early Proterozoic glaciation at low palaeolatitudes
	2b. Ghaap Group large number of subunits (V*…) Includes Schmidtsdrift, Campbell Rand & Asbestos Hills Subgroups	Carbonates with siliciclastics, iron formations Late Archaean / Early Proterozoic c. 2.56 Ga	Range of shallow marine and lacustrine stromatolites (some v. large), oolites, pisolites in carbonates, filamentous and coccoid organic-walled microfossils (*eg* cyanobacteria) in siliciclastics / carbonates as well as cherts of banded iron formations (BIF): Schmidtsdrift, Campbell Rand & Asbestos Hills Subgroups	Formations with carbonate rocks (eg Vb, Vc, Vgd, Vu, Vf, Vh, Vsb, Vsm, Vgu, Vgf) are most palaeontologically sensitive. Classic Early Proterozoic stromatolitic successions and cyanobacterial microfossils (Ghaap & Postmasburg Groups of Griqualand West Basin). Early continental shelf environments (margins of Kaapvaal Craton).
	2a. Vryburg Formation (Vv, Vvk, Vvg)	Lavas, siliciclastics, carbonates 2.64 Ga	Stromatolites in carbonates	

1. VENTERSDORP SUPERGROUP Lavas, tuffs interbedded with metasediments (fluvial & lacustrine siliciclastics, chert, dolomite) Neoarchaean (Randian) *c.* 2.7 Ga	**"Pniel Sequence":** **Allanridge Fm (Ra)** **Bothaville Fm (Rb)**	**Bothaville Formation** (**Rb**) siliciclastics (conglomerates, quartzites), tuffs basalt, andesite lavas	Conical stromatolites	Very early record of non-marine benthic life Organic-walled microfossils possibly present (not yet recorded) LIP (Large Igneous Province) voluminous basaltic eruptions Stromatolites recorded from borehole cores in Free State, but also expected in N. Cape
	Platberg Group: **Kameeldoorns Fm (Rka)** **Makwassie Fm (Rm)** **Rietgat Fm (Rr)**	**Rietgat Formation** (**Rr**) – lavas, tuffs, siliciclastic sediments, stromatoliitic limestones, cherts **Kameeldoorns Fm (Rka)** – varied siliciclastic sediments with limestones and cherts above	Small branching lacustrine stromatolites, ooids in carbonates in Rietgat Formation Stromatolites in Kameeldoorns Fm in NW Province, possibly also in N Cape	
	Klipriviersberg Group (Rk)	lavas	No fossils recorded	

NOTES:

1. For Precambrian units, only fossiliferous formations are considered individually in the table. There are also a large number of igneous and metamorphic rock units of negligible palaeontological sensitivity that can be identified as such from the 1: 250 000 map keys (*NB* Need to know common rock types – consult geological dictionary or elementary textbook)

2. For Proterozoic successions with a large number of formations, controversial stratigraphy and poor mapping control at 1: 250 000 scale, only major subunits (eg subgroups) are named in the table (*eg* Transvaal Supergroup: subdivisions on published maps are often outdated *cf* Geology of South Africa volume, 2006. Several relevant maps still not published).

3. Formational names are not used on the Clanwilliam 1:250 000 sheet (3218). Symbols used in the table are those from more recent geological maps, and will be used on revised Clanwilliam sheet (expected 2008/ 2009).

PALAEONTOLOGICAL SIGNIFICANCE OF ROCK UNITS

COLOUR OF ROCK UNIT	PALAEONTOLOGICAL SIGNIFICANCE / VULNERABILITY	RECOMMENDED ACTION
RED	very high	field scoping study recommended before excavation takes place
PURPLE	high	desk top study + scoping study may be necessary
GREEN	moderate	desk top study
BLUE	low	no action required (any fossil finds to be reported by developer)
BLACK	insignificant or zero	no action required

NB.1. **These significance / vulnerability ratings are *provisional***

NB.2. **Some rock units are largely unfossiliferous, but have thin subunits of high palaeontological significance (*eg* Table Mountain Group).**

6. HISTORY OF PALAEONTOLOGY IN THE NORTHERN CAPE

This section of the report presents a brief, and somewhat selective, historical account of some of the major palaeontological discoveries and developments in the Northern Cape. The review presented is neither chronological nor stratigraphic in design. Instead, major segments of the Cape fossil record are treated more or less in the order in which they first received scientific attention. Please note that full references for this section have not yet been collated in the bibliography provided at the end of the report.

1. Prehistoric records

For thousands of years the Khoi-San hunter-gatherer and herder peoples of the Northern Cape must have been aware of fossilised bones, teeth and strange animal tracks, either embedded in rocks or lying exposed on the ground. These indigenous peoples are renowned as acute observers and interpreters of nature. Nevertheless, the biological affinities of these fossil remains need not have been patently obvious to them, just as the biological origins of fossils were not widely accepted in Europe until the late seventeenth century (Rudwick, 1976). In the case of unfamiliar, long-extinct groups of marine organisms, such as stromatolites or trilobites, this may be unsurprising. It is difficult to believe, however, that the highly skilled trackers of the Later Stone Age were not drawn to "read" some of the exceptionally well-preserved vertebrate trackways found in the Karoo in terms of the passage of four-footed, animal-like beings. Of course, they would have recognised that these beings could not have been any of the Karoo animals with which they were already very familiar, none of which, besides, was capable of imprinting solid rocks. It is conceivable that some sort of supernatural significance might have been attributed to these puzzling fossil phenomena. Perhaps they were even seen as traces of visitors in animal form from another spirit world, hidden beneath the seemingly impenetrable rocky surface of the Karoo. Unfortunately, we shall probably never know.

2. Coastal Caenozoic

The record of scientific palaeontology in the Northern Cape extends back as far as the late eighteenth century, before fossils were formally recorded from any other region of South Africa. In 1779 the famous naturalist-explorers Mr William Paterson and Colonel Robert Gordon noted the presence of fossil shells in marine deposits on top of coastal cliffs near Port Nolloth while *en route* north to the "Great River" (Orange). They also distinguished between these raised beach deposits, now recognised as the Pliocene Avontuur Formation, and shell middens of anthropogenic origin (Forbes & Rourke, 1980, Raper & Boucher 1988, Pether 1994). Paradoxically, given this promising early start, the rich Caenozoic palaeontology of the Namaqualand coast has been sadly neglected since Gordon and Paterson's times. There are a few early papers on coastal Caenozoic marine invertebrates and mammals by Haughton (1928, 1932) and Stromer (1931). Wagner and Merensky (1928) recognised the significance of fossil molluscs (the so-called "Oyster Line") as biomarkers for exceptionally diamond-rich deposits near Alexander Bay (see also Reuning 1931, Du Toit 1954). Work by John Pether and colleagues over the past couple of decades has revealed a wealth of unstudied palaeontological resources along the Namaqualand coast, much of which is threatened by mining (Pether 1994, Pether *et al.* 2000, Roberts *et al.* 2006 and refs. therein).

3. Dwyka and Ecca Groups

The majority of nineteenth century records of fossils from the Northern Cape concern the diverse aquatic and terrestrial biotas of the Main Karoo Basin in the south of the province. In 1803 the naturalist H. Lichtenstein described fossil "eel-fish" up to a metre long from Ecca Group sediments at Onder Downes near Calvinia (Anderson 1974, MacRae 1999). These "fish" are actually peculiar band-shaped fossil burrows with prominent, curved cross-ridges that presumably reminded Lichtenstein of ribs. The surprisingly diverse non-marine trace fossils of the Dwyka and Ecca Groups were noted by Abel (1935) and comprehensively reviewed by Anderson (1974) in her thesis and a series of later papers. Important Ecca trace assemblages have been recorded from the Tanqua Karoo and Roggeveld Escarpment area more recently by Wickens (1996 and earlier reports).

In about 1835 the Frenchman Alexis Verreaux acquired the first recorded specimen of the small aquatic reptile *Mesosaurus* from the lower Ecca Group. It was preserved on a slab of rock that was apparently being used as a pot lid in a Griqua hut near Kimberley (MacRae 1999). This became the type specimen of *Mesosaurus*, finally described by Gervais in 1865 and now housed in the Musée d'Histoire Naturelle in Paris. Numerous mesosaurid specimens were described from the Whitehill Formation across the Northern Cape in the late nineteenth and early twentieth century by workers such as Guerich (1889), Seeley (1892) and Broom (1904, 1908, 1913; see McLachlan & Anderson 1973). Identical fossils were also discovered in the Iratí Formation of Brazil in 1886. Mesosaurid reptiles subsequently played an important role as key fossil evidence for the ancient supercontinent Gondwana (*cf* Du Toit 1954). The other famous fossils shared by the Whitehill and Iratí Formations, the pygocephalomorph crustaceans, were only discovered in South Africa in 1909 (Rogers & Du Toit, 1909), with important later studies on Kimberley specimens by Woods (1922) and Broom (1931; *cf* McLachlan & Anderson 1973). Palaeoniscoid fish were described from Whitehill rocks in the Calvinia area by Broom in 1913 (*cf* Evans & Bender 1999). A recent benchmark study on the Whitehill Formation biota, including important Northern Cape material, is the doctoral thesis by Oelofsen (1981).

Numerous fossil plant records from the western outcrops of the Dwyka and Ecca Groups of the Northern Cape were also made around the turn of the century, many of them by geologists of the Geological Commission of the Cape of Good Hope such as A.W. Rogers, E.H.L. Schwarz and the famous South African geologist Alex du Toit, who was also a competent palaeobotanist (*cf* Anderson & McLachlan 1976, Anderson & Anderson 1985). Abundant petrified wood was noted in the Ecca by early survey geologists such as A.W. Rogers (1909). Key early systematic work on such material from the Main Karoo Basin (*eg* Van Wyks' Vlei, and Norokei Pan in Gordonia), was published by Walton (1925) and has been updated recently by Bamford (1999).

4. Beaufort Group

The first recorded finds of fossil vertebrate remains from the Beaufort Group were made in the Beaufort West area of the Western Cape in the 1820s. From the late 1830s onwards exciting discoveries of pareiasaurs, dicynodonts and other previously unknown tetrapods were made by the well-known road engineer and amateur geologist Andrew Geddes Bain. Bain's material, most of which ended up in the Natural History Museum, London, came from the "reptiliferous beds" of the Eastern Cape and elsewhere in the Great Karoo (*eg* Bain 1856a, b). Consequently A.G. Bain is often honoured as the "Father of South African Palaeontology". Readable accounts of the early pioneers of Karoo vertebrate palaeontology, including outstanding characters such as Bain himself, Robert Broom, Alex Du Toit, Sydney Rubidge and many others, have been given by Rogers (1937), Cluver and Barry (1977) and MacRae (1999). Authoritative perspectives on the early phase of Karoo vertebrate palaeontology up to the mid twentieth century are provided by Broom in Rogers (1909), Haughton (1919), Von Heune (1925), Broom (1932) and Du Toit (1954). In these key works, Von Heune (1925) gives a teutonically systematic account of the distribution of Karoo fossils within the various biozones recognised at the time, Broom (1932) traces the ancestry of mammals among the ancient Karoo therapsids, while Du Toit (1954) places the Karoo fossils within a broader Gondwanan context – long before continental drift was taken seriously by most geologists. A simple, tripartite fossil zonation of the Beaufort succession was proposed by H.G. Seeley as early as 1892, and more elaborate biostratigraphic schemes were erected by Broom and D.M.S. Watson in the early years of the twentieth century (Rubidge 1995).

Since locality information is rarely provided, it is unfortunately impossible to follow the early history of Karoo palaeontology in the Northern Cape from the sources listed above. This would entail reviewing the vast volume of primary palaeontological literature and older museum collection records. Several early Karoo fossil collections have also gone missing, or are now housed abroad (notably Bain's material in London, Broom's stolen specimens in New York, and Von Huene's specimens in Tũbingen). An important early collector in the Northern Cape was the Government Geologist of the Cape Colony, Andrew Wyley, who undertook a long geological journey through the region in 1857-1858 (Rogers 1937). Numerous fossil bones (all lumped together as *Dicynodon*) and plants were apparently collected *en route*. The eminent German palaeontologist Friederich Von Huene also travelled extensively in the interior and published useful biostratigraphical lists of Karoo fossils found by previous workers in the various districts of the Northern Cape (Von Heune 1925). They include a range of palaeoniscoid fish, labyrinthodont amphibians, pareiasaurs, dicynodonts, therocephalians, and other therapsids from the districts of Fraserburg, Victoria West, Richmond, Hanover and Colesburg. These specimens were mainly collected by workers such as H.G. Seeley in the 1890s as well as by Robert Broom and S.H. Haughton in the first two decades of the twentieth century. Palaeoniscoid fish were described from the Colesburg and Fraserburg Districts by Woodward (1889, 1893) and further fish fossils from Fraserburg by Broom (1913). The famous Blourug fossil fish site near Victoria West was only discovered in the 1940s (Bender 2004). Beaufort Group petrified woods were studied by Walton (1925). Beaufort Group floras, including a few Northern Cape taxa, were reviewed by Du Toit (1954) and compared with Gondwana floras elsewhere.

5. Crater lake biotas

In the early decades of the twentieth century pioneering officers of the geological survey – unlike some of their modern counterparts – were alert to the value of fossils not only for correlation purposes but also for palaeoenvironmental reconstructions. They managed to discover a surprising array of palaeontological material during their challenging reconnaissance excursions into the outer reaches of the Cape Colony. For example, the first (and still almost only) Cretaceous dinosaur remains from the Northern Cape – from a small exposure of crater lake deposits near Goodhouse – were discovered and described by Rogers (1913, 1915) and Haughton (1915). Detailed investigation of slightly younger crater lake sediments in the Arnot Pipe at Banke, Bushmanland led to a series of palaeontological studies on lacustrine and adjacent terrestrial biotas by E. Reuning and colleagues (Reuning 1931, Haughton 1931, Rennie 1931 *etc*). In the late 1980s this work culminated in the influential palynological study of Arnot material by Scholtz (1985) as well as detailed studies of comparable Cretaceous crater lake biotas and sedimentology at Stompoor in Bushmanland by R.M.H. Smith (Smith 1986a,b, 1988, 1995).

6. Caenozoic of the interior

Palaeontological research on Caenozoic biotas of the Northern Cape interior has generally followed in the wake of diamond prospecting and related geological studies on ancient drainage networks (Haughton 1932, Rogers 1937, Du Toit 1954, Klein 1984). Fossil wood, mammal bones and teeth from the famous diamondiferous Vaal River gravels were discussed in a key early paper by the brilliant, but somewhat opaque, English geologist G.W. Stow (1871). A series of palaeontological works on the rich Pleistocene mammalian fauna of the Vaal River gravels in the Barkley West and Windsorton area, including carnivores, elephants, hippos, horses, pigs and other extinct ungulates, by H.B.S. Cooke and others followed (*eg* Cooke 1941, 1947, 1949). The even richer Miocene gravel faunas of the lower Orange River at Arrisdrift were discovered through diamond mining in the 1970s (Pickford & Senut 2003 and refs therein). Regional studies on early drainage networks of the Northern Cape by Malherbe *et al.* (1986) and De Wit (1993) yielded sparse but important fossil material of Caenozoic mammals, petrified wood, freshwater molluscs and trace fossils.

7. Archaean & Early Proterozoic stromatolites

The recognition and description of fossils from the older Precambrian (Archaean / Early Proterozoic) successions in the Northern Cape lagged far behind work on the more obvious and familiar Karoo Supergroup fossils. The first Precambrian stromatolitic limestones identified as such in southern Africa were those described by Young (1932) from the "Transvaal dolomites" (Campbell Rand succession of the Transvaal Supergroup) in the Griqualand West region. In 1934, Young compared the Griqualand West fossils with modern stromatolites growing in tropical seawaters of the Bahamas (See also Young 1940, Young & Mendelssohn 1948). Stromatolites, in this case lacustrine rather than marine, were described by De la Winter in 1963 from the yet older Ventersdorp Group succession on the basis of borehole cores drilled in the Free State.

