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Neogene and Quaternary vertebrate biochronology of the Sperrgebiet and Otavi Mountainland, Namibia

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Since 1991, the Namibia Palaeontology Expedition has discovered well over 100 fossiliferous localities in Namibia which have provided useful biochronological data. The Otavi karst field has yielded fossiliferous breccias which span the period from late Middle Miocene (ca 13 Ma) to Recent. At several vanadium occurrences, including Berg Aukas and Harasib 3a, it is clear that vanadium mineralisation occurred during the Miocene, whereas at others, such as Rietfontein, mineralisation was taking place as recently as the Pleistocene. The only substantial vanadium deposit that remains undated is Abenab. The diamondiferous proto-Orange terrace deposits are now known to span the period early Miocene to basal Middle Miocene (Auchas, Arrisdrift) while the meso-Orange terraces are of Late Miocene and Plio-Pleistocene age. The raised beach deposits north of Oranjemund are older than previously thought, the earliest (50 m beach) dating from the Pliocene while the youngest ones (sub-10m beaches) are of Late Pleistocene to Recent age. There are boulders in some of the beach deposits at Oranjemund that may well represent reworked material from the 90 metre beach, although *in situ* deposits of this age have not been found in Namibia. The onset of desertification in the Namib dates from the end of the Early Miocene, some 17 Ma. The sandstones have yielded enormous quantities of fossil ostrich eggshells as well as mammals in a relatively complete succession spanning most of the Miocene and Pliocene. The widespread Kamberg Calcrete which overlies the Tsondab Sandstone has yielded Pleistocene fossils and stone tools at a number of localities, but its onset could have occurred during the late Pliocene to early Pleistocene, some 2.6 Ma. The newly available geochronological data has thus provided important constraints on the timing of geological events in Namibia and has resolved much of the debate that centred on the ages of the superficial rocks in the country.

Introduction

Cenozoic strata cover a substantial part of Namibia including much of the coastal strip, the Namib Desert, and a vast area in the east of the country, the Kalahari Desert. Even in high relief areas, such as the Otavi Mountains, there are Neogene and Quaternary sediments which accumulated in karst settings. The literature on these deposits is voluminous, but very little of it deals with the geochronology of the strata, with the result that widely varying interpretations of the timing of events have been published. For example, the Tsondab Sandstone, which is one of the most extensive Cenozoic deposits in the country, has estimated ages ranging from Karoo (Rust, 1996) through Cretaceous (Koch, 1961) to Eocene (Ward and Corbett, 1990) and Neogene (Pickford *et al.*, 1995).

Henno Martin and Hermann Korn were well aware of the value of fossils and stone tools for providing age estimates for the superficial deposits of Namibia (Korn and Martin, 1955; Martin, 1963, 1973a, 1973b; Martin and Wilzewski, 1972) but palaeontolgical remains and *in situ* artefacts proved difficult to locate with the result that by Namibia's independence in 1990, fewer than a dozen localities had been dated with reasonable confidence. There were four Early Miocene mammalian sites in the Sperrgebiet (Stromer, 1926) in sediments that had accumulated in valleys incised into the Namib Unconformity Surface (NUS - the Namib coastal plain below the Tsondab Sandstone and other cover rocks). The Tsondab Sandstone itself had yielded a single rodent fossil at Rooilepel which indicated an Early Miocene age (Corbett, 1989) (now considered to be early Middle Miocene in age). A single Late Pleistocene age estimate had been made for a cave deposit at Kombat, Otavi Mountains (Robinson, 1959) and a few pan deposits had yielded mammals that provided age estimates (Pia, 1930). Apart from these few biochronologically dated occurrences, none of the other Cenozoic deposits of Namibia had yielded any dateable material.

Over the past decade the Namibia Palaeontology Expedition has been actively surveying many parts of the country for fossils and has discovered well over 100 palaeontological localities in numerous deposits ranging in age from Early Miocene to Holocene. These deposits can be classed into several depositional categories (Table 1, Fig. 1).

