

THE KAROO, A GEOLOGICAL AND PALAEOONTOLOGICAL SUPERLATIVE: ECONOMIC POTENTIAL OF DEEP HISTORY

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Abstract

Rocks of the Karoo Basin preserve a world class assemblage of fossils which document the early evolution of tortoises, dinosaurs and mammals. These rocks, deposited over an extensive period from the Late Carboniferous (300 million years ago) to the Early Jurassic (180 million years ago), witnessed environmental change from glaciers, through aeolian desert dunes, and culminating in vast outpouring of volcanic lava. This is the only place in the world where such an extended fossil record of early evolution of “reptilian” life is preserved in a single basin, and chronicles the most distant evolutionary ancestry of mammals in remarkable detail. Apart from being a pivotal area for the study of early “reptile” biodiversity and evolution, it also offers great potential for palaeotourism and job creation if properly managed, but could lead to irreparable damage to this precious heritage resource if exploited inappropriately.

Introduction

Because of the unique antiquity of its geological record, South Africa is the single country in the world which has: the oldest evidence of life on Earth; the oldest multi-cellular animals; the most primitive land-living plants; the most distant ancestors of dinosaurs; the most complete record of the more than 80 million year ancestry of mammals; a remarkable record of human origins and of human achievements through the last four million years. In fact it is not possible to write a comprehensive text on the development of life on earth without referring extensively to the South African fossil record. In recognition of this, the South African Government identified Palaeontology and Palaeoanthropology as one of five key research themes in its National Research and Development Strategy of July, 2002.

Many of these superlatives are centred on the rocks of the Karoo Basin (fig. 1) which span a time period from the Late Carboniferous (300 million years ago) to the Early Jurassic (180 million years ago) and preserve a world class assemblage of fossils which document the early evolution of tortoises, dinosaurs and mammals. During this time the environment changed from a landscape covered by glaciers, through an inland sea, progressively arid fluvial deposition, aeolian desert dunes, and culminating in vast outpouring of volcanic lava. This is the only place in the world where such an extended record of early evolution of “reptilian” life is preserved in a single basin, and apart from being a pivotal area for the study of early tetrapod biodiversity and evolution, it also offers great potential for palaeotourism if properly managed.

Evolutionary History of the Karoo Basin

During the Late Carboniferous (300ma) southern Africa, being part of the supercontinent Gondwana, was situated within polar latitudes and was covered by continental ice sheets

and glaciers. The deposits of these glaciers today form thick sequences of tillite (type of rock deposited by glaciers) of the Dwyka Group (Smith 1990).

As Gondwana, including the present day southern Africa, began to drift north out of polar latitudes, the ice sheets melted completely, giving rise to a large inland sea in which the earliest reptiles from Gondwana lived. These aquatic forms, called mesosaurs, have been found only in South Africa, Namibia, and Brazil and prove the existence of a shallow sea stretching between these countries, further evidence that Africa and South America were once joined (Oelofsen and Araujo 1987).

At the same time as the mesosaurs flourished in this newly formed inland sea, a major mountain chain began to develop south of the present shoreline of South Africa as a result of Andean-style collision of the Palaeo-Pacific plate under the African plate (Johnson et al. 1997). This mountain range, the remnants of which today make up the Cape Folded Mountain belt, was higher than the modern Himalayas. As a result this formed an upland from which most of the sedimentary fill of the Karoo basin was derived.

Rivers draining this highland transported sediment into the inland sea and formed large, Mississippi -style deltas. The resulting deposits today comprise the rocks of the Ecca Group. In the northern part of the basin, these deltaic deposits accumulated thick peat sequences dominated by the famous *Glossopteris* flora, which has a distribution across all Gondwanan countries and have given rise to economically important coal reserves (Cadle et al. 1993; Cairncross 1989).