8. Late Proterozoic– Cambrian biotas

On the whole, early geologists struggled harder and longer to find plausible fossils within the much younger Precambrian successions of the Gariep, Nama and Vanrhynsdorp Groups in the Northern Cape. In 1925 "obscure impressions" and dark string-like structures were noted in shales of the Nama Group in Gordonia (Haughton and Frommurze 1936). They are now identified as cyanobacterial strings or vendotaenids. Large, dome-shaped, concentrically-laminated structures in black Nama limestones near Modderdrif on the Orange River were compared to " giant onions" but recognised as stromatolites rather than petrified vegetables by De Villiers and Söhnge (1959). The first invertebrate fossils from the South African Nama Group – conical shells of the typical Ediacaran genus *Cloudina* from limestones near Vioolsdrif - were reported by Grant only in 1990. A few years later, in the early 1990s, J.E. Almond and P. G. Gresse discovered abundant goblet-shaped shells south of Vioolsdrif that were later described from Namibia by Grotzinger *et al.* (2000) as *Namacalathus*. Diagnostic Early Cambrian trace fossils of the ichnogenus *Phycodes* (now *Treptichnus*) were reported from the Vanrhynsdorp Group near Nieuwoudtville by G.J.B. Germs in 1973. Large conical stromatolites and a range of trace fossils spanning the Precambrian / Cambrian boundary were later described from the Vanrhynsdorp Group by Gresse (1992). The importance of the thick, trace fossil-rich

Vanrhynsdorp succession for biostratigraphic correlation of the Precambrian / Cambrian boundary and for understanding behavioural evolution among burrowing invertebrates leading up to and following the Cambrian Explosion of multicellular life has only recently been recognised (Buatois 2007, Almond 2008).

9. Cape Supergroup

Rich shelly invertebrate assemblages have been recorded from the Devonian Bokkeveld Group of the Western Cape since the 1830s (Rogers 1937, MacRae 1999). However, palaeontological attention only extended over the entire outcrop area of the Cape Supergroup, including the southern margins of the Northern Cape, in the late 1960s and 1970s. This research initially centred round benchmark theses by a cohort of pioneering geology research students from the University of Stellenbosch. Rust (1967) discovered numerous trace fossil localities in the often rugged terrain of the Table Mountain Group, including several key sites in the Nieuwoudtville area of the Northern Cape. Theron (1970, 1972) recorded for the first time the remarkably rich trace fossil assemblages, and sparser shelly fossils, within the northern outcrop area of the Bokkeveld Group (*eg* Onder Bokkeveld region). The early work of Loock (1967) on the Witteberg Group largely focussed on outcrops in the Western Cape, including the southwestern Tanqua Karoo. Detailed studies of supposed algae and vascular plants (*eg* lower Witteberg lycopods) and from the Cape Supergroup by Plumstead (1967, 1969) are also relevant to Northern Cape outcrop area, although a number of her plant-like fossils (*eg Spirophyton*) have since proved to be traces (*cf* Anderson & Anderson 1985). Serious work on the impoverished but biogeographically important fish faunas in the western outcrop area of the Bokkeveld and Witteberg Groups only commenced in the 1990s (Almond 1997, Anderson *et al.* 1999a,b).

7. OUTLINE GEOLOGICAL HISTORY OF THE NORTHERN CAPE

The geology of the Northern Cape comprises a vast range of sedimentary, igneous and metamorphic rocks that record geological events, evolving environments and biotas over the past 2.7 billion years or so (*c.* 2.7 Ga). Because most of the province currently enjoys a warm, semi-arid climate, rates of chemical and mechanical weathering are low and vegetation cover is usually sparse. Extensive areas of fresh bedrock are therefore exposed at the surface in the interior as well as along the coast. In contrast, equivalent aged rocks in the eastern half of South Africa and elsewhere in the southern hemisphere are often deeply weathered and covered in thick soils and dense vegetation (*eg* South America, India), or lie buried beneath several kilometres of ice (Antarctica). For these reasons, the Northern Cape is not only a wonderful area for exploring southern Africa palaeontology but also a key region for understanding Gondwana geology as a whole. Furthermore, geologically recent (Neogene) uplift of the subcontinent - due to rising hot mantle rocks below the continental crust - has led to the erosive stripping away of much of the younger sedimentary cover to reveal unusually good exposures of very old crustal rocks beneath. The Northern Cape therefore features numerous exceptionally interesting geological localities of Precambrian as well as Phanerozoic rocks. Many of these are localities are worthy of protection and development as informative Geosites in their own right, irrespective of whether or not they host important fossil heritage (Section 9).

The geological history of the Northern Cape is best broken up into a chronological series of chapters, each of which is characterised by distinctive episodes of rock formation. These may involve (a) igneous activity (*eg* granite intrusion, lava eruption), (b) rock deformation (eg folding, faulting) and recrystallisation or metamorphism as a result of continental collision or mountain building, or (c) deposition of discrete packages of surface sediments. The sedimentary rocks are formally organised into a hierarchical system of defined units called formations, groups and supergroups in order of increasing geological significance. All the major rock units present in the Northern Cape (with an emphasis on fossiliferous sediments) are listed in Table 2, and in more detail on Table 3 of Section 5. Bold numbers in brackets (**1**, **2** *etc*) within the text below refer to the major geological units listed in Table 2.

NB This account should be read, if at all, in conjunction with the A4 simplified geological map of South Africa (See end of this section), the simplified stratigraphic column for the Northern Cape (Figure 2.1), as well as the palaeontological database of Northern Cape rock units presented in Tables 5.1 and 5.2 (Section 5). The aim here is to provide a simplified geological context for the fossil biotas listed in the database. For more extensive, accessible accounts of Northern Cape geology and fossils, please consult the recommended general reading list, especially the well-illustrated books by MacRae (1999) and McCarthy & Rubidge (2005). The latter is especially useful for following the confusing pattern of continental movements responsible for much of the Northern Cape's Precambrian geology, while the former provides a more detailed overview of Phanerozoic geology and fossils. A recent comprehensive but technical review of South African geology is given in the volume edited by Johnson *et al*. (2006). A short, illustrated account of Northern Cape geology is available on the webiste of the Northern Cape regional office of the Council for Geoscience.

A. Aftermath of the collision between the Kaapvaal and Zimbabwe Cratons (Ventersdorp Supergroup)

The geological history of the Northern Cape, as recorded by rocks exposed at the surface, begins with the eruption of vast volumes of basaltic lava onto the surface of the Kaapvaal Craton in the latter part of Archaean Eon (*c*. 2.7 Ga). A craton is a thick plate of old continental crust, and the Kaapvaal Craton, which consolidated some three billion years ago, was one of the first continental blocks to form on Planet Earth. The rapid eruption of these lavas – the **Klipriviersberg Group** of the **Ventersdorp Supergroup** (**1**) - may have been provoked by the collision of the Kaapvaal Craton with the Zimbabwe Craton to the north. Relicts of the once thick and extensive outcrop of Ventersdorp lavas, now recognised as one of the world's oldest LIPs (Large Igneous Provinces), are found in the northeastern margins of the Northern Cape near Kimberley. Deeply buried beneath them is the older continental crust of the Kalahari Craton itself.

Later phases of intercratonic collision created several parallel, fault-bound valleys separated by linear mountain chains on the Kaapvaal Craton. The valleys were infilled by a combination of volcanic rocks (lavas and tuffs or ashes) and a range of continental sediments constituting the **Platberg Group**. Limestones and cherts (fine-grained, flinty silica-rich rocks) were deposited within the warm waters of lakes that formed along the valley floors. The limestones contain the oldest macrofossils (*ie* fossils visible with the naked eye) likely to occur in the Northern Cape (but hitherto recorded from boreholes in the Free Statel Fig. 4.1). They are small, branching freshwater stromatolites constructed by communities of photosynthetic microbes such as cyanobacteria ("blue-green algae"). The cherts may well contain well-preserved microfossils, but this has yet to be confirmed. The upper Ventersdorp succession (**"Pniel Sequence"**) also comprises a variety of sediments - mainly siliciclastics such as conglomerates and quartzites eroded from the mountainous uplands, but with some conical stromatolites too (**Bothaville Formation**) – followed by a final pulse of volcanic lavas (**Allanridge Formation**).

B. Flooding of the Kaapvaal Craton with warm continental shelf seas and development of the first oxygen-rich atmosphere (Transvaal & Olifantshoek Supergroups)

Around 2.6 billion years ago, towards the end of the Archaean Eon, subsidence of the Kaapvaal Craton allowed huge areas around its margins to be flooded by shallow seas. These were the first real continental shelf seas in the geological record. Shallow tropical waters favoured the precipitation of vast amounts of carbonate rocks, to a large extent mediated by microbial activity. The carbonate rocks of the **Transvaal Supergroup** (**2**) originally formed as limestones but in many cases they were secondarily altered to dolomites. These "Transvaal dolomites" crop out in the Ghaap Plateau in the northeastern corner of the Northern Cape. Extensive shoals of stromatolites thrived in these tropical seas, especially in shallow, well-lit inshore areas. The highly variable shapes and sizes of the stromatolite domes and columns reflect contrasting environmental conditions as well as the different microbial communities responsible for their construction. Stromatolites are especially prolific in the **Ghaap Group**, but also occur within other subdivisions of the thick Transvaal succession. A range of well-preserved microfossils, including cyanobacteria, is preserved in finer-grained sediments of the Ghaap Group, including carbonates as well as cherts.

Attractive banded iron formations (BIF) occur at several intervals within the Transvaal succession (*eg* **Asbestos Hills Subgroup**, **Postmasburg Group**). These are striking, strongly-laminated sediments composed of regularly alternating bands of iron minerals (*eg* haematite) and chert (*eg* blood-red jasper). The bands are thin but individual layers may extend for tens or hundreds of kilometres. BIFs are especially characteristic of the Early Proterozoic interval between 2.5 and 2.4 Ga. Their abundance then may reflect the initial build-up of free oxygen in the oceans as a consequence of cyanobacterial photosynthesis. The fine sedimentary banding was probably caused by fluctuations in oxygenation, and hence iron solubility, within shallow sea waters. Oxygen levels may have been controlled in turn by seasonal blooms of microbial phytoplankton. Early Proterozoic BIFs as well as extensive manganese deposits are mined in the Northern Cape between Postmasburg and Hotazel (*eg* Sishen, Dingleton).

During the Archaean / Proterozoic boundary interval enormous quantities of CO_2 were drawn down from the primitive, CO_2-rich atmosphere through rapid chemical weathering of continental rocks in tropical climates. Silicate minerals combined with CO_2 to form soluble carbonate compounds that were washed out to sea by rivers. The carbon was then trapped in the crust as carbonate rocks (limestones, dolomites) forming the thick Transvaal succession rather than being recycled back into the atmosphere as CO_2. This massive net removal of atmospheric CO_2 led to global cooling and eventually plunged the planet into a major glacial episode (global icehouse). Water-lain tillites (coarse glacial sediments) within the Postmasburg Group (**Makganyene Formation**) suggest that major ice sheets were present at sea level close to the palaeoequator (6-16º S) around 2.4 Ga, perhaps implying global glaciation at the time. The extensive precipitation of ironstones during this period probably took place from deep, stagnant and anoxic (oxygen-poor) waters beneath floating ice sheets that covered much of the world's oceans. The Makganyene event may be an early example of the planet-wide "Snowball Earth" glacial episodes that have also been postulated for the latest Precambrian or Cryogenian Period (see Subsection D below).

Following the return of warmer climates, renewed photosynthetic activity by prolific cyanobacteria gradually built up the first oxygen-rich atmosphere on Earth over the next half-billion years or so (2.4 to 1.9 Ga). On the Kaapvaal Craton shallow marine conditions with stromatolitic carbonates gave way to a period of uplift, rifting and extensive erosion. Sedimentation by braided river systems formed the **Olifantshoek Supergroup** (**3**) in the west. These rocks crop out in the Northern Cape as a narrow band formed by the Korannaberg and Langberg ranges to the north and south of Olifantshoek itself, to the west of the Ghaap Plateau. The reddish hues of the Olifantshoek fluvial sediments – these count as some of the worlds oldest continental "red beds" - reflect an abundance of "rusty" oxidised iron minerals on land, and hence the development of an oxygen-rich atmosphere, by about 1.9 Ga. Marine intervals within the Olifantshoek succession preserve stromatolites and microfossils. Deeply weathered ferruginous soils (laterites) within the **Gamagara Formation** are considered by some geologists to imply microbial activity on land as well – *ie* the inception of the first terrestrial ecosystems.

C. Complex continental movements culminating in the Supercontinent Rodinia (Namaqua-Natal Metamorphic Belt)

Roughly between two and one billion years ago, a complex - and still poorly understood - succession of tectonic, sedimentary, metamorphic and igneous events along the western and southern margins of the Kaapvaal Craton generated a broad band of high-grade metamorphic rocks and igneous intrusions (*eg* granites) known as the **Namaqua-Natal Metamorphic Belt** (**4**). Since these rocks are uniformly unfossiliferous, they will not be discussed here in detail and are not subdivided in the stratigraphic tables in this report (See McCarthy and Rubidge 2005 for a short, illustrated account). In the Northern Cape today Namaqua-Natal igneous and metamorphic rocks form the spectacular rugged landscapes across much of northern Namaqualand, from the West Coast eastwards along the Orange River to Upington and beyond. Similar tough "basement rocks" also underlie the Karoo Basin in the southern portion of the province as well as the Kalahari Basin in the north.

Around 1.8 Ga convergence and finally collision between the Kaapvaal Craton and the Congo Craton to its northwest compressed the intervening oceanic crust, together with the Olifantshoek and older Kaapvaal sediments, to form the **Ubendian Belt** (Kheis Province). This wide zone of highly metamorphosed, intensely deformed rocks and granitic intrusions would have originally underlain an extensive range of high fold mountains comparable to the modern Himalayas. It essentially represented the glueing or *accretion* of new continental crust onto the northwestern edge of the Kaapvaal Craton. Much of the Ubendian Belt rocks were re-metamorphosed and re-deformed by tectonic events later in the Proterozoic Eon but a narrow band survives more or less unaltered along the Orange River / Gariep between Pofadder and the eastern Richtersveld. Quite separately, a small group of kimberlite pipes – the highly explosive igneous intrusions that brought up diamonds from the upper mantle - were punched up through the crust and overlying Transvaal sediments in the Kuruman area around 1.65 Ga (**Kuruman Kimberlite Province**).

Subsidence and thinning of continental crust between 1.6 and 1.4 Ga created a separate Richtersveld block in the west and an expanded Kaapvaal unit in the east. Marine shelf sediments of the **Bushmanland Group** were deposited within the intervening shallow basin, which was initially still floored by continental crust. Complete rifting of this crust occurred locally (*eg* eastern Namaqualand) to form a narrow arm of a new ocean that now extended along the southern margin of the Kaapvaal Craton. However, by 1.1 Ga these various continental blocks had reversed their motions yet again, re-converging and fusing with one another along an extensive series of highly deformed and metamorphosed collision zones, intruded by granites, known as the **Kibaran Belts**. These local collisions were but a small part of a global series of similar "Grenvillean" events that eventually created the ancient **Supercontinent Rodinia**. Like Pangaea much later in Earth history, Rodinia incorporated more or less all the world's blocks of continental crust into a single, enormous landmass straddling the palaeoequator. Rodinia was criss-crossed by a vast network of high fold mountains. Under these circumstances, rates of chemical weathering and erosion of rocks must have been extremely high, especially in the tropics, leading once again to plummeting CO_2 levels in the Earth's atmosphere and the onset of global icehouse conditions in the Late Proterozoic Era (see next section). The deeply eroded roots of the once lofty Kibaran / Grenvillean mountain ranges of southern Africa are now exposed in the Northern Cape as the Namaqua-Natal Metamorphic Belt.