Karst Deposits

The Otavi Mountains and Kaokoland have long been

Table 1 : Depositional Environments of Namibian Cenozoic strata

Karst and Epikarst	Etaneno, Berg Aukas 7, Asis Ost, Berg Aukas 6, Aigamas, Rietfontein, Nosib, Friesenberg, Jägersquelle, Berg Aukas 5, Berg Aukas 4, Harasib 3a, Berg Aukas 3, Berg Aukas 2, Berg Aukas 1, Elephantenberg, Uisib, Gabus, Rodgerberg, Dogleg, Kombat E900, Rocky I-IV (Kaoko), Tim's Cave, Erova, Otjimatemba, Ondera, Robbie's Pass
Fluvial	Arrisdrift, Auchas (AMSE), Auchas (AM02), Langental Miocene Site, Glastal, Grillental, Fiskus, Elisabethfeld, Usakos, Windhoek
Pan	Strauchpfütz Carbonate, Zebra Pan Carbonate, Khommabes, Namib IV, E-Bay, North of Bushman Hill, Ai-Ais, Soavis, Abenab
Aeolianite	Rooilepel, GP Pan, Karingarab, Namib-Naukluft (many sites), Eisenkieselklippenbake, West Pan, Norabeb, Kahari, Diep Rivier, Tsauchab, Schmidtfeld, Awasib Cliffs, Kolmanskop, Kalkrücken, Obib, Sossus Sand Sea, Daberas Duine, Target Pan, Skilpadberg Quarries
Calcrete	Kamberg, Elim, Skorpion, Elfert's Tafelberg, Target Pan Calcrete, Rooilepel Calcrete
Travertine	Kaukausib Fontein, Grillental, Gamachab
Littoral Marine	'CDM' Beaches, Tsondabmund, Walvis Bay, Buntfeldschuh, Langental Eocene Site, Rooikop, Rooibank
Crater	Chalcedon Tafelberg, Graben, Brukkaros

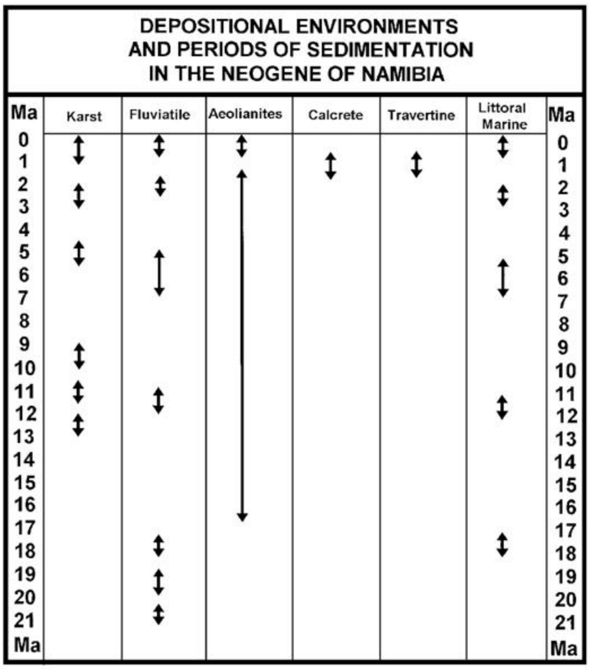

Figure 1 : Depositional environments and periods of sedimentation in the Neogene of Namibia.

known to possess extensive cave systems and other karst features (Schneiderhöhn, 1921, 1929) and the sedimentary nature of some of the Otavi vanadium ores has been evident for some time (Verwoerd, 1957) but the period of mineralisation was generally unknown, with estimates ranging from Palaeozoic to Cenozoic. Schwellnus (1946) concluded that some of the vanadium minerals were extremely young after discovering crystals of descloizite on bones and teeth in breccia deposits at Rietfontein. Robinson (1956) reported that breccias at Kombat were of Pleistocene to Recent age on the basis of bovid and other material from the site. These fossils were often coloured blue or green because of the presence of copper minerals in them. However, it was not until the Namibia Palaeontology Expedition of 1991 that extensive fossil-rich deposits were found in many localities in the Otavi Mountains and Kaokoland (Senut *et al.*, 1992). The occurrence of fossiliferous breccia of Middle Miocene age enclosed in nodules of crystalline descloizite at Berg Aukas provided the first convincing evidence that the main period of vanadium mineralisation at this mine was about 13-12 Ma (Pickford, 1993). This was followed by the discovery that the vanadium prospect at Harasib 3a was extremely fossiliferous. At this locality there is evidence of two periods of mineralisation, an earlier one which was reworked to produce rounded and eroded crystals of descloisite, and a later one that was probably contemporaneous with accumulation of the fossils at about 10 Ma (Late Miocene). Crystals from the latter period of mineralisation are euhedral and show no signs of rounding. Efforts to locate fossils at Abenab were not successful, possibly because this deposit was formed in a cave system that was not open to the surface at the time of deposition.