As the Ecca sea filled with sediment through time, and the deltas prograded basinwards, large tracts of river channels and floodplains became emergent. This led to the development of extensive fluvial floodplains constituting the oldest rocks of the Beaufort Group. These floodplains were inhabited by the earliest land-living reptiles known from the southern hemisphere (Rubidge 1995). Initially, this early terrestrial environment was restricted to the southwestern parts of South Africa (Rubidge 2000; Modesto et al. 2001a), but with time it expanded to cover most of the country and provided an ideal habitat for the diversification and evolution of these early reptiles.

After deposition of the Beaufort Group fluvial deposition continued and the rocks of the overlying Moltene Formation (fig. 1) were deposited mainly by shallow, braided rivers (Hancox 2000) and are host to abundant fossils of the seed-fern *Dicroidium* as well as insects and fish. Rocks of this Formation provide an unrivalled window into Late Triassic plant and insect biodiversity, close to the time of the origin of dinosaurs, mammals, and possibly the flowering plants (Anderson et al. 1999). Up till now, no fossils of reptiles have been discovered in the Moltene Formation, but the presence of fossilised trackways record the earliest presence of dinosaurs in southwestern Gondwana (Raath et al. 1991).

By contrast, the overlying rocks of the Elliot Formation, deposited as sediment in an arid fluvial floodplain environment, preserve a wide variety of reptilian skeletal remains

including the recently described large sauropod dinosaur *Antetonitrus* (Yates and Kitching 2003) and a smaller prosauropod known as *Massospondylus* (Kitching and Raath 1984). Also present in this formation is the oldest known tortoise from Africa (*Australochelys*) (Gaffney and Kitching 1994), and some of the earliest mammals (*Megazostrodon* and *Erythrotherium*) (Gow 1986).

Progressive aridification culminated in large aeolian desert sand dune deposits which are preserved today as spectacular golden cliff faces of the Clarens Formation (Visser 1984; Smith 1990). Coupled with this desertification in the Jurassic Period, early fragmentation of Gondwana led to vast outpourings of continental flood-basalts. These extensive lava deposits today make up the Drakensberg Mountains.

Fossil heritage

The first fossil reptiles from the Karoo were found in the 1830's by Andrew Geddes Bain, and were the first specimens of a new group of "reptiles" called the therapsids which were recognized as being the distant ancestors of mammals. Since then thousands more vertebrate fossils have been discovered in the rocks of the Karoo by such legendary names in palaeontology as Robert Broom, Sidney Haughton and James Kitching, and are housed in various fossil collections around the country.

In general "reptiles" are classified into three large groups. Anapsids are today represented by the tortoises, but during Permian-Triassic times a variety of these forms flourished and are well represented by numerous forms from the Permian Beaufort Rocks of South Africa of which the most notable are the 3m long pareiasaurs. From early anapsids found in South Africa it has been suggested that the group diversified initially in southern Africa (Modesto 2000), and indeed one of the earliest tortoises from Gondwana *Australochelys* comes from near Clocolan in the Free State Province (Gaffney and Kitching 1994).

The second major group of "reptiles", synapsids, have only a single temporal opening. These forms are particularly well represented in the rocks of the Beaufort Group and are considered to be the ancestors of mammals. The Karoo rocks hosts the richest and most diverse assemblage of these animals. Previously the South African therapsids were considered to have had their origins in Russia but recent discoveries from South Africa suggests that many of these lineages may actually have arisen in southern Gondwana (Modesto, Rubidge and Welman 1999; Modesto and Rubidge 2000; Rubidge 1995). The uppermost Karoo sedimentary rocks are host to *Megazostradon* and *Erythrotherium*, some of the oldest and most primitive mammals known.

Also in the rocks of the Karoo are the diapsids, the third major group of reptiles. This group includes lizards, crocodiles, dinosaurs and birds. In the lowermost Elliot Formation the dinosaur *Antetonitrus* is present and is considered to be the oldest sauropod dinosaur (Yates and Kitching 2003) and higher in the Elliot Formation are some of the oldest and most primitive ornithischian dinosaurs (Butler et al. 2007).