D. From the fragmentation of Rodinia to the formation of Gondwana (Gariep Supergroup, Nama Group, Kuboos-Bremen Suite)

The **Gariep Supergroup** (**5**) is a very diverse assemblage of highly deformed and metamorphosed marine sediments, including rift- and shelf- related siliciclastics, iron formations and limestones, as well as basaltic igneous rocks. In the Northern Cape these rocks crop out in two separate areas – (a) the northwest coast of Namaqualand and the Richtersveld just south of the Orange River, as well as (b) the Vredendal Inlier area near Vanrhynsdorp, where they just extend into the province along the Bokkeveld Escarpment. The Gariep rocks date back to the roughly 100 million year interval (*c.* 780/770 Ma to 650 Ma) before, during and after the fragmentation of Rodinia which started around 700 Ma. They comprise oceanic crust and shallow shelf to deep sea sediments that formed within the **Adamastor Ocean**. This seaway lay off the western margin of that local portion of Rodinia known as the **Kalahari Craton**.

The Late Proterozoic Era when these events occurred is one of unusual interest because of widespread geological and palaeontological evidence for profound changes in global environments, including climate. These may have included as many as three or four "Snowball Earth" events – *ie* global glacial episodes during which most of the planet was mantled in thick ice sheets. At least two of these glacial events are represented by the **Kaigas Formation** (*c.*750 Ma) and **Numees Formation** (*c.* 560 Ma) diamictites or tillites seen within the Gariep successions of South Africa and southern Namibia. In the intervening intervals climates were generally warm and tropical, as shown by the development of stromatolitic limestones on the continental shelf as well as capping volcanic atolls or seamounts offshore. These dramatically fluctuating environments provided the context for the initial development and diversification of complex marine life on Earth, including the earliest diverse plankton, multicellular algae and metazoans (animals).

By about 650 Ma the Adamastor Ocean was beginning to close as the Rio de la Plata Plate (another fragment of Rodinia, and now part of South America) approached from the west. The Gariep rocks on the ocean floor and western margin of the Kalahari Craton were squeezed between these two converging continental blocks to form a belt of fold mountains built of deformed and metamorphosed sediments and volcanics. The sheer weight of the thickened mountain belt on the cratonic margin caused an elongate crustal depression (technically known as a foreland basin) to develop between the rising fold mountain belt in the west and the interior of the Kalahari Craton to the east. This relatively narrow N-S depression, situated along the edge of the Kalahari Craton, provided the depositional setting for the sediments of the Nama and Vanrhynsdorp Groups of Namibia and Namaqualand (**6**).

In the Northern Cape the **Nama Group** crops out in a narrow, interrupted zone from Vioolsdrif on the River Orange, where it builds the spectacular Neint-Nababeep Plateau, and southwards past Springbok. Additional outcrops occur in the Gordonia region to the northwest of Upington. The contemporary but separate **Vanrhynsdorp Group** crops out in southern Namaqualand (*eg* Knersvlakte region) and the adjacent Bokkeveld Plateau, for example to the west and north of Nieuwoudtville. Both these thick sedimentary successions span the palaeontologically critical Precambrian / Cambrian boundary interval, from roughly 550 to 540 Ma, during which the "Cambrian Explosion" of multicellular life occurred. This was the time interval when the first substantial invertebrate shells appeared, as did most of the peculiar "soft-bodied" vendozoan / vendobiontan organisms of the Ediacaran Period. Indirect evidence from trace fossils documents increasingly complex foraging behaviour and larger body size among burrowing animals. The Nama and Vanrhynsdorp Groups are made up of a mixture of marine siliciclastic and carbonate sediments, undeformed and only lightly metamorphosed for the most part. They include shallow water limestones, some with spectacularly large domal and columnar stromatolites, as well as nearshore shelf sands, offshore muds, and submarine fan deposits (turbidites). Sandy-pebbly braided river sediments occur at the base of both groups, and finer-grained fluvial "red beds" characterise parts of the earliest Cambrian Fish River Subgroup (Nama Group), though this is predominantly shallow marine to coastal (intertidal or estuarine) in origin.

Final closure of the Adamastor Ocean occurred around 550 Ma in the north (Richtersveld / S. Namibia) and a few tens of millions of years later (*c*. 500 Ma?) in the south (Vanrhynsdorp area). Oblique collision of the Rio de la Plata and Kalahari Cratons thrust great slices of the Gariep succession eastwards onto the margin of the Kalahari block and also deformed the western edge of the Nama and Vanrhynsdorp successions situated there. Following deformation and metamorphism of the Gariep and (to a much lesser extent) Nama rocks, a number of granitic and other intrusions – the **Kuboos-Bremen Suite** (**7**) – were injected into these older metasediments in the Richtersveld region of the Northern Cape. The intrusions range from Early to Mid Cambrian in age (*c*. 521-507 Ma) and are naturally unfossiliferous.

The resulting fold-thrust mountain belts and related intrusions of the Cape region formed part of an extensive global network of so-called **Pan African belts** of similar latest Precambrian / earliest Cambrian age. These mark the suture lines between the various continental blocks that successively collided and fused together to form a new southern supercontinent, **Gondwana**, with Africa at its core. Gondwana provided the setting for the rich variety of geological events and extinct ecosystems that characterised this region over the next four hundred million years and more, until the birth of Africa as a separate continent in the Early Cretaceous Period.

E. The Cape Basin – continental and shallow marine sedimentation on the southern margin of Gondwana (Cape Supergroup)

Within only a few tens of millions of years of their formation, the Pan African fold mountains of the Cape Region had been largely reduced by erosion to a low-lying plain, exposing the folded metasediments and granite intrusions in their roots. Renewed crustal thinning and subsidence along the line of the Pan African suture zone commenced in the Late Cambrian Period (*c*. 500 Ma). An extensive E-W depression floored by continental crust known as the **Cape Basin** was formed. This basin separated the southern African region of Gondwana from the Falklands Plateau and elements of modern Antarctica to the south. The deeper reaches of the new continental basin were soon flooded by cool marine waters of the **Agulhas Sea**. Over the next 150 Ma or so of the Palaeozoic Era, a ten kilometre–thick succession of shallow marine, coastal and terrestrial siliciclastic sediments was deposited within the Cape Basin. These rocks are called the **Cape Supergroup** (**8**). Equivalent Gondwanide basins stretched along the southern margin of Gondwana from the South American region in the west, across Antarctica and into Australia in the east. Only the northern margins of the Cape Supergroup crop out in the Northern Cape. Here, closer to the still elevated interior of Gondwana, the succession is generally coarser-grained and much thinner than seen to the south. The youngest formations have been eroded away during later Gondwana glacial episodes (see below). Levels of deformation (folding, faulting *etc*) in the Cape Supergroup are generally low here, favouring good fossil preservation, since this region was least affected by the later formation of the Cape Fold Belt.

For most of the Early Ordovician to Early Devonian Period (*c*. 480 – 410 Ma) a very extensive network of braided rivers flowed southwards across a broad, gently sloping coastal plain down to the Agulhas Sea. Vast quantities of quartz sand and small pebbles were transported from the eroding interior of Gondwana and deposited as cross-bedded sandstones of the **Table Mountain Group**. In the Northern Cape these rocks crop out along the Bokkeveld Escarpment east of Vanrhynsdorp and on the Bokkeveld Plateau around Nieuwoudtville. As the continental crust flooring the Cape Basin gradually subsided under their weight, over three kilometres of fluvial sediments accumulated in deeper parts of the basin. Closely comparable thick sandstone successions of this age are found mantling the margins of ancient Gondwana, for example in South America, North Africa, the Iberian Peninsula, the Middle East and Antarctica. Several thin, mudrock-rich intervals featuring a limited range of marine to estuarine trace fossils, such as trilobite feeding burrows, show that the narrow Agulhas Sea occasionally rose and flooded the wide coastal plain far inland. In latest Ordovician times (*c*. 440 Ma) a succession of two, short-lived glaciations on Gondwana was the probable cause of global mass extinction episode at this time. In the Cape this event is marked by the thin glacial tillites of the **Pakhuis Formation** and the overlying post-glacial mudrocks of the **Cederberg Formation**. The latter record the rapid inundation of the Cape Basin by cold seas after the final melting of the Gondwana ice sheets. The dark, fine-grained mudrocks of the lower Cederberg Formation are famous for their unique fossils of marine invertebrates and primitive jawless fish (anaspids, conodonts) in which many of the soft tissue structures such as muscles and gills have been faithfully replicated by clay minerals.

A substantial rise in global sea levels in the Early Devonian Period finally drowned the Cape coastal plain, by then situated around 60º S, beneath a wider and deeper Agulhas Sea. Table Mountain fluvial sandstones were more or less abruptly replaced by continental shelf sediments of the Early to Mid Devonian **Bokkeveld Group** (*c*. 410 – 390 Ma). In the Northern Cape the lower Bokkeveld Group sediments are well exposed in the Onder Bokkeveld region to the east of the Cederberg, while the upper Bokkeveld Group crops out on the northwest margins of the Tanqua Karoo, north of Elandsvlei. Fluctuating global sea levels were responsible for the deposition of alternating mudrock-dominated and sandstone-dominated formations in deeper, offshore and shallower, inshore settings respectively. Sedimentological evidence points to the important role of major storms in the deposition of the impure Bokkeveld sandstones or *tempestites*. The lower Bokkeveld Group (**Ceres Subgroup**) is well-known for its abundant marine invertebrate fossils - trilobites, brachiopods, molluscs *etc* - of the high palaeolatitude Malvinokaffric Faunal Realm. Similar fossils, and in some cases identical species, are known from then adjacent parts of Gondwana such as the Falkland Islands / Malvinas, Antactica and South America (Brazil, Bolivia *etc*). Because carbonate minerals are more soluble in cold water than warm, buried shells were soon dissolved and are usually preserved as moulds, and there aren't any substantial Bokkeveld limestones. The northern outcrops of the Bokkeveld Group, where fossil shells are rare, yield instead some of the richest and best-preserved assemblages of Palaeozoic shallow marine trace fossils recorded anywhere in the world. Inshore, more ecologically restricted (deltaic or estuarine?) settings are represented in the upper Bokkeveld Group (**Bidouw Subgroup**). In the Cederberg region, and probably also further north in the Northern Cape, these contain important low diversity assemblages of fossil fish, such as the armour-plated placoderms, early sharks, acanthodians ("spiny sharks") and rare bony fish.

Only the lowermost, Mid to Late Devonian, formations of the following **Witteberg Group** (*c*. 390-375 Ma) are represented in the Northern Cape. Younger Witteberg successions were either not deposited here, since the coastline of the Agulhas Sea had retreated southwards by then as a result of global regression (sea level fall), or they were completely eroded away before or during Permocarboniferous glaciation on Gondwana. The Northern Cape Witteberg sediments reflect shallow, nearshore marine settings on a cold, wind-swept and storm-dominated shelf. Offshore mudrocks are proportionately less important than in the Bokkeveld Group, and abundant mica suggests prevailing subpolar climates onshore (*at* around 80º or more S), with correspondingly low rates of chemical weathering. Indeed, one or more short-lived glacial events are recorded in latest Devonian rocks of the Witteberg Group in the Western Cape, and also in South America. This time interval witnessed a rapid succession of mass extinction events that particularly affected tropical, warm-water loving organisms. This suggests that global cooling, Gondwana glaciation and related sea level fluctuations played an important role in these biotic crises. Unsurprisingly, fossil assemblages in the lower Witteberg sediments are sparse and low in diversity. They are dominated by trace fossils, especially the complex spiral burrow systems called *Spirophyton*, but scattered marine invertebrates (*eg* brachiopods), fragmentary fish remains (placoderms, sharks, acanthodians) and transported land plant debris (mainly stem fragments of lycopods or club mosses) also occur. Given the high, subpolar palaeolatitudes and intermittent glaciation on Gondwana, it is perhaps surprising that any organisms could thrive here at all.

F. Formation of the Supercontinent Pangaea and Karoo Basin sedimentation

Starting in the Late Carboniferous and continuing into the following Permian and Triassic Periods, dense oceanic crust flooring the **Panthalassa Ocean** to the south of Gondwana began to sink down beneath the edge of the supercontinent, eventually to be recycled back into the hot mantle below. This process, known as *subduction*, compressed the Gondwana crust, including the Cape Supergroup rocks within the Cape Basin situated to the north of the Falkland Plateau. The resulting folding and thrust faulting of the Cape sediments, as well as the underlying older crust, gave rise to the **Cape Fold Belt** between 280 and 230 Ma. Levels of deformation and metamorphism within the Cape Fold Belt were quite low, and were not associated with the intrusion of hot granitic magmas. Therefore preservation of Cape Supergroup fossils within many parts of the Cape Fold mountains, especially the less compressed N-S Cederberg range, is often remarkably good. The influence of Cape deformation barely extended into the Northern Cape outcrop area of the Cape Supergroup, where the beds are still almost flat-lying.

The Cape Fold Belt is just the local sector of a much more lengthier, Himalayan-scale belt of fold mountains called the **Gondwanides** that stretched along the entire southern margin of Gondwana. Subduction, crustal compression and collision events here and elsewhere during the Carboniferous and Permian can be seen as the final stages of assembly of a new **Supercontinent Pangaea**. This vast landmass, which at its acme incorporated all the major crustal blocks on the planet and stretched from pole to pole, lasted less than 100 million years before breaking up again. The southern region of Pangaea incorporating Africa is still known as Gondwana and was stable enough to survive more or less intact for millions of years following the fragmentation of Pangaea.

Loading of the southern margin of Gondwana / Pangaea by the thickly piled-up rocks forming the Cape Fold Belt caused a broad compensatory depression to form on the inner side of the mountains. This was the **Main Karoo Basin** – another example of a foreland basin. Over the succeeding 100 million years (Late Carboniferous to Early Jurassic Periods) it was gradually infilled with glacial, marine / lacustrine and continental sediments of the **Karoo Supergroup** with a total thickness of around 10-12km. Karoo Supergroup sediments of the Main Karoo Basin underlie almost the entire southern half of the Northern Cape Province. Smaller outcrops of Karoo sediments belonging to the Karasburg (= Warmbad) and Aranos / Kalahari Basins extend from southern Namibia into the Vioolsdrif / Richtersveld area and Gordonia respectively.

The first phase of Karoo sedimentation was the deposition of up to 900m of glacial tillites and interglacial mudrocks of the **Dwyka Group** (**9**) roughly between 330 and 290 Ma. The Dwyka succession records at least four successive expansions and contractions of Antarctic-scale ice sheets across Gondwana (now southern Pangaea). It is the local representative of comparable Permocarboniferous glacial deposits preserved on all the major fragments of this ancient supercontinent. The formation of thick icecaps on Gondwana occurred as this region drifted slowly across the southern palaeopole. Chemical weathering of silicate rocks in the lofty new mountain belts of youthful Pangaea trapped large quantities of atmospheric CO_2 to form marine shelf limestones at low palaeolatitudes. The proliferation of land-based vegetation from the Late Devonian Period onwards also permanently withdrew lots of atmospheric CO_2 when large volumes of plant material were buried in the crust as peats and coals, rather than being recycled back into the atmosphere by decomposion. This happened on Laurasia (northern Pangaea) in the Late Carboniferous (*eg* Coal Measures of Euamerica) and on Gondwana in the Early/Mid Permian Period (*eg* Ecca coals of Southern Africa). The predictable end result was that Planet Earth was tipped back into global icehouse conditions for a period of some 70 million years (Late Devonian – Early Permian). However, in contrast to the Snowball Earth episodes of the Precambrian, much of the globe outside Gondwana, including the oceans, remained ice-free. Interestingly, although substantial fluctuations in global climate and sea level certainly occurred, the protracted Permocarboniferous glacial interval is *not* associated with a mass extinction event (Contrast the smaller-scale End Ordovician and Late Devonian Gondwana glacial events outlined above).