None of the 32 biochronologically dated karst deposits in the Otavi Mountains and Kaokoland are older than late Middle Miocene. Most of them (26) are Pleistocene or younger. The most vigorous vanadium mineralisation took place in the late Middle Miocene and dwindled thereafter, producing prospects such as Harasib 3a, rather than economically viable deposits such as Berg Aukas.

Fluvial Deposits

In contrast to the karst deposits, Namibia's fluvial sediments yielded evidence of their age from the outset of research on them. Historically the first strata to be dated were those in the northern half of the Sperrgebiet (Stromer, 1926) of Early Miocene age. These deposits all occur in palaeovalleys incised into the Namib Unconformity Surface (Ward, 1987b) and thus provide an important geochronological constaint on the age of maturation of this surface. The main period of incision into the NUS took place during the late Oligocene, a period of low sea level, and backfilling of the palaeovalleys resulted from the rise in sea-level that occurred during the early Miocene (Fig. 6).

In the late 1970's, slightly younger fluvial deposits were found in the Orange River valley at Arrisdrift (Corvinus and Hendey, 1978; Pickford *et al.*, 1995, 1996). Prior to this discovery, the Orange River Terrace deposits were all thought to be of Pleistocene age (Fowler, 1976). Subsequently, Early Miocene fossils have been found at Auchas, revealing that the Orange River Valley was also backfilled at the same time as the

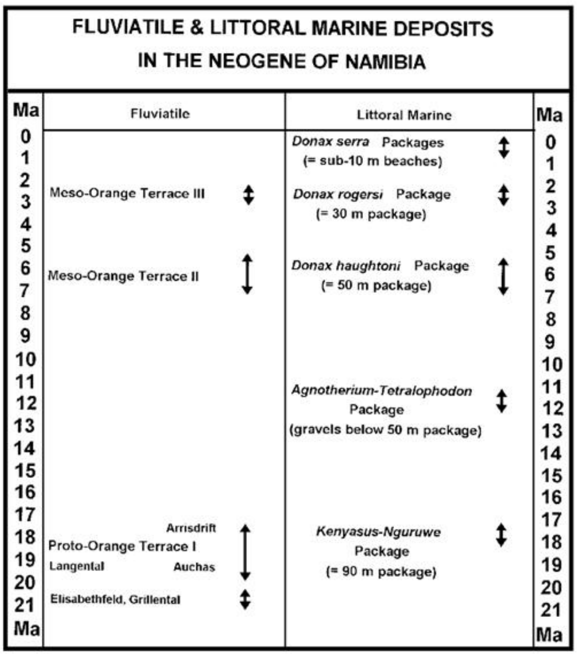

Figure 2 : Fluvial and littoral marine deposits in the Neogene of Namibia. Note the close correspondence between sedimentation episodes in the two systems.

smaller valleys in the northern Sperrgebiet.

There are several suites of fluvial deposits in the Orange River Valley, known as the Proto-Orange and Meso-Orange terraces (Figs. 1 and 2). There are varying opinions about the number of depositional episodes that are represented in each terrace, but it seems certain that the proto-Orange terrace is a composite one, with at least two sedimentary events - Auchas (Early Miocene age) and Arrisdrift (basal Middle Miocene age). The Meso-Orange terrace is also composite but, not having yielded any fossils, its age is unknown, although geomorphological relations indicate that it must be younger than the Proto-Orange terrace. It is likely to contain sediments deposited during the Mio-Pliocene (terrace II) as well as in the Plio-Pleistocene (terrace III), although direct proof of the timing of events is lacking. The main line of argument for suggesting this is that there appears to be a one-to-one correlation between the history of deposition in the valley on the one hand and of the development of raised littoral marine deposits along the southwest African coast during the Neogene on the other.