Biodiversity changes

Because the rocks of the Karoo were deposited as sediment over an extended period of more than 180 million years and are rich in fossils, the Karoo provides a natural laboratory to study biodiversity changes over an extended period, and to study the effects of extinction events on biota. Five major global extinction events have been recognised over the past 500 million years (Raup and Sepkoski 1982). With the threat of the current “sixth extinction”, global mass extinction events and their impact on the biota of the time are receiving increased attention. Because the Karoo Supergroup records two of these “Big Five” events, it is an excellent place to study faunal diversity patterns through time, and specifically the periods relating to mass extinction events.

The greatest extinction event was the Permo-Triassic extinction which was responsible from the decimation of 70 % of creatures on land and 90% of marine creatures (Erwin, 1990, 1994) and is well preserved in the Karoo rocks on Lootsberg Pass north of Graaff-Reinet. It has been estimated that the Permo-Triassic extinction sequence took at least 50 000 years ($\pm 10\,000$ years) to accumulate, but could have been shorter (Smith and Ward, 2001). There is much debate surrounding the cause of this extinction event, but in the Karoo Smith and Ward (2001) consider that this event occurred during an environmental changeover from wet to dry floodplain environments, bringing about a faunal change to a recovery fauna comprising drought-tolerant taxa in the early Triassic.

The other biotic turnover event of the Karoo, recognised in the Elliot Formation, affected dinosaurs. It corresponds with the Triassic-Jurassic boundary, which has been recognised as one of the global mass extinctions. In South Africa, this event records a faunal changeover from large basal sauropod (Yates and Kitching 2003) and prosauropod dinosaurs to smaller forms such as *Massospondylus* (Kitching and Raath 1984). Until now this extinction has not received much attention in South Africa, but is the subject of current studies. A major problem in understanding the effect of this event in the terrestrial realm is the largely unresolved state of the taxonomy of early dinosaurs.

Palaeotourism

The opportunity to hunt for fossils in the field is one of the most stimulating aspects of palaeontological research, and little can match the excitement of discovering the remains of some prehistoric organism that has lain buried and unexposed for hundreds of millions of years. This requires the recognition of a tiny speck of bone protruding from the rock. It is the subsequent identification and excavation that requires the skill which makes the precious discovery a scientific masterpiece or disaster. The preservation of an organism as a fossil is dependent on a number of natural co-incidences including rapid burial of the organism after death to ensure it is not scavenged by predators or broken down by the elements. It is also essential that the substrate be the correct levels of alkalinity and acidity. The fact that a fossil is preserved at all is almost a miracle, and for this reason each fossil has to be treated with the utmost care and respect as it is impossible to manufacture another one if it is damaged. As fossil excavation proceeds every bit of information has to be accurately recorded – its position in the stratigraphic record, locality, orientation, representation. Back in the laboratory the actual slow and painstaking preparation of the fossil takes place as the preparator carefully and skilfully removes the bone from the surrounding rocky matrix taking special care not to damage

the precious fossil in any way. This process may take many months or even years. The recent preparation of an almost complete three metre long dinocephalian skeleton at the University of the Witwatersrand took 23 years to complete!

As it lies in the field the fossil may appear as only a tiny piece of protruding bone. The identification and further recognition of the significance of this discovery requires the experience and skill of a trained palaeontologist in order to interpret it for an untrained tourist and to make it exciting. In addition it is necessary to be able to make interpretations about the depositional environment from the surrounding rocks.

The full potential of palaeotourism has not yet been realised in South Africa, but already several threats have reared their ugly head. These need to be addressed before any palaeotourism can be allowed to proceed.

Fossils exposed and damaged by trampling – as tourists walk over potential fossil fields in the Karoo, new fossil discoveries will be made and others which have been exposed in the past will be eroded out of their rocky enclosure and so will be ripe for collecting. This requires treatment by somebody who has been trained to record all available evidence, and not just any tourist operator.