In the Northern Cape Dwyka sediments are found in a broad curve around the outer edge of the main Karoo Supergroup outcrop, from the Tanqua Karoo in the south across the flat plains of Bushmanland and into the Kimberley region to the north. Pre-glacial and subglacial erosion removed a substantial thickness of older rocks before the Dwyka tillites were deposited. Relicts of pre-Dwyka valleys, further hollowed-out and smoothed by glacial action (*eg* lower Orange River valley), as well as striking striated pavements carved into hard bedrock by moving ice-bound sediment at the base of icesheets are known from several Northern Cape localities (*eg* Nooitgedacht near Kimberley). At various times ice sheets moved into the Karoo Basin from the south, east and northern highlands, transporting lumps of exotic rocks (glacial erratics) over hundreds of kilometres. In the Main Karoo Basin the advancing ice sheets extended out over a cold shallow sea to form floating ice shelves that dumped unsorted rock debris on the seabed as they melted. The massive water- and land-lain Dwyka tillites themselves only very rarely yield fossils, of course. Sparse marine faunas (*eg* palaeoniscoid fishes, sharks, molluscs, arthropod and fish traces) are found within interglacial and post-glacial mudrocks. Reddish-weathering, coarse sandstones and conglomerates at the base and top of the Dwyka succession in more northern parts of the Northern Cape are interpreted as proglacial outwash deposited onshore by streams issuing out from the melting ice front. These fluvial and lacustrine redbeds contain sporadic plant fossils recording the rapid establishment of post-glacial *Glossopteris* vegetation as soon as the ice had receded.

After the final melting of the main Gondwana ice sheets in the Early Permian (*c*. 290 Ma) the western part of the Karoo Basin was occupied by a vast interior seaway rather like the modern Caspian or Black Seas. This largely land-locked **Ecca Sea**, which was floored by buoyant continental crust and therefore never very deep, was probably brackish to freshwater through most of its existence. It stretched right across western Gondwana, covering the southern Africa interior as well as parts of modern South America (*eg* Brasil). During Mid Permian times, from about 290 to 266 Ma, the Ecca Sea gradually shrank in area and depth as it was infilled by a succession of siliciclastic sediments of the **Ecca Group** (**10**). The Ecca rocks of the Main Karoo Basin, extensively intruded and baked by Jurassic dolerites, underlie huge areas of the Northern Cape, from the northern Tanqua Karoo up to Calvinia and Loeriesfontein and then eastwards to the Kimberley – Philipstown area. There are also small Ecca outcrops in Gordonia and the Richtersveld that are connected to separate Karoo basins in southern Namibia and Botswana.

The Ecca sediments include a range of offshore mudrocks formed by the slow settling of fine sediment in quiet waters, submarine fans built out by successive underwater avalanches of sediment mixed with water (turbidites), and deltaic deposits constructed by large coastal rivers. Nearshore tempestites (storm deposits) are seen in the northern part of the basin in the Carnarvon – Britstown region. A small range of marine invertebrates and fish (*eg* bivalves, sharks) are preserved at the base of the Ecca Group (*eg* at Douglas and in the Tanqua Karoo). However, most Ecca fossils are of non-marine animals - various groups of aquatic arthropods (crustaceans, eurypterids, king crabs) and primitive thick-scaled palaeoniscoid fish that thrived in these vast and peculiar intracontinental seaways or megalakes of southwestern Gondwana. The most famous aquatic animal from the Ecca is the small swimming reptile *Mesosaurus*. The discovery of almost identical mesosaurid remains in South America as well as in Southern Africa (Northern Cape, Namibia) in the late nineteenth and early twentieth century provided tantalizing evidence for the previous existence of an ancient supercontinent Gondwana, and hence for continental drift. *Mesosaurus* lived at a time (*c*. 280 Ma) when the Ecca Sea experienced stupendous blooms of phytoplankton whose partially decomposed remains are preserved in dark, carbon-rich mudrocks in the Main Karoo Basin (**Whitehill Formation**). These carbonaceous mudrocks are even mined as oil shales in Brazil. Substantial swampy forests dominated by the distinctive Gondwanan gymnosperm *Glossopteris* thrived along the margins of the Ecca Sea. Large logs, rafts of leaves and other plant debris were occasionally swept offshore during storms and are preserved as carbonaceous compressions or petrified wood. Substantial Ecca Coal Measures developed in swampy deltaic settings along the margins of the eastern Karoo Basin at this time but not preserved in the Northern Cape.

By Late Permian times the receding Ecca seaway had been largely infilled by deltaic and other coastal deposits. For the remaining 90 million years or so of its existence the Main Karoo Basin was essentially dry land – a vast, monotonous, semi-arid to desert plain embedded deep within Gondwana, ringed by craggy fold mountains in the south and west, and by more subdued uplands of basement rocks elsewhere. As southern Gondwana drifted further from the southern palaeopole into warmer latitudes and the youthful Cape Fold Mountains rose along its southern and western margins, huge volumes of siliciclastic sediment were fed into the landlocked Karoo Basin by a series of Mississippi-sized meandering rivers. Sandstones and thin conglomerates were laid down within the sinuous river channels stretching far into the basin (coarser sediments deposited closer to the mountain source areas have not been preserved). Occasionally, perhaps during seasonal floods, these rivers burst over their low, well-vegetated banks to deposit large quantities of finely layered silt and mud on the adjacent floodplain. Between floods, calcrete-rich soils typical of semi-arid climates developed on the floodplain, which was also dotted in wetter times by pools and even extensive shallow lakes. The several kilometre-thick succession of fluvial and lacustrine sediments of Late Permian to Early Triassic age that accumulated within the Main Karoo Basin in Late Permian to Early Triassic times (*c*. 266-250 Ma) is known as the **Beaufort Group** (**11**). In the Northern Cape this stratigraphic unit crops out extensively above the Great Escarpment in the south, from Sutherland across to Colesburg (Upper Karoo region).

The Beaufort Group is famous among palaeontologists for its impressive fauna of terrestrial and freshwater vertebrates. Most notable is a wide range of herbivorous and carnivorous therapsids ("mammal-like reptiles") that constituted the dominant group of large tetrapods in the Late Permian / Early Triassic interval, long before the ascendancy of the dinosaurs. This was the period when the first complex, vertebrate-dominated ecosystems were established on land. These featured small-bodied insectivores, crocodile-sized amphibians, and herds of specialised megaherbivores (*eg* dinocephalians, dicynodonts) that were hounded in life and scavenged after death by some of the oldest known terrestrial superpredators (*eg* gorgonopsians). Although there must have been fairly lush *Glossopteris* and horsetail-dominated vegetation to support these intricate foodwebs, especially along moister riverbanks and lake margins, environmental conditions did not favour preservation of many fossil plants. The Karoo Basin lay at palaeolatitudes of around 70º S during early Beaufort Group times. Climates were continental and therefore highly seasonal, with alternating long, hot summers and cold, dark winters. Far from the Panthalassic Ocean, and in the rainshadow of the lofty Gondwanide mountains, annual rainfall was probably variable and low, as in the modern Karoo, so water imported by perennial rivers must have played an important ecological role. Many smaller animals probably escaped drastic fluctuations variations in food supply (*eg* new plant growth, or insects) and availability of free water through hibernation or aestivation in underground burrows. Some larger animals, such as the some of the social dicynodonts, dinocephalians and their predators, may even have abandoned the vast plains of the Karoo Basin each year in times of physiological or ecological stress, undertaking long seasonal migrations across southern Pangaea.

The sediments and fossils of the lower Beaufort Group (**Adelaide Subgroup**) are of additional palaeontological interest because they provide the best available record for environmental and biotic changes on land during two successive mass extinction events. These are the end-Mid Permian (end-Guadalupian) event of 260.4 Ma, which affected large dinocephalian therapsids as well as flora, and the even more catastrophic end-Permian event of 251.4 Ma. The latter may have wiped out over 90% of living plant and animal species and marked the dramatic end of the Palaeozoic Era. Recent data from the Main Karoo Basin and elsewhere indicate that both extinction events were associated with episodes of extreme global warming leading to protracted, severe drought across much of Pangaea. The resulting mass die-off of terrestrial vegetation also entailed radical changes in sedimentation patterns (*eg* high rates of soil erosion, prevalence of braided river systems, flash floods, red beds), and finally precipitated the almost complete collapse of terrestrial ecosystems. The ultimate trigger of dramatic global warming in the Mid to Late Permian remains controversial, but may have involved the release of tremendous volumes of methane (a powerful greenhouse gas) from buried coal deposits in China and Siberia when these were extensively intruded by hot basaltic magmas of LIPs.

The youngest Karoo Supergroup sediments in the Northern Cape belong to the upper Beaufort Group (**Tarkastad Subgroup**) of Early Triassic age (*c*. 250 Ma). They crop out on the eastern edge of the province south of Colesburg. These reddish mudrocks and buff braided river sandstones reflect persistent arid conditions following the end-Permian biotic catastrophe. They yield abundant skeletal remains and burrows of the pig-sized herbivorous therapsid *Lystrosaurus* that flourished across Pangaea in Early Triassic times in the absence of large land predators. Small burrowing cynodonts – the sophisticated therapsid subgroup that gave rise to the first true mammals by the end of the Triassic Period – are also found.

Clearly, representatives of younger units of the Karoo Supergroup would have originally been deposited within the various Karoo basins in the Northern Cape. These would have included fluvial, lacustrine and desert sediments of the Late Triassic to Early Jurassic Stormberg Group, and contained fossils of some of the earliest mammals and dinosaurs. However, all traces of these younger continental deposits have been removed by extensive regional erosion during Cretaceous to Tertiary times.

G. Karoo Igneous Event, fragmentation of Gondwana and post-Karoo igneous activity (Karoo Dolerite Suite, Kimberlites *etc*)

In the Early Jurassic Period the dramatic **Karoo Igneous Event** signalled the end of Karoo Basin evolution and foreshadowed the imminent break-up of Gondwana. Over a period of only a few million years (*c*. 184-179 Ma, with a strong peak around 183 ± 2 Ma) enormous volumes of hot basaltic magma were intruded into the continental crust of southern Gondwana. Some of the magma crystallised below the surface to form complex, interconnected and cross-cutting systems of dolerite sills and dykes that fractured and baked the surrounding country rocks. In addition, vast sheets of fluid lava were repeatedly erupted at the surface *via* volcanoes and fissures, mantling the landscape beneath thick piles of black flood basalts (*eg* Drakensburg Group of South Africa). Drakensberg-type flood basalts were undoubtedly erupted in the Northern Cape region, but have since been removed by post-Gondwana erosion. Extensive intrusions (sills, dykes, volcanic pipes or diatremes) of the **Karoo Dolerite Suite** (**12**), some of which would have fed volcanoes and fissures at the land surface above, are preserved here, however. They mainly - but not exclusively - intrude Karoo Supergroup rocks in the nothern two thirds of the Main Karoo Basin as far south as the Great Escarpment. The Karoo dolerites do not themselves contain fossils, but baking and mineralisation of adjacent Karoo sediments by the intrusions may variously promote or compromise fossil preservation and collection.

Basaltic rocks of closely similar Early Jurassic age are also found in adjacent parts of Antarctica and Australia, which together with southern African examples form the **Karoo-Ferrar Igneous Province**. The total volume of magma involved here was around 2.5 *million* cubic kilometres! This is one of several large igneous provinces (LIPs) in the geological record that have recently been related by some geologists to mass extinction events (the Late Permian extinction events, for example). The Karoo-Ferrar LIP correlates well with a minor but significant global extinction at 183 Ma, the end-Pliensbachian event. So far this extinction has mainly been recognised from the fossil record of marine invertebrates, but further work in the Karoo and elsewhere may well reveal contemporary extinctions of terrestrial fauna and flora. As with the earlier Permian extinction events, intrusion of buried coals by hot LIP magmas and consequent mass release of methane, in turn causing dramatic global warming, may have been an important contributory factor.

The stretching, fracturing and final break-up of the long-lived Supercontinent Gondwana took place in several stages during the Mid Jurassic to Early Cretaceous Period. The process may have been initiated by the rise of a mushroom of hot, buoyant magma within the mantle underlying eastern Africa, the Mozambique Plume. This mantle plume may also have been responsible for the Karoo-Ferrar LIP, though this remains controversial. The extension of major fracture zones across southern Gondwana from Mid Jurassic times (*c.* 175 Ma) eventually caused the supercontinent to split into two large subunits – **East Gondwana** (India, Madagascar, Antarctica, Australia) and **West Gondwana** (Africa, South America). These finally drifted apart in the Early Cretaceous (from about 135 Ma) to form the early Indian Ocean. Around 130 Ma a second mantle plume – the Tristan Plume – was responsible for the eruption over Western Gondwana of large volumes of basaltic lavas of the Etendeka-Paraná Province. Relicts of this thick flood basalt succession are found today on opposite sides of the South Atlantic, in Brasil and Namibia. Crustal thinning, rifting and finally formation of new oceanic crust were soon initiated and South America started to drift away from Africa. These two continental blocks finally separated in the Late Cretaceous (90 Ma), leaving the Southern Atlantic Ocean to open between them. Voluminous shelf sedimentation along the West Coast passive (*ie* tectonically inactive) margin dates from this period.

In the Northern Cape igneous activity related to the break-up of Western Gondwana and the formation of the South Atlantic is represented by a series of large WNW- to N-striking dolerite dykes in southern Namaqualand and along the West Coast, reflecting early crustal stretching along the margins of the future the rift zone. The **Koegel Fontein Complex** of rift-related granites and associated igneous intrusions crops out between Bitterfontein and the coast and is Early Cretaceous in age (*c.* 144-134 Ma). The earlier history of rifting finally leading to drifting and the formation of the proto-Atlantic Ocean between Southern Africa and South America is best recorded in Jurassic to Cretaceous rocks that are now largely buried beneath younger sediments on the continental shelf off the West Coast (Subsection I below). The Mesozoic rocks have been extensively drilled during exploration for hydrocarbons such as petroleum and gas fields associated with major Orange Basin off the southern Namibian and Namaqualand coast. The onset of rifting occurred sometime in the Late Jurassic with the formation of fault-bound valleys (grabens) parallel to the future coastline. These grabens were infilled with volcanic rocks, coarse alluvium and fine-grained, organic-rich mudrocks deposited in lakes that developed along the valley bottoms (*c.* 130 Ma). Around 120-117 Ma (Early Cretaceous) rifting was replaced by broader thermal subsidence, the eruption of flood basalts and the invasion of the sea to form a proto-Atlantic Ocean between Africa and South America. Sediments of this age comprise a mixture of continental red beds (reflecting prevailing warm, humid climates) with the first marine sandstones and shales. Continental drift was well underway by 112 Ma, with drowning of the whole inter-continental rift by deeper seas. Fine muds were deposited offshore (*eg* as submarine fans), with sandier, deltaic sediments nearshore and fluvial deposits on the adjacent forested coastal plain. By early Late Cretaceous times (90 Ma) an open connection between the South Atlantic and the Indian Oceans had formed. Global fluctuations in sea level, complicated by intermittent continental uplift, controlled cyclical patterns of sedimentation on the young African continental shelf. High levels of weathering and erosion in the continental interior during the Cretaceous fed huge volumes of sediments onto the shelf *via* the mouths of the palaeo-Orange and Olifants (or Karoo) river systems. Fluvial input had largely ceased by the Palaeocene, however, and later shelf sedimentation was dominated by organic and chemical deposits (*eg* planktonic oozes, precipitation of phosphates, manganese and glauconite), with intermittent pulses of land-derived sediment during periods of sea level fall / continental uplift.

Several hundred small-scale igneous intrusions, notably **kimberlites** (**13**) and related alkaline igneous pipes, are scattered widely across the Northern Cape. They are of considerable geological and economic interest as host rocks of diamonds that were delivered from sources in the upper mantle by extremely explosive igneous activity. About half of them are Jurassic to Early Cretaceous in age (*c*. 200-110 Ma), spanning the break-up of Gondwana (**Victoria West** and **Group II Provinces**). Most of these kimberlites are clustered in the central part of the Interior Plateau, from Victoria West northwards to Kimberley and Kuruman. The other half – those of the **Kimberley** and **Gordonia Provinces** – were intruded within a thirty million year interval during the Late Cretaceous (*c*. 100-70 Ma). These younger kimberlites are spread from the central Karoo northwards to the Namibia and Botswana borders. Olivine melilitite and carbonatite pipes and related intrusions dated either side of the Cretaceous / Tertiary boundary (*c*. 70 – 55/60 Ma) are grouped near Garies in Namaqualand and around Gamoep on western edge of the Bushmanland Plateau. Salpeterkop near Sutherland in the SW Karoo is the hydrothermally alterered relict of a Late Cretaceous (75-66 Ma) carbonatite volcano (**Sutherland Suite**). The age distribution of these post-Karoo alkaline igneous intrusions in southern Africa suggests that they may be somehow related to the north-eastwards drift of the African plate over a series of stationary hotspots in the mantle. It is suggested that these hotspots – namely the Tristan, Vema and Bouvet hotspots now located in the South Atlantic – caused melting at the base of the African plate as it drifted overhead. Successive pulses of alkaline magma were generated and were eventually emplaced near or at the surface as linear (NE-SW) clusters of volcanic pipes and other intrusions.