Pan Sediments

Pan sediments are common in the margins of the Namib Sand Sea (Ward, 1987b) and elsewhere in Namibia. Most of the sediments are poorly fossiliferous, but some have yielded mammals. Most of the pan deposits near the Kuiseb River appear to be relatively young (Pleistocene to Recent) although some of them, including the Zebra Pan Carbonate are likely to be of Miocene age, being intercalated in aeolianites of early Middle Miocene age (Fig. 1). The Namib IV Pan in the northern part of the Namib Sand Sea is Middle Pleistocene, having yielded remains of the extinct elephant, *Elephas recki*, and acheulean artefacts (Shackley, 1980, 1982). The Strauchpfütz carbonates in the central Sperrgebiet are probably of Pleistocene age on the basis of their geomorphological setting, but the only fossils found there (gastropods) yield no geochronological information. The Ai-Ais pan deposits of Damaraland are late Pleistocene to Recent in age, having yielded remains of the extant oryx (*Oryx gazella*). Various pans in the Kalahari borderlands of Namibia contain fossil freshwater gastropods and some of them such as Soavis and Abenab near the Otavi Mountains have yielded mammals. Soavis yielded extant bovids (Springbok, *Antidorcas marsupialis*) and Abenab yielded a fossil warthog (*Phacochoerus*) (Pia, 1930) suggesting a late Pleistocene age for their development.

Aeolianites

Aeolianites are by far the most voluminous Cenozoic deposits in Namibia, covering much of the coastal strip from the Orange River in the south to the Kuiseb in the north, with various smaller deposits along the Skeleton Coast and vast deposits in the Kalahari.

The debate about the age of the onset of desert conditions in Namibia was summarised by Brain (1984) and Ward and Corbett (1990). There were two main schools of thought, one holding that the desert must be at least as old as the Cretaceous, the main argument being that the specialised coleopteran fauna and plants that occur there today required vast spans of geological time to evolve (Koch, 1961, 1962). The other was that it must be considerably younger, being no older than Middle Miocene, the argument being based on geomorphological relationships (Partridge and Maud, 1987). Ward and Corbett (1990) opted for a compromise between these two extreme viewpoints, and suggested that desert conditions probably began during the Eocene. Rust (1996) proposed that the Tsondab Sandstones accumulated during the Karoo period, but recent palaeontological results reveal that this hypothesis is untenable.

The discovery of fossil mammals and bird eggshells at many levels in the Namib aeolianites by the Namibia Palaeontology Expedition (Fig. 3) has resolved the uncertainty by providing clear evidence as to the age of the deposits. At their base they are late Early Miocene (Kamberg, Zebra Hill) and early Middle Miocene (Rooilepel). The presence of fossils throughout the succession of dune deposits has permitted a biostratigraphic scale to be erected (Pickford and Dauphin, 1993; Senut and Pickford, 1995; Senut *et al.*, 1995) which has been calibrated by rodent biochronology (Fig. 3).

It is now reasonably clear that aeolianite deposition began in the Namib about 17-16 million years ago and

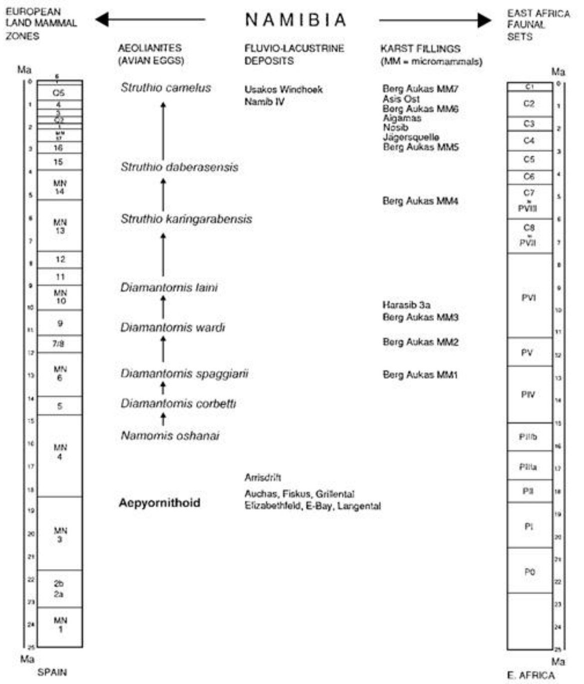

Figure 3 : Biostratigraphy of the Namib aeolianites based on struthious egg shells and correlations to East African Faunal Sets and European Land Mammal Zones.

has continued with minor gaps ever since. The onset of hyperarid conditions in the Namib coincides in time with a cooling plunge in the temperature of the world's oceans at the end of the early Miocene (Fig. 4), a drop that was probably triggered off by the expansion of the Antarctic Ice cap to continental size at this time. It is interesting to note that the onset of other 'west coast' deserts of the world, including the Atacama in South America, also date from this period. Prior to this the climate of the Namib was subtropical with summer rainfall but after the change, its southern half (south of Walvis Bay) became temperate with winter rainfall, a climatic regime that it still enjoys today.