Fossils and fossil sites vandalised – experience has shown that once fossil sites have been utilised for tourism and shown to the public they get vandalised as tourists return to the sites and collect exposed bone, or else damage exposed bone by bashing away at it with a hammer or stone. Only those who have been trained in palaeontological procedures understand the uniqueness and significance of every occurrence.

Site access denied to palaeontologists – professional palaeontologists in South Africa have been forbidden access to farms by landowners to excavate fossils previously discovered by the palaeontologists as a result of unscrupulous “ecotourism” operators offering cash incentives to have the fossils left in situ. Although there is nothing wrong with this in principle, it could lead to palaeontologists being denied access to key research sites. This will result in the storyline, the lifeblood of the palaeotourism industry, being depleted.

These violations will lead to short term gains by a few unscrupulous operators, but would ensure the long term drain and destruction of a heritage which could provide a valuable source of income to an arid and impoverished part of South Africa. The only solution is close co-operation amongst all interest parties, scientists, landowners, tour operators, local authorities etc., so that all can benefit.

Solution

The Palaeontological Society of Southern Africa has formulated a Palaeotourism Protocol which addresses all the problems in an effort to enable palaeotourism to provide long term sustainable benefit to individuals and institutions. Key to this is the principle of beneficiation of the science to the benefit of the science so that the storyline presented to tourists is in line with recent scientific trends. In line with this approach sites for tourism

and suitable tourist routes should be identified, reputable travel and tourism companies should be approached, and only guides who have a valid collecting permit from SAHRA should be permitted to operate.

Conclusion

The rocks of the Karoo basin of South Africa preserve one of the most remarkable and extended sequences of terrestrial tetrapod development from the Permian to the Jurassic and provide the most complete documentation of the evolutionary development of early mammals in the world. In addition they provide a record of the evolving palaeoenvironments in which these changes in biodiversity occurred, and record the devastating effects of the “mother of all mass extinctions” (Erwin 1994) and the subsequent biotic recovery.

Although similar geological successions are present in India, China, and Russia, they are not as complete (Rubidge 2005). The global significance of the Karoo Supergroup lies in its representation of the most complete Permian-Jurassic sequence having implications for global biostratigraphic and correlative studies. This fragile heritage has unique opportunities for palaeotourism and job creation, if responsibly managed.

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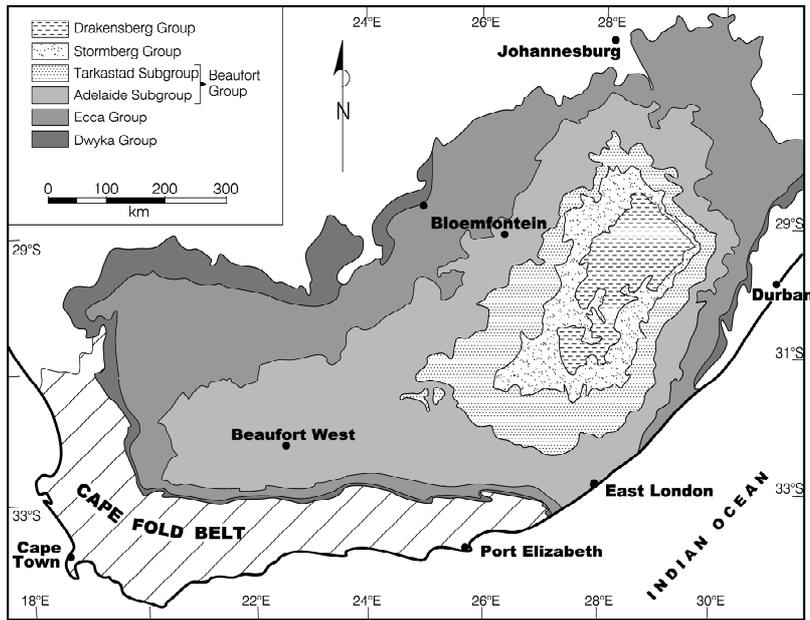


Figure 1: Distribution of the rocks of the Karoo Supergroup in South Africa.