The younger volcanic pipes are of considerable palaeontological interest because fine-grained crater lake deposits are occasionally preserved above them. This is due to negligible landscape erosion over much of the Interior Plateau of southern Africa since Late Cretaceous times. Rare glimpses of Late Cretaceous to Early Tertiary (Paleogene) faunas and floras of the youthful African interior are provided by well-preserved fossil assemblages from these crater lake deposits (*eg* Stompoor, near Prieska and Kangnas near Goodhouse, Orange River). They include a diversity of fish, frogs, reptiles, insects, rare dinosaurs and plant remains (leaves, wood). Rich pollen spectra (most notably those from the Paleogene Arnot Pipe near Banke, Bushmanland) permit tentative reconstructions of vegetation and climates during an important period of biotic and environmental change worldwide, following the end-Cretaceous mass extinction event.

H. Post-Gondwana erosion and sedimentation in the continental interior (Kalahari Group, river gravels, pedocretes *etc*)

For the most part the interior of southern Africa has been the scene of protracted denudation (weathering and erosion) rather than sedimentation since the birth of a separate African continent in the Early Cretaceous. Weathering and erosion have been promoted by Africa's high average elevation above sea level from birth. This was exacerbated by intermittent uplift during the Late Caenozoic that increased river gradients, and hence their erosive power. Furthermore, warm, rainy climates supporting vigorous drainage networks for much of the Late Cretaceous and Early Tertiary / Paleogene – a interval of some one hundred million years – encouraged deep chemical and biological weathering of surface rocks and the rapid removal of the resulting rock debris by water action. Humid temperate climates for most of this period are supported by pollen spectra as well as by abundant petrified woods of podocarps (gymnosperms related to modern yellowwoods) preserved in onshore as well as offshore deposits of Early Cretaceous to Paleogene age. By the end of the Cretaceous the Great Escarpment – a major topographic break separating the elevated Interior Plateau of southern Africa from the low-lying coastal plain - was established more or less in its present position and functioning as an important drainage divide. Huge volumes of sediment eroded from the continental margins and interior had already been transported by major new river systems to the coast and thence spread out over the continental shelf by waves and currents.

The **Kalahari Group** (**14**) is the only thick, geographically extensive succession of continental sediments of post-Gondwana age found in the Northern Cape region. It blankets most of the province from Upington north to the Namibia and Botswana borders. Locally the group reaches over 200m in thickness where it overlies bedrock depressions, though normally it is much thinner. The oldest Kalahari sediments are potentially fossiliferous, but rarely exposed, river gravels of ill-defined Late Cretaceous age (< 90 Ma). They are mostly confined to buried channels that in many cases are probably pre-Karoo in age, having been originally carved into the underlying bedrock by the Dwyka ice sheets. The basal fluvial deposits are overlain by thick lacustrine clays reflecting the development of enormous but shallow, saline lakes in the Kalahari region after 60 Ma (Paleogene). These lakes formed when crustal uplift along linear belts or "axes" in the African interior caused ponding up of the waters of several major river systems within a relatively depressed **Kalahari Basin**. These lakes eventually dwindled in size and had largely dried up by Miocene times. This is attributed to increasing regional aridity as well as fluvial input from the north being redirected towards the East Coast (*eg via* the Zambezi system) as a result of southwestward extension of the East African Rift Valley (*c*. 20 Ma). Younger Kalahari sediments include deposits of braided rivers, aeolian dunes, pans, small freshwater lakes (with limestones and abundant diatom remains), and pedocretes - *ie* cemented soils, including silcretes and locally very thick calcretes. This suite of upper Kalahari sediments reflects the onset of climatic aridity in the Northern Cape interior from at least the Mid Miocene (*c*. 15 Ma) onwards, following the establishment of the cold Benguela current along the west coast. The youngest Kalahari sediments in the Northern Cape are the unconsolidated reddish aeolian sands of the **Gordonia Formation** of Late Pliocene / Pleistocene to Recent age (the well-known "Kalahari Sands"). They are up to 30m thick and form part of a vast dune sea or erg that stretches northwards to the equator and beyond. During more arid "glacial" intervals of the Quaternary, with colder climates, stronger winds and less vegetation cover in the continental interior, the vast Kalahari sand erg must have stretched intermittently southwards into Bushmanland and Namaqualand, where relict patches of red sands are still preserved here and there.

Besides the Kalahari Group, a variety of Late Cretaceous to Recent continental deposits of fluvial, lacustrine, terrestrial and other origins (**15**) is found in the Northern Cape interior. For the most part these are very limited in both thickness and lateral extent, so the majority are not indicated on published geological maps at 1: 250 000 or smaller scales. Nevertheless, in many cases they are of considerable palaeontological (and archaeological) interest.

The complex pattern of drainage evolution in the Northern Cape during the Cretaceous to Tertiary has been intensively studied by geologists because of its implications for diamond mining in alluvial and coastal gravels. In Mid to Late Cretaceous times an ancient **Karoo River** drained the Northern Cape interior from Kimberley to southern Namaqualand. This drainage basin was separated by an elevated barrier of basement rocks running across the Northern Cape (the Transvaal – Griqualand Axis) from a more northerly **Kalahari River** that drained southern Botswana and flowed to the West Coast *via* the lower reaches of the Orange River or Gariep. By Mid Tertiary times the headwaters of the ancient Karoo River, now the upper Orange and Vaal systems, had been captured by headwards erosion of the lower Orange across the Griqualand – Transvaal axis barrier. The greater part of the semi-arid Interior Plateau was henceforth drained into the South Atlantic by the expanded Orange River system. Much of Bushmanland and the northern Karoo was once drained by a now extinct river system known as the **Koa River** / **Geelvloer Palaeo-valley** that fed into the Orange near Henkries in the Miocene Epoch, when climates were still much wetter than today. By the Plio-Pleistocene, intensifying aridification and the capture of its headwaters by the Krom and Sak River networks led to the choking by sediment of the Koa River and the establishment of the modern, largely ephemeral drainage network.

Relict gravel deposits of Late Cretaceous and younger ages are preserved at various elevations on pediments (eroded bedrock surfaces) and as alluvial terraces along these ancient, Cretaceous or Tertiary river courses. The older gravels are often well-consolidated by pedocretes and contain important fossil remains, such as mammal bones and teeth, petrified wood, molluscs and trace fossils, that allow us to date their deposition and reconstruct changing environments, vegetation and wildlife in the Cape interior. In the Northern Cape, important gravel successions spanning the Late Cretaceous to Recent interval are found, for example, along the Vaal, Orange and Olifants Rivers, as well as in the Koa Palaeo-valley. The **Arrisdrift Formation** gravels along both north and south banks the lower Orange River have yielded petrified subtropical woods and a very rich fossil fauna of terrestrial and aquatic vertebrates of Early to Mid Miocene age (>18-14 Ma). These include several fish, numerous reptiles and birds as well as over thirty-five species of mammals. The famous **Vaal River gravels** in the Windsorton – Kimberley – Douglas area of Late Cretaceous to Recent age have also yielded a range of Mid to Late Pleistocene mammals (*eg* probiscideans, hippos, horses, bovids, pigs and carnivores). They also contain several very important Early Stone Age archaeological sites (*eg* Kanteen Kopje). Unfortunately, many of these fossiliferous deposits have already been severely disturbed by diamond mining and remain understudied in palaeontological terms.

Quaternary alluvial deposits along modern ephemeral drainage courses are often exposed by donga erosion in the Central Karoo (*eg* Britstown, Noupoort) and elsewhere in the Cape interior. Locally they have yielded valuable fossil and subfossil remains, notably the bones, teeth and horn cores of larger mammals such as ungulates and proboscideans. These fossils document the origins and evolution of the modern Karoo-Namaqualian mammalian fauna that thrived here before widespread large mammal extinctions in historical times. Extensive surface deposits in the Northern Cape include rocky colluvium on mountain slopes, alluvial fans in the foothills and sheets of braided stream deposits on the plains. Most of these coarser, poorly consolidated "drift" sediments are probably of Late Neogene or Quaternary age and in the main are unfossiliferous. However, sparse fossils of arid-adapted biota such as calcretised termitaria, plant rootlet casts, freshwater molluscs, ostrich eggshells and mammal bones and teeth do occur, for example in the **Kwagga's Kop Formation** of southern Namaqualand. Abundant pedocretes (silcretes, calcretes) within Caenozoic continental sediments reflect prevailing semi-arid climates in the region since Miocene times at least, and some are considerably older than this. For example, widespread formation of massive silcretes overlying deeply-weathered bedrock in southern Africa may have been associated with major climate changes (cooling, desiccation) at or shortly after the end of the Cretaceous Period (*c.* 65 Ma) according to some geologists (this is controversial, however). Alkaline igneous activity in the Northern Cape at this time (see above) may have reinforced or exacerbated these climate fluctuations locally. Exceptional relict silcretes on the Interior Plateau near Platbakkies are at least Early Miocene in age, and might even extend back to the Late Jurassic. Silcretes at elevations of +90m asl along the Namaqualand coast are inferred to be Late Eocene to

Oligocene in age (*c*. 40-30 Ma), while others preserved within fossilferous palaeochannels are probably Late Oligocene / Early Miocene (*c*. 25-20 Ma; Subsection I below).

A broad spectrum of other "drift" deposits of non-fluvial origin are scattered across the Northern Cape interior. Calcareous spring deposits (calc tufa), for example, formed at the edge of the Ghaap Escarpment and may enclose vertebrate bones, teeth and plant remains. There are also fossiliferous sediments (flowstones, breccias *etc*) in karstic cave systems such as Wonderwerk near Kuruman, as well as peats, organic-rich muds, shelly limestones and siliceous diatomites from numerous Pleistocene palaeolakes and pans that developed during warmer, wetter intervals of the Pleistocene (*eg* in the Kimberley and Sishen areas). Many of these Pleistocene to Holocene deposits are of considerable archaeological as well as palaeontological interest. Because of their thin, localised nature, and in some cases their economic potential, they are especially vulnerable to destruction by uncontrolled development.

I. Post-Gondwana sedimentation along the West Coast (West Coast Group)

During the early Cretaceous separation of Africa and South America, fault-bound valleys formed parallel to the approximately N-S basement structural grain during basement extension and collapse along the early coastline. Dolerite dykes intruded the faults and lineaments in the basement, with volcanic activity in places.

Vigorous erosion during the later Cretaceous exposed the coastal bedrock of metasediments and gneisses from beneath a cover of Nama, Dwyka and younger rocks. Notwithstanding, large-scale topographic aspects of the coastal plain, its backing escarpment and major drainage lines still reflect persistence of the basal Dwyka topography, formed beneath huge glaciers ~300 Ma. In more detail, faulting during continental breakup affected coastal topography. Deposits from these times are only preserved in rare instances, One example, a graben preserved some distance to the north of Kleinzee, contains lignitic lacustrine deposits that have yielded Lower Cretaceous pollen, indicating deposition between 145 and 130 Ma.

The coastal plain would have been transgressed during Cretaceous high sea-levels. Eocene transgressive events also affected the coastal plain and deposits of this epoch are found in southern Namibia, *viz*. at Buntfeldschuh and Langental, but little evidence of this earlier marine history remains along the Namaqualand coast. Rather, much of the further evolution of the coastal drainages took place during these times, with flushing of pre-existing deposits to the offshore depositories. The coastal plain bedrock became deeply weathered and kaolinized under the influence of the humid tropical climates of the later Cretaceous and early Tertiary, with silcrete duricrusts developing.

Remnants of the late Cretaceous African Surface have been preserved on the escarpment and coastal hinterland, as silcrete-capped mesas underlain by deeply-kaolinized bedrock. However, not all the weathering-profile silcretes are necessarily latest Cretaceous; those on valley flanks of current drainages are probably early to mid-Tertiary. Along the present coast these older weathering profiles have been truncated by marine transgressions.

Incised into this ancient, weathered land surface are remnants of fluvial palaeochannels, whose infills have also been kaolinized, disguising their presence (informally called the "Channel Clays"). These channel sediments, the **Koingnaas Formation**, consist of subangular quartz conglomerates, locally rich in diamonds, overlain by beds of clayey sand, clay and carbonaceous material containing plant fossils. Silcrete has also formed in places within the channels, sometimes preserving traces of plants. The deeply weathered nature of these channel infills suggests a considerable age, but their age has been controversial. Podocarp pollen is dominant and shows that yellowwood forests once typified a well-watered Namaqualand coast. Protea pollen indicates an age not older than Maastrichtian (end-Cretaceous), but pollen of Oleaceae (ironwoods) and Asteraceae (daisies) indicate that the age is not older than Oligocene ~34 Ma. Fossil wood of a tropical mahogany tree has also been identifed. These deposits show that humid weathering (kaolinization) continued along the Namaqualand coast during the Oligocene and the earliest Miocene, when the ancient river systems became largely inactive. The possibility remains open that the stratigraphy of these deposits is more complex than thought and that the channels were active over a considerable time span during the early Tertiary.

Three extensive marine formations containing warm-water mollusc assemblages occur beneath the aeolian cover sands of the Namaqualand coastal plain. The oldest of these is the **Kleinzee Formation** which is found up to 90 m asl. (the **90 m Package**). Petrified teeth of suids and a hominoid tooth have been found in the basal gravels. These were reworked from preceding terrestrial deposits of Arrisdrift Formation age (*c*. 18 - 17.5 Ma). The deposits are decalcified and generally lack all but the most robust macrofossils such as oysters. However, a shelly, more distal marine (shelf) facies of pebbly muddy sands and clays is very locally preserved at lower elevations, beneath the younger marine deposits. Strontium isotope ages of 16-15 Ma have been obtained from foraminifera (microfossils of protozoans) sealed in clay at one such occurrence in the Hondeklip area (Langklip), consistent with deposition during the decline from the high sea level of the warm mid-Miocene climatic optimum *ca*. 17 to 15 Ma. The sparse shelly fauna from the Kleinzee Formation is poorly preserved and mainly unstudied, but the curious, thick-shelled bivalve *Isognomon gariesensis* is the zone-fossil for this formation.

The previous Miocene marine beds were eroded during rising sea-level of the early Pliocene warm period and the fine sands of the **Avontuur Formation** (the **50 m Package**) were deposited between 5-4 Ma as sea-level receded from the transgression maximum of about 50 m asl. The Avontuur Formation also contains a basal concentration of petrified and abraded vertebrate remains inherited from earlier periods. This "Basal, petrified, mixed assemblage" or *remanié* fauna includes shark teeth and the bones and teeth of extinct whales, proboscideans, rhinocerotids, bovids and equids. The oldest fossils present are the bear-dog *Agriotherium* sp. (13 - 12 Ma) and the gomphothere *Tetralophodon* (12 - 9 Ma), but the age indicated by most of the material is terminal Miocene (7.5 - 5 Ma). The youngest taxa in the reworked basal assemblage constrain the maximum age of the 50 m Package. The important, unpetrified finds from within the deposits are the Langebaanian (Varswater) phocid (seal) *Homiphoca capensis* and the suid (bushpig) *Nyanzachoerus kanamensis*. This deposit is broadly contemporaneous with the Varswater Formation exposed at the West Coast Fossil Park near Saldanha (W. Cape). Much of the Avontuur Formation is also decalcified, but it must have been very shelly originally and in places shell fossils are abundant so that the shell fauna is quite well-known. The zone fossil is the extinct "surf clam" *Donax haughtoni*.