It is likely that the endemic plants and insects of the Namib Desert resulted from a comparatively short period of intense evolution (17 million years or so), rather than a more drawn out, more leisurely evolutionary process (65 million years or more).

Calcretes

Calcrete deposits are widespread in Namibia. They crop out widely in the coastal strip as well as in the high interior of the country. The latter deposits merge with those of the Kalahari in Botswana and of high Namaqualand in South Africa. Because few if any fossils had been found in these calcretes there has been uncertainty about their time of formation with estimates ranging in age from Cretaceous (Passarge, 1904) to Miocene (Ward and Corbett, 1990) and Recent. The extremely thick calcretes of the Kalahari region as far west as the Weissrand near Mariental certainly give the impression of great age. However, fossils have now been recovered from beneath the calcretes at Areb (east of Springbok), northern Namaqualand, South Africa. The Areb fluvial deposits, beneath about 25-30-metres of calcrete, are of early Pliocene to late Miocene age (ca 6-4 Ma) (Pickford *et al.*, 1999). The calcretes in this area must therefore be younger than about 4 Ma and since these deposits merge northwards with those of the Kalahari, then those too are likely to be Pliocene to Pleistocene (Figs. 1 and 4).

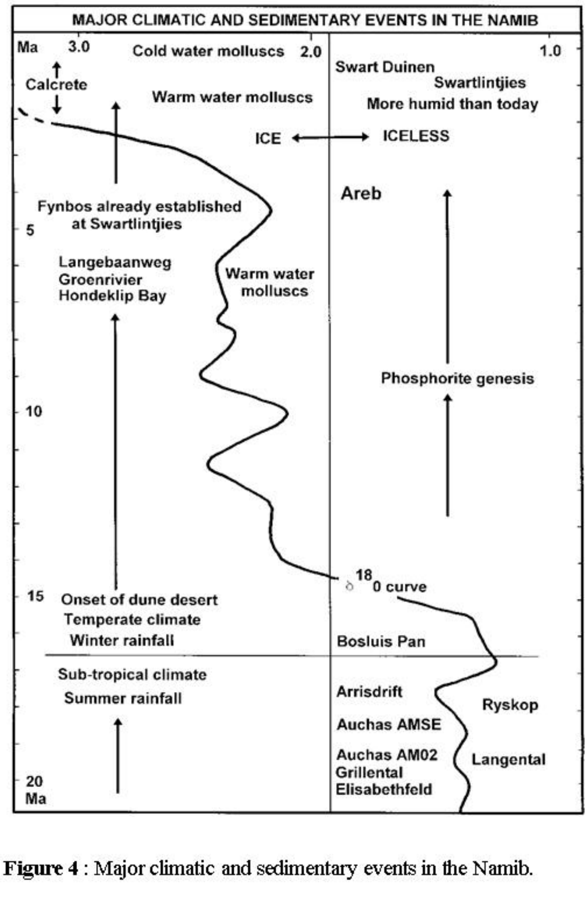

Figure 4 : Major climatic and sedimentary events in the Namib.

Fossils found in calcretes of the Namib coastal plain are all of Pleistocene to Recent species. The presence of stone artefacts in several of these calcrete deposits also attests to their relative youthfulness. At Elim and nearby outcrops, the calcretes have yielded remains of *Equus* and *Oryx gazella* as well as stone tools. It seems unlikely that the Kamberg Calcrete, as these coastal plain deposits are known, are as old as Middle Miocene as proposed by Ward and Corbett (1990).

It now appears more likely that all the calcretes of Namibia and neighbouring countries are Plio-Pleistocene to Recent in age, and that they owe their formation to climatic conditions brought about during the Quaternary (glacial) period.

Travertine

There are extensive travertine (onyx-like) deposits in the Namib coastal strip, especially in the Sperrgebiet. Impressive outcrops occur in the lower Grillental, at Kaukausib and Gamachab. Early work suggested a Cretaceous (Merensky, 1909) or early Miocene (Greenman, 1970) age for these formations. Corbett (1989) realised that they must be considerably younger than previously thought and because of their present-day altitude (30 m asl), he correlated the Grillental travertines with the 30-metre littoral marine package for which a Pleistocene age was proposed (Pether, 1994).

Fossil mammals (the suid *Notochoerus* and large bovids) have now been found in travertines at Kaukausib Fontein, upstream from the Grillental occurrence, and they indicate that the deposits accumulated during the late Pliocene to Pleistocene