The Avontuur Formation in turn was eroded by yet another rising sea-level associated with a warm period later on during the Pliocene Epoch. The **Hondeklip Formation** or **30 m Package** was deposited as sea level declined from a high of about 30 m asl. An age-diagnostic vertebrate assemblage associated with the Hondeklip Formation has not yet been recovered and so its age is not constrained by vertebrate datums. Notwithstanding, it is the last, major formation of the coastal plain, deposited during a high sea-level never since exceeded. With its warm-water molluscan fauna, it is unlikely to postdate the inception of major cooling in the Benguela System and in Antarctica. Accordingly, the 30 m Package is not likely to be younger than ~3.0 Ma and may correspond with the second major sea-level highstand in the mid Pliocene at ~3.0 to 3.4 Ma. The Hondeklip Formation is mainly coarse-sandy and extensively decalcified and reddened. Shelly fossils are quite sparse and more need to be found. The zone fossil is the large extinct "surf clam" *Donax rogersi.*

The fossils shells that are extinct species are of considerable interest. Many are transitional forms that are ancestors of the present-day southern African fauna and so provide the clues to their unelaborated or unknown ancestries. The warm-water fossil shells present in these older, Neogene formations include species that today inhabit the east coast of southern Africa only as well as tropical West African species. Chief among the warmer water indicators is the oyster *Crassostrea margaritacea*, which is abundant. Despite the intensification of upwelling along this coast from late Miocene times, its influence was clearly not as great during late Neogene interglacials as in the present interglacial. The explanation may be sought in latitudinal shifts and reduced intensity of the trade winds, which would have been associated with shifts in upwelling loci and reduced upwelling, as well as with an enhanced tendency for Agulhas water to round the southern tip of Africa and influence the Benguela system. Clearly, too, tropical taxa from the West African province were not cut-off from the southern African coast by an upwelling barrier. The onset of bipolar glaciation and the Quaternary climatic mode caused considerable local extinction and speciation in the shallow marine molluscan fauna, such that the Quatenary, post Hondeklip Formation (30 m Package) faunas are essentially modern.

Close to the seaside, the Hondeklip Formation is eroded and overlain by the younger, Quaternary "raised beaches" that extend up to about 15 m asl. The name **Curlew Strand Formation** has been proposed for this composite of old beaches, equivalent to the Velddrif Formation of the SW Cape Coast. It comprises the 8 - 12 m Package (~400 ka BP?, in part), the 4 - 6 m Package (Last Interglacial (LIG) ~125 ka BP) and the 2 - 3 m Package (mid-Holocene 6-4 ka BP).The LIG beach is the best-preserved, but the older unit is poorly known and may not always conprise deposits of identical age. Along the Namaqualand shoreline, these beaches are poorly sampled for fossil shells, but West African tropical taxa must have ranged down the coast as they are found in equivalent deposits of the SW Cape. Rare surprises have come to light in these deposits, such as isolated occurrences of South American and mid-Atlantic island species.

A variety of terrestrial deposits also make up the coastal plain of the Northern Cape. For the most part these are extensive aeolian dune and sandsheet deposits that overlie the eroded tops of the marine sequences. More locally there are colluvial (sheetwash) and ephemeral stream deposits associated with nearby hillslopes; sometimes these underlie or are interbedded between the marine formations. Formed within the upper parts of the marine and terrestrial sequences are pedocretes and palaeosols of a variety of types, compositions and degrees of development. The fluvial sequences preserved on the flanks of Namaqualand rivers are very poorly known, although these are diamondiferous in places. A very broad correlation with sea-level history is expected (Table 3).

The main formations recognized within the West Coast Group are set out in Table 3 (Section 5), which is a very preliminary stratigraphic scheme. Much needs to be done in the correlation of pedocretes and the colection and analysis of fossils that are usually associated with more persistent palaeosurfaces. For example, the top of the early Pliocene marine Avontuur Formation in the Hondeklip area is eroded away and a cryptic contact separates pristine marine sediments and reworked marine sediments. On the cryptic surface are sparsely scattered bones (tortoise, zebra, ostrich, jackal, various antelopes, rhino). This erosion surface and the overlying terrestrial sediments must be younger than the ~2.6 Ma *Equus* (horses) dispersal in Africa because of the zebra (*Equus capensis*) bones. The jaw of a species of gazelle found there is the likely ancestor of the springbok. The fossil tortoises from various deposits of Namaquland are different extinct species and more detailed collection of tortoise fossils holds promise for the improvement of the terrestrial stratigraphy.

The above account may impart the impression that these deposits are all "sorted out" and scientifically understood. This is not the case. Some crucial specimens have been noticed and saved, all of which would fit into an average bedroom wardrobe. Currently, efforts are under way at De Beers Namaqualand Mines to rescue more fossils and to identify mining-pit exposures that have geoheritage/geotourism value. These efforts should be extended to other operations along the Northern Cape coast.

J. Offshore fossil biotas on the Namaqualand shelf

After the rifting phase, with its volcanicity, faulting and terrestrial/lacustrine sedimentation, the rifted landscape was covered by vast volumes of sediment delivered to the expanding Cretaceous South Atlantic Ocean. Wide coastal plains and deltas formed as many large rivers deposited their sediments. Marine processes spread the finer sands and muds further to form shelves extending seawards and slumping at the shelf edges carried sediments downslope into deep water. Successive continental shelves built out and upwards as the underlying crust subsided in phases. These now fill what is called the Orange Basin, which includes an accumulation of Cretaceous sediments exceeding 6 km off the Northern Cape coast. The layering can be "imaged" by seismic techniques; reflections of sound waves from the different layers. In places, drilling has recovered long cores through the sequences. These reveal the actual sediments and provide that are used to interpret and date the palaeo-environmental history of the Orange Basin. The main purpose of these efforts has been to evaluate the potential for "fossil fuels", oil and gas, which are derived from the slow, natural "distillation" of fossil organic matter as it is deeply-buried in a subsiding basin. The natural gas that has been located could possibly be commercially-viable in the future.

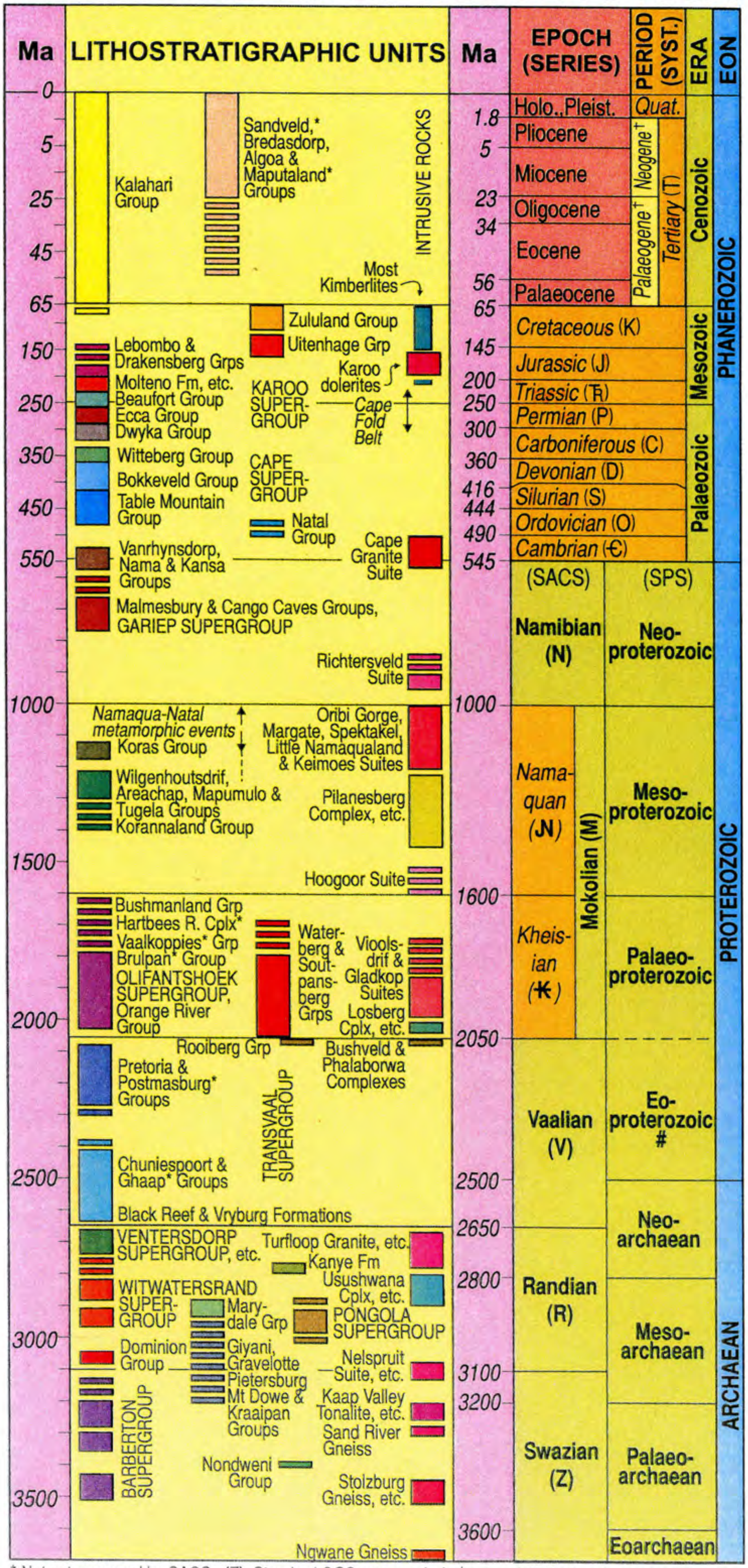
These Cretaceous sediments are exposed at the seabed along the inner edge of the Orange Basin. Marine diamond-mining activities have encountered silicified wood from fossil trees of the Cretaceous coastal plains in such abundance and scale that they has been referred to as a fossil forest. This material has eroded out of the sands, gravels and palaeosols of the Cretaceous fluvial coastal plains. Doubtless other remains also occur and this is where we might expect to find dinosaur fossils. However, material that is exposed on the seabed becomes very altered in appearance, by staining, borings, encrustation *etc.* and thus unusual objects or potential fossils may appear as "usual weird stuff".

Farther offshore, the bedrock of the continental shelf consists of various Miocene limestones, deposited at various depths and palaeoenvironments during the early to mid-Miocene. By these times not much terrigenous sediment was reaching the main shelf and it was evidently being trapped in estuaries and a coastal mudbelt. The limestones are made up of the skeletons of small calcareous-shelled organisms with scattered macrofossils that lived in clear tropical seas off Namaqualand.

During later Neogene and Quaternary times, the shelf off Namaqualand was dominated by upwelling processes, with high organic productivity and authigenic mineralization of seabed rocks, clays and biogenic particles by phosphatization and glauconization. Extensive crusts or "hardgrounds" formed on the limestone seabed. Sea level oscillated repeatedly, dropping to ice-age palaeoshorelines as much as 140 m or so below present sea level. The hardgrounds were eroded during shallowing episodes and recemented again during interglacial deepening. This has produced a wide array of multiphase phosphorite "nodules", phosphatic shell casts of various ages, phosphatized bones of fishes, whales and land-living animals that roamed the ice-age exposed shelf. A sample of this material turns up in bottom-trawl fishnets, scientific dredging and during diamond operations.

Except for areas off the mouths of the Orange and Olifants Rivers, the latest Quaternary deposits mantling the shelf are generally quite thin; a shelly gravel of shallow-shelf origin is overlain by Holocene shelf muddy sands. Off Namaqualand, the ice-age palaeoshoreline gravels are dominated by a "venus shell" clam, *Tawera philomela*. This "cold-water" species, along with others, reached the Cape coast from the mid-Atlantic islands of Tristan da Cunha and Gough, apparently thrived here and then became extinct locally during the last deglaciation. During the deglaciation, warm-water species from the south and east coasts "invaded" the Namaqua shoreline temporarily. This shows a much more marked influence of Agulhas water rounding the Cape and affecting the Benguela System during the global-warming steps and meltwater pulses of the last deglaciation. Importantly, these dramatic changes in the fauna of the West Coast in the quite recent geological past came to light when De Beers Marine geologists brought shell samples to the S. A. Museum for identification.

STRATIGRAPHY OF SOUTH AFRICA



* Not yet approved by SACS (Z) Standard CGS map symbol †Subperiod (Subsystem)

SPS = Subcommission for Precambrian Stratigraphy # Not ratified by IUGS

8. PALAEONTOLOGICAL HERITAGE AND THE LAW

Fossil heritage in South Africa is protected, with important exceptions, by the **National Heritage Resources Act of 1999** (NHRA, Act 25 of 1999). This act replaces the earlier National Monuments Act of 1969 (Act 28 of 1969). Under the new act, fossils are treated as a subcategory of heritage – *palaeontological heritage* - and are regarded as part of the national estate.

The NHRA does not define the term "fossil" but does offer its own definition of the term "palaeontological" which might be reasonably taken to circumscribe all fossil heritage:

> *(xxxi) "palaeontological" means any fossilised remains or fossil trace of animals or plants which lived in the geological past, other than fossil fuels or fossiliferous rock intended for industrial use, and any site which contains such fossilised remains or traces (NHRA, 1999, p. 10)*

According to the NHRA it is illegal to own, collect, damage or destroy South African fossils without a permit. Such permits would usually be granted only to qualified palaeontologists or other heritage specialists. It is also illegal to buy or sell South African fossils. However, when fossils form part of an economically important industrial resource (*eg* coal, fossiliferous limestone, phosphate deposit), they can apparently be destroyed and sold *en masse*.

The NHRA provides for the setting up of Provincial Heritage Resources Agencies (PHRAs) to manage most aspects of fossil heritage including, for example, permits and database management. However, some key issues (*eg* export and destruction permits) are dealt with at a national level by SAHRA (South African Heritage Resources Agency), based in Cape Town. In practice, several provinces, including the Northern Cape, have yet to establish PHRAs backed up by appropriate palaeontological expertise. Palaeontological heritage in these provinces is entirely managed by SAHRA.

9. FOSSILS IN ECOTOURISM, PUBLIC EDUCATION & CONSERVATION SITES

1. Palaeotourism

Palaeontological tourism (or palaeotourism) is a rapidly growing component of the local and international ecotourism boom in southern Africa. It can play an important constructive role in public education as well as community upliftment in otherwise economically depressed areas. Recently developed or well-established palaeotourism initiatives in the RSA include, for example, the West Coast Fossil Park at Langebaan Weg, the Fossil Trail at the Karoo National Park, the Kitching Exploration Centre at Nieu-Bethesda, and the Cradle of Mankind in Gauteng. These initiatives provide lots of up-to-date information from professional palaeontologists and well-trained local guides, while access to the fossils concerned is well controlled.

There is very real concern within the palaeontological community, however, about the proliferation of uncontrolled palaeotourism in this country. This involves visits to sometimes remote fossil sites by poorly- or unsupervised groups, often led by tourism professionals with little knowledge about palaeontology or appreciation for the sensitivity of fossil material and sites. Some private landowners in the Karoo have proved reluctant to permit fossil collection by academic palaeontologists because this undermines the ecotourism potential of their land. Even well-intended educational initiatives have inadvertently led to damage of fossil heritage (*eg* fossil sites near Clarens). Concern is most acute among palaeontologists dealing with especially sensitive fossil vertebrate remains such as Karoo reptiles and Caenozoic hominin sites. Fossils of "lower" groups have also been subject to unauthorised, and usually incompetent collection, however, such as stromatolites at Boetsap in the Northern Cape, Devonian invertebrates in the Western Cape, or rare vendobiontans in southern Namibia.

In response to these concerns a lengthy Palaeotourism Protocol was drafted for discussion by several members of the PSSA in 2002. Among its recommendations were a system for registration of all fossil sites to be made available for palaeotourism, the employment by ecotourism operators of accredited specialist guides on site visits (*cf* rock art sites), and the development of a code of ethics for landowners regarding fossil sites under their control. Other PSSA members felt that a control-orientated approach was likely to fail, even if sympathetic new legislation could be promulgated. More effective, proactive public education, more consistent and generous feedback to landowners and communities from the palaeontological comminuty, combined with vigorous pursuit of individuals and organisations that contravened the existing National Heritage Resources Act were seen as more realistic options. This controversial but important issue remains unresolved.

2. Education

At South African schools key topics such as fossils, evolution, extinction and environmental change through time are now well represented in the Revised National Curriculum for science education at both junior (GET) and senior (FET) levels. The new Grade 10 science syllabus (History of Life and biodiversity: History of life on Earth), for example, includes coverage of "Key events in life's history for which there is evidence from southern Africa".

For the most part, science teachers are ill prepared to handle these topics in the classroom, however. The situation is exacerbated by resistance to exposing learners to evolutionary “propaganda” among many parents and teachers as well. Although new South African textbooks are becoming available, in many cases these still mainly refer to overseas examples. There remains a shortfall in accessible material – including fossil displays, good illustrations of fossils and reconstructions of extinct organisms, written and web-based material - on South African “fossil stories” to give local relevance to these new concepts.

3. Palaeosites & fossil conservation

A list of key Geosites – *ie* sites of outstanding geological significance, educational and heritage value – is being compiled by the Conservation and Geotourism Committee (CGC) of the Geological Society of South Africa. Proposed Geosites in the Northern Cape include the Augrabies Falls near Upington, the Nieuwoudtville waterfall, glacial pavements with petroglyphs in the Kimberley area (*eg* Nooitgedacht), Verneuk Pan near Brandvlei, and Salpeterkop, a Cretaceous volcano near Sutherland. There are numerous other candidates for Geosite status, a number of them man-made, in this vast province with its wealth of exceptional geological exposures. Examples are the Big Hole at Kimberley, the spring Eye of Kuruman, Simon van der Stel’s 1685 copper mine near Okiep, the Black Rock manganese ore exposure near Hotazel, orbicular diorite near Okiep, specularite mines at Blinkklipkop near Postmasburg, and Snowball Earth tillites in the Richtersveld.

It is a matter of some urgency that a comparable inventory and conservation status assessment of fossil Palaeosites be compiled for each province. This would be undertaken with a view to ensuring long-term protection for these sites as well as provision – where appropriate – of on site and other information for the general public. This project would require the systematic review of recorded fossil sites representing all the fossiliferous stratigraphic units in each province, giving priority to those that are of key palaeontological importance and high sensitivity. Compilation of such databases is part of the mandate of SAHRA and HWC but would be best achieved in collaboration with the PSSA and GSSA. Palaeosites might be recognised, for example, as a special subcategory of Geosites.

In the Northern Cape potential candidates for special protection as formally recognised Palaeosites include:

- spectacular stromatolites of the Early Proterozoic Transvaal Supergroup stromatolites at Boetsap (already damaged)
- latest Precambrian giant stromatolites at Swartbas on the banks of the Orange River
- rich marine trace fossil localities of the Devonian Bokkeveld Group in the Onder Bokkeveld area
- marine fossil sites of the lowermost Ecca Group near Douglas
- prolific Mid Permian fossil fish sites in with Whitehill Formation near Loeriesfontien
- Ecca trace fossil assemblages at Brassefontein / Sakrivier near Brandvlei, or the historically important “eel fish” locality near Calvinia mentioned by Lichtenstein (1803)
- Late Permian Gansfontein palaeosurface near Fraserburg (fossil trackways)
- Late Permian fossil fish localities (*eg* Blourug) in the Beaufort Group near Victoria West

- Cretaceous / Palaeogene crater lake sites in Bushmanland and elsewhere (*eg* Banke, Kangnas, Stompoor)
- Miocene vertebrate fossil localities along palaeodrainage systems of the interior (*eg* Bosluispan, Arrisdrift Formation of the lower Orange River)
- Key exposures of fossiliferous Late Caenozoic sediments of the West Coast Group along the Namaqualand coast, including abandoned diamond mining sites

Some potential Geosites / Palaeosites of late Caenozoic age – such as the Vaal River gravels at Kanteenkoppie and elsewhere, or Wonderwerk Cave near Kuruman – are also, or primarily, of considerable archaeological significance. Please note however that, as emphasised elsewhere, a site-based approach to fossil conservation cannot provide adequate protection for the greater part of palaeontological heritage which is largely hidden and *not* site-specific.

4. Recommendations

As they stand the SAHRA and HWC provincial palaeotechnical reports are essentially a management tool to facilitate the rapid assessment of the potential palaeontological sensitivity of proposed developments in their respective regions. However, since they provide a brief overview of known fossil heritage within each province, the reports could also serve as an effective springboard for further educational initiatives to promote better awareness and conservation of fossil heritage outside the formal heritage impact "industry".

Such initiatives, might include, for example:

1. Making the report, or a modified version thereof, freely available to interested parties – including EIA and HIA organisations and developers - not only as **hard copies** or on **CD** but also on approved **websites** (*eg* SAHRA website, provincial websites, existing PSSA website and/or a new dedicated fossil heritage website).

Iziko Museums Cape Town are developing an ambitious SA biodiversity website that will incorporate fossil material and perhaps cross-references to items on fossil sites (Dr Hamish Robertson, pers. comm.. 2008). The PSSA are considering the development of an educational South African fossil website to showcase local palaeontological heritage. Palaeontological data from the SAHRA reports, illustrated appropriately, would usefully complement these and similar internet projects.

2. Publication of a well-illustrated colour **booklet** on the fossil heritage of each province, placing the most interesting local fossils in a geological and palaeoenvironmental context (*eg* outcrop illustrations, visually attractive reconstructions of ancient biotas and habitats). Such a booklet should be designed to appeal to interested adults (including ecotourists), teachers and learners, as well as those professionally involved in heritage management. The necessity to conserve our fossil heritage should be emphasised, and reference made to educational fossil displays and publicly accessible sites in the province.

3. Public awareness of provincial fossil heritage can also be enhanced through publication of attractive **brochures** and **posters**, as well as **DVDs**. Obviously, additional sponsorship needs to be sought to realise many of these projects.

4. Development of a systematic **inventory of the most important recorded fossil sites** (**Palaeosites**) in each province in collaboration with bodies such as the PSSA and the Geological Society of South Africa (GSSA), as discussed above.

5. Development of stimulating **teaching materials for schools** that are geared towards the new GET and FET school science syllabuses and emphasise fossil heritage occurring in each province (*eg* worksheets, information sheets, posters, fossil replicas, colour illustrations, reconstructions). Collaboration with the provincial education department as well as experienced teachers and curriculum advisors is obviously required here.

6. Promotion of **educational displays on local and provincial fossil heritage at provincial museums** and other appropriate institutions (*eg* provincial offices of the Council for Geoscience). There are several isolated local museums in the Northern Cape with very small budgets and a limited amount of local fossil material, but little or no in-house knowledge concerning its significance or how best to use the fossils for display / educational purposes. A sponsored, province-based programme to provide display educational materials - such as rocks, fossils, time charts, posters, geological maps, brochures, illustrations and explanatory information on local fossils - could promote geological and fossil heritage in a cost-effective way and be usefully integrated with a network of local and provincial Geosites / Palaeosites. Note that displays need regular monitoring and periodic upgrading.

10. NORTHERN CAPE PROVINCE FOSSIL HERITAGE: KEY REFERENCES

This list includes key references, especially more recent review papers and books, directly concerning or relevant to fossil heritage within the stratigraphic units covered by this report. The tables in the report were compiled from a more extensive list of technical papers, as well as a considerable body of unpublished data.

NB. Some additional references mentioned in Section 6 on the history of palaeontology in the Northern Cape have still to be incorporated here.

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This list includes key references, especially more recent review papers and books, directly concerning or relevant to fossil heritage within the stratigraphic units covered by this report. The tables in the report were compiled from a more extensive list of technical papers, as well as a considerable body of unpublished data.

NB. Some additional references mentioned in Section 6 on the history of palaeontology in the Northern Cape have still to be incorporated here.

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APPENDIX 1: GLOSSARY OF SOME COMMON TECHNICAL TERMS

For unfamiliar groups of fossils, geological terms (*eg* periods of geological time), consultation of a standard geology textbook or dictionary is recommended (See References).

acritarch – miscellaneous assemblage of probably unrelated organic-walled microfossils of uncertain affinity, mainly marine, of Precambrian to Recent age

aeolian sediments (aeolianites) = sediments deposited by wind (*eg* dune sands)

archaeology = the scientific study of the behaviour, history, culture, evolution and environment of ancient humans (Genus *Homo*) and their close relatives, mainly based on their artefacts and sites where they were active. The archaeological record stretches back some 2.5 *million* years in time. Compare palaeontology below.

BIF = banded ironstone formations - sedimentary rock composed of alternating bands of iron ore and chert

biomat = thin sediment layer bound together by mucilaginous microbes (*eg* cyanobacteria)

biostratigraphy = the correlation of rocks of similar age using fossils

biozone (or **assemblage zone**) = stratigraphic unit defined on basis of occurrence of one or more biostratigraphically significant **zone fossils** (*eg* vertebrate assemablge zones of the Great Karoo Basin)

calcrete = lime-cemented pedocrete

carbonates = sediments composed of carbonate minerals (*eg* limestone, dolomite, calcrete)

chert = very fine-grained / cryptocrystalline or amorphous (non-crystalline) siliceous sedimentary rock (*eg* flint)

clastic sediment – sediment composed of aggregate of transported rock fragments & mineral grains (*eg* conglomerate, sandstone, limestone breccia, tillite)

coprolite = fossil faeces (*eg* hyaena dung)

cyanobacteria – important subgroup of photosynthetic bacteria, previously known as blue-green algae

diamictite – very poorly sorted clastic sediment composed of large rock fragments embedded in a fine-grained matrix. Typical examples are glacial tillites and scree deposits

diatomite = fine-grained siliceous sediment composed largely of the tiny shells of diatoms, a group of unicellular algae (= diatomaceous earth)

duricrust = pedocrete (qv)

evaporites = sediments precipitated as result of evaporation of highly saturated solutions, such as brines (*eg* rock salt / halite, gypsum)

eurypterid = extinct group of aquatic predatory arthropods closely related to scorpions and king crabs (= water scorpion)

fluvial sediments = deposited by rivers (alluvium)
foraminiferan (foram) = important marine group of planktic or bottom-dwelling amoeboid protozoans, usually with a shell of calcium carbonate

fossiliferous = fossil bearing

Ga = billions of years old

gastrolith = stomach stone (*eg* of dinosaur, bird)

ichnofossils = trace fossils (qv). An assemblage of trace fossils is an ichnoassemblage

igneous rock = rock formed by cooling or crystallisation of a rock melt or magma (*eg* basalt, dolerite, granite)

intrusion = igneous body formed by the underground crystallisation of magma that has been forced into the surrounding "country" rocks (*eg* granite pluton, dolerite dyke or sill)

lacustrine sediments = deposited in lakes

laterite = red, iron-rich soils formed from highly weathered bedrock

lignite = incompletely coalified plant material with a woody structure, intermediate in grade between peat and bituminous coal; often Tertiary in age

Ma = millions of years old

macrofossils = substantial-sized fossils that can be seen with the naked eye (macroscopic)

member = subdivision of a sedimentary rock formation characterised by distinctive lithology (rock type), palaeontology and / or other features (*eg* Soom Member of Cederberg Formation)

metasediments = metamorphosed sediments (*eg* quartzite = metamorphosed sandstone). **High grade metasediments** = sedimentary rocks that have been strongly metamorphosed, and therefore not fossiliferous (*eg* schist, gneiss), as opposed to **low grade metasediments** that have only been slightly metamorphosed, and may therefore still contain fossils (*eg* quartzites, slates)

metavolcanics = metamorphosed volcanic rocks

metazoan = multicellular animal (*cf* unicellular protozoans)

microfossils = microscopically small fossils (*eg* pollen, spores, acritarchs, foraminiferans)

microvertebrates = disarticulated skeletal remains of large- or small-bodied vertebrates, such as isolated bones, scales and teeth

oncolites, oolites = rounded structures formed in carbonate settings through accretion or precipitation of concentric layers round a central core, under the influence of currents

palaeontology = the scientific study of ancient ("prehistoric") life, from bacteria and biomolecules to bananas and bigwigs. This field mainly concerns organisms other than humans, but also includes the scientific study of fossil humans and their primate relatives (palaeoanthropology) as well as the study of animal and plant remains at archaeological sites (archaeozoology, archaeobotany). There is therefore considerable overlap and cross-fertilisation with the field of archaeology (qv) which has a specifically human emphasis. The palaeontological record stretches back some 3.5 billion years in time.

palynomorphs = organic-walled microfossils of plant, or plant-like origin (*eg* spores, pollens)

pedocretes = secondarily cemented soils (*eg* lime-cemented **calcretes**, silica-cemented **silcretes**, ferruginous cemented **ferricretes**)

pseudofossil = fossil-like structure found in rocks that does not have a biological origin (*eg* fern-like mineral dendrites)

regression = retreat of the coastline due to sea-level fall

rhizolith (**rhizomorph**) – fossilised root cast in ancient soil horizon

shelly fossils = macroscopic invertebrates with mineralised shells (*eg* molluscs, trilobites)

silcrete = silica-cemented pedocrete

siliciclastics = sediments mainly composed of silicate minerals (*eg* quartz, feldspar, clays), as opposed to **carbonates** (see above)

soft-bodied = unmineralised (*eg* tissues other than bones, teeth, shells)

stromatolite = finely-laminated horizontal, dome-shaped or columnar structures formed by rhythmic growth and sediment trapping by bottom-dwelling microbes (*eg* cyanobacteria); usually preserved in carbonates, freshwater or (mostly) marine

submarine fan = conical-tapering subaqueous deposit usually formed in deep sea or lake by succession of turbidites (qv)

termitarium = termite nest (fossil examples usually calcretised)

tetrapod = four-legged, air-breathing vertebrate, including amphibians, reptiles, birds and mammals and their extinct relatives, but not fish

therapsids ("mammal-like reptiles") = major subgroup of tetrapods that dominated terrestrial ecosystems during the later Permian and earlier Triassic Periods and eventually gave rise to the mammals

thrombolites = stromatolite-like microbial mounds with a distinctive "clotted" rather than laminar texture inside

tillites = glacial sediments

trace fossils / **ichnofossils** = fossilised animal behaviour in the form of burrows, borings, trackways, coprolites, tools and the like
transgression = invasion of coastal area by the sea as refult of sea level rise (*cf* regression)

tufa = calcareous (or siliceous) rock formed by precipitation from springs, seeping water in cave systems (*eg* flow-stone)

tuffs = volcanic ashes

turbidite = bed of sediment deposited by a submarine avalanche or turbidity flow

vascular plants = terrestrial plants with well-developed vascular transport tissues (xylem, phloem) such as ferns, gymnosperms, angiosperms (but not mosses, algae)

vendozoans / **vendobiontans** = problematic macroscopic fossils of late Precambrian (mainly Ediacaran) age with a peculiar quilted or tubular substructure, controversial biological affinities

volcanic rocks = igneous rocks formed by the eruption of molten magma / lava at the Earth's surface (*eg* basalt, rhyolite)

zone fossil = fossil taxon (usually a species) used to define a particular time interval within one or more sedimentary successions (*eg* ammonite species for marine Cretaceous rocks, or therapsid species for terrestrial Permian rocks)

APPENDIX 2: 1:250 000 SCALE GEOLOGY SHEETS & SHEET EXPLANATIONS, NORTHERN CAPE

The 1: 1 000 000 geological map of the RSA (4 sheets) published by the Council for Geoscience, Pretoria (previously the Geological Survey) provides a very useful overview of the geographical distribution of fossiliferous and other rock units within South Africa.

Most of the vast area of the Northern Cape Province has been mapped at 1: 50 000 scale on at least reconnaissance level by the Council for Geoscience, Pretoria, on the basis of fieldwork and remote sensing (*eg* satellite and aerial photographs).

The province is covered by no less than 28 maps at 1: 250 000 scale, as shown on the plan in **Figure A2.1**. The majority of these geological maps have now been compiled and published by the Council, each accompanied by a separate sheet explanation (*NB* Some of these explanations are only available in Afrikaans, while a few maps have brief explanations printed on the same sheet). Several geological sheets and explanations have been compiled but are not yet published (*eg* Loeriesfontein, Garies, Alexander Bay), and others are currently being revised (*eg* Clanwilliam).

The level of attention paid to palaeontology varies markedly between sheet explanations, depending on the interests and priorities of the compilers and the stratigraphic units present in the area mapped (**Table A2.1**). For the most part, fossils are only mentioned in passing, or largely neglected, in sheet explanations for Northern Cape geology maps, even where extensive fossiliferous units are present. Therefore these publications usually do not constitute as useful a resource on local palaeontological heritage as might be expected.

1: 250 000 SCALE GEOLOGICAL MAPS, NORTHERN CAPE			
Sheet Name & Number	**Mapping status**	**Sheet Explanation**	**Palaeontology coverage**
2520 Nossob	published, 1988	Thomas *et al*. (1988), 17 pp.	moderate (Caenozoic) to poor (Palaeozoic)
2620 Twee Rivieren			
2622 Morokweng			
2720 Noenieput	published, 1988	Thomas & Thomas (1989), 16 pp.	moderate (Caenozoic) to poor (Palaeozoic)
2722 Kuruman			
2724 Christiana	published, 1994	Schutte (1994), 58 pp.	poor
2816 Alexander Bay	compiled 2008 (due 2009)	compiled by Minnaar *et al*. (due 2009)	extensive (J. Almond *et al*)
2818 Onseepkans	published 2008	Moen & Toogood (2007), 101 pp.	v. poor (mainly basement rocks in area)
2820 Upington	published, 1988	Moen (2007), 160 pp.	absent (though fossiliferous sediments present)
2822 Postmasburg			
2824 Kimberley	published, 1993	Bosch (1993), 60 pp.	poor
2916 Springbok	published, 2001	Marais *et al*. (2001), 103 pp.	moderate to poor (including Nama Group)
2918 Pofadder	published 2008	Agenbacht (2007), 89 pp.	moderate (Mainly basement)
2920 Kenhardt	published, 1998	Slabbert *et al*. (1999), 123 pp.	poor
2922 Prieska	published, 1995	not yet published	
2924 Koffiefontein	published, 1992	Zawada (1992), 30pp	poor, almost absent
3017 Garies	map compiled (due 2008)	compiled by C. De Beer (due 200?)	limited (mainly basement rocks)
3018 Loeriesfontein	map compiled (due 2009)	compiled by P. Macey *et al*. (due 2009)	extensive (J Almond)
3020 Sakrivier	published, 1990	Siebrits (1989), 19 pp.	modest
3022 Britstown	published, 1991	Prinsloo (1989), 40 pp.	modest
3024 Colesberg	published, 1997	Le Roux (1993), 12 pp.	poor
3118 Calvinia	published, 2001	De Beer *et al*. (2002), 92 pp.	extensive
3120 Williston	published, 1989	Viljoen (1989), 30 pp	modest
3122 Victoria West	published, 1989	Le Roux & Keyser (1988), 31 pp.	extensive
3124 Middelburg	published, 1996	Cole *et al*. (2004)	extensive
3218 Clanwilliam	published, 1973 (revision compiled 2008, due 2009)	no separate sheet explanation new one in preparation	extensive (Almond *et al*.)
3220 Sutherland	published, 1983	Theron (1983), 29 pp.	modest
3222 Beaufort West	published, 1979	Johnson & Keyser (1979), 14 pp.	modest

Fig. A2.1. Summary of 1: 250 000 geological maps and sheet explanations covering the Northern Cape.

Fig. A2.1. PLAN OF 1: 250 000 GEOLOGICAL SHEETS COVERING THE NORTHERN CAPE PROVINCE (*NB* not all these geological maps have been published)

APPENDIX 3: NORTHERN CAPE FOSSIL COLLECTIONS

This list is necessarily incomplete, but can be updated as more data become available.

1. FOREIGN MUSEUMS

American Museum of Natural History, New York
Important early collection of Karoo vertebrates, illegally sold to the museum for private gain by Robert Broom (*cf* MacRae 1999)

Natural History Museum, London
Important nineteenth century collections of Karoo vertebrates made by AG Bain, Thomas Bain, HG Seeley, WG Atherstone, J.H. Whaits, A "Gogga" Brown, D.R. Kannemeyer and other pioneers. Includes important type material described by Richard Owen, T.H. Huxley and others (*cf* MacRae 1999).

Musee d'Histoire Naturelle, Paris
Type specimen of *Mesosaurus* from Kimberley (MacRae 1999).

National Earth Science Museum, Windhoek
Geological Survey of Namibia
Collections from the Nama Group, Miocene Arrisdrift Formation etc from southern Namibia that are of direct relevance to N. Cape palaeontology

2. SOUTH AFRICAN COLLECTIONS OUTSIDE THE NORTHERN CAPE

Bernard Price Institute for Palaeontology
University of the Witwatersrand
JOHANNESBURG, Gauteng
bpipal@geosciences.wits.ac.za
(011) 717-6685
Major collections of most groups and stratigraphic intervals, especially from the Main Karoo Basin.

For educational purposes, see also the following facility run by the BPI near Graaff-Reinet in the Eastern Cape:
Kitching Fossil Exploration Centre
Nieu-Bethesda, Eastern Cape
(049) 849-1733
Educational displays and fossil tours relevant to Karoo Basin Palaeontology.

Transvaal Museum
Paul Kruger Street, PRETORIA, Gauteng
PO Box 413, Pretoria, RSA 0001
Tel: (012) 322 7632
Extensive collections, including Robert Broom specimens.

Iziko South African Museum
Victoria Street, CAPE TOWN, Western Cape
(021) 481-3800

Extensive collections of most fossil groups and stratigraphic intervals, especially Main Karoo Basin.

Karoo National Park
BEAUFORT WEST, Western Cape
Material displayed on Fossil Trail and Interpretation Centre relevant to Karoo Basin as a whole.

Albany Museum
Somerset Street
GRAHAMSTOWN 6139, Eastern Cape
(046) 622-2312
Holdings of N. Cape material unknown at present.

National Museum
BLOEMFONTEIN, Free State
Extensive collections from the Karoo Basin and Caenozoic of the interior.

Council for Geoscience, Bellville
Important collections from the Nama and Vanrhynsdorp Groups, Cape Supergroup, Ecca Group

Council for Geoscience, Pretoria
280 Pretoria Street
Silverton, Pretoria
(012) 841-1911
Major collections of most groups and stratigraphic intervals, especially Main Karoo Basin, Cape Supergroup

Natal Museum
Private Bag 9070
Pietermaritzburg 3200
KwaZulu-Natal
Some fossils from the Karoo of the N. Cape (*eg* Ecca Group, Kimberley)

Rubidge Collection (Private)
Nieu-Bethesda, Eastern Cape
Key collections of Karoo vertebrates, including many types described by Broom and others. Visits by appointment only.

3. NORTHERN CAPE MUSEUMS

Institutions that might hold, as well as those known to have, fossil collections from the Northern Cape are listed here. In many cases, such as most of the small local museums, there is probably no formal inventory of fossils in their collections. Indeed, they are often unaware of the identity or potential value of palaeontological material in their care. It is important that a comprehensive database of fossil collections held in Northern Cape Museums is compiled, appropriate levels of curation are assured, and that institutions are assisted to make the most of specimens in their care for educational, display and research purposes.
Selected sites of geological importance (jncluding Geosites) are also mentioned here.

Alexander Bay

Small collection of local fossils (James Brink, pers. comm.. 2008) – probably from West Coast Group.
Important area for diamond mining and West Coast group fossils (*eg* Oyster Band of Hans Merensky, 1927)

Barkley West Museum

Display of archaeological and geological material from Pleistocene and older Vaal River gravels (*eg* famous Canteen Kopje site nearby).
Archaeological material also displayed at the Cultural History Museum.
Important Geosite – Nooitgedacht glacial floor (Dwyka age) – situated between Kimberley and Barkley West (Contact: McGregor Museum, Kimberley).

Brandvlei

Verneukpan – potential Geosite.
Brassefontein / Zak Rivier – potential Ecca Palaeosite

Britstown Museum
Raath Street (originally Holy Trinity Church)
Fossil collections?

Calvinia Museum
(027) 341-1043 / 8500
Focus on cultural history, 4-legged ostriches…
Fossil collections?
Historical Ecca "eel fish" fossil site of Lichtenstein (1803) at Onder Downes nearby.

Carnarvon Museum
Small collection of Ecca fossils, including traces and petrified wood.

Colesberg-Kemper Museum
Murray Street, Colesberg
(051) 753-0678
Small nineteenth century collection of local Karoo fossils (esp. palaeoniscoid fish, therapsids).

Danielskuil
Local sinkhole Boesmansgat on farm Mount Carmel is reputed to be second deepest ands largest in the world.

Douglas
Important site for marine fossils from uppermost Dwyka / lowermost Ecca Groups – potential Palaeosite.

Fraserburg Museum
Old Rectory
One of best local museum fossil displays in the N. Cape (in collaboration with Iziko Museum, Cape Town). Focus on Karoo tetrapods – pareiasaurids, therapsids, palaeoniscoid fish, petrified wood *etc*.

Gansfontein palaeosurface (Palaeosite / Geosite) showing well-preserved Permian trackways and other trace fossils is nearby (See Geosite brochure by C. de Beer).

Griquastad / Griquatown – Mary Moffat Museum
Main Street
Fossil collections?

Hotazel
Potential Geosite – Black Rock managenese ore exposure

Hopetown
First diamond discovery in South Africa by Erasmus Jacobs (1866) – "Eureka" diamond - from alluvial gravels of Orange River (Potential Geosite)

Kakamas
Augrabies Falls – potential Geosite (major waterfall and gorge cut through basement granites)

Kathu

Potential Geosite - world's largest open-cast iron mine. Precambrian Banded iron formations (BIF).

Kimberley McGregor Museum
Atlas Street, Kimberley
(053) 839-2700
http://www.museumsnc.co.za
Extensive fossil collections from range of stratigraphic units in the Northern Cape = key provincial palaeontological collection, managed by archaeology department.
See also:
Kimberley Mine Museum adjacent to the Big Hole diamond mine (potential Geosite)
Tucker Street, Kimberley 8301
(0531) 31557/8/9

Kuruman
The Eye (Gasegonyana) – major spring draining Ghaap Plateau dolomites – portential Geosite
Wonderwerk Cave between Kuruman and Danielskuil – important archaeological and Pleistocene palaeontological site (National Heritage Site). Managed by McGregor Museum, Kimberley.
(053) 384-0680, 082-832-7226
Moffat Museum
Moffat Lane
(053) 712-1352
fossils unlikely

Loeriesfontein
Potential Palaeosites for fossils from the Whitehill Formation.

Nababeep Museum
Focus on history of copper mining in the area
Fossil collections?

Nieuwoudtville
Potential Geosite – Niuewoudtville waterfall
Key area for Precambrian / Cambrian trace fossils

Postmasburg
Potential geosite – ancient specularite mines at Blinkklipkop

Prieska Museum
Victoria Street
(053) 691-2242
Fossil collections?

Springbok – Namaqualand Museum
Old Synagogue
(027) 718-8100
Fossil collections?
Local potential Geosites include Orbicular diorites and Simon van der Stel;s copper prospect near O'Kiep

Sutherland
SAAO – display of fossils relating geological time to cosmic phenomena.
Potential Geosite – Salpeterkop (Cretaceous volcano, with crater lake sediments)

Upington
Council for Geoscience - Regional Office for Northern Cape
Josling Street 24, Upington
(054) 332-1403
Educational fossil display in preparation
See also:
Kalahari-Oranje Museum
Schroeder Street, Upington
(054) 332-6064
Fossil collections?

Victoria West Museum
47 Church Street
Victoria West 7070
(053) 621-0413
Important Karoo fossil displays (B.J. Kempen Hall), focussing on well-preserved palaeoniscoid fish from nearby Beaufort Group site of Blourug.

Williston Museum
Old Mission Building
Small fossil collections, including *Mesosaurus*.

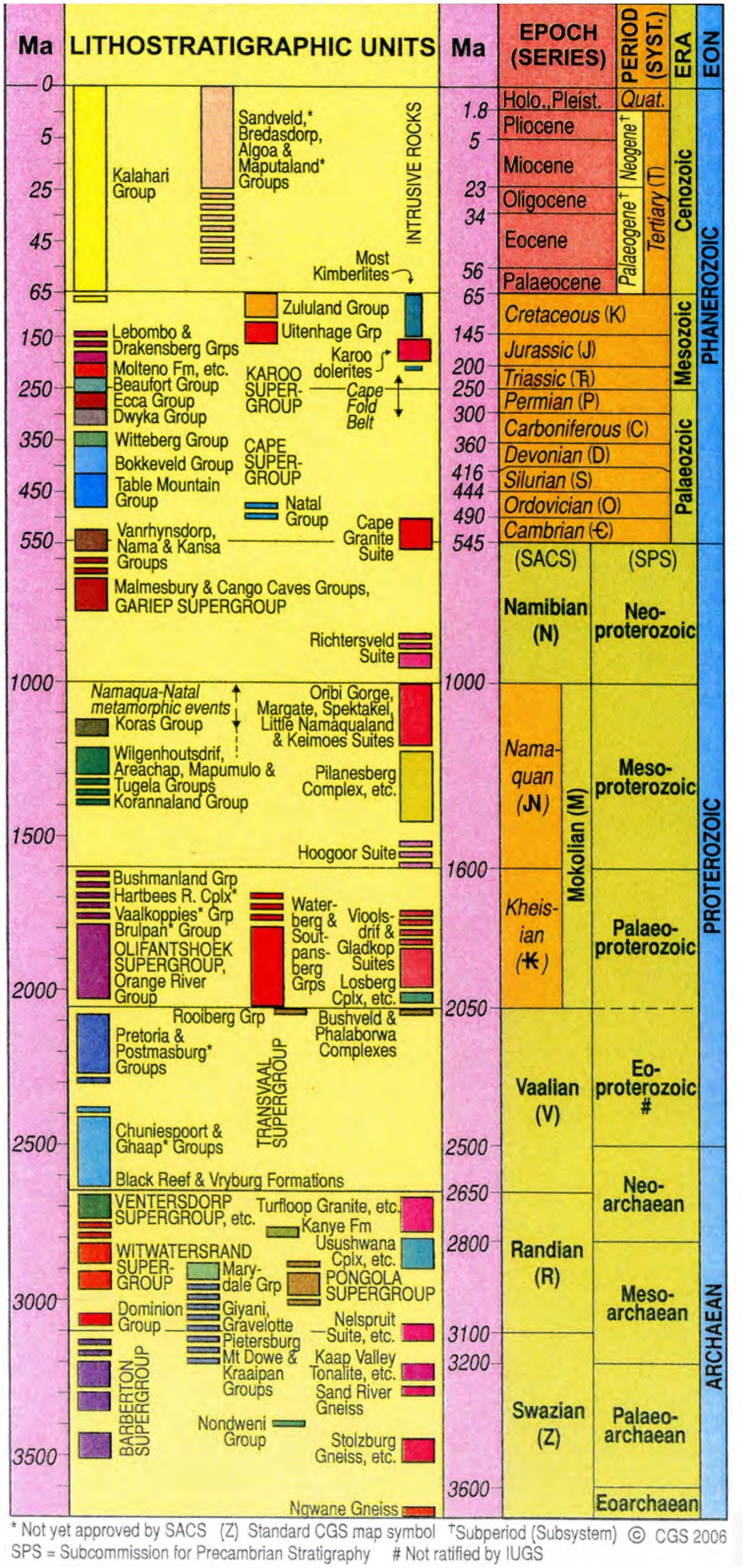

Fig. 7.1. Simplified stratigraphic table for South Africa
(From Johnson *et al*. 2006. *The geology of South Africa*. Published by the Council for Geoscience, Pretoria)

Fig. A2.1. PLAN OF 1: 250 000 GEOLOGICAL SHEETS COVERING THE NORTHERN CAPE PROVINCE (*NB* not all these geological maps have been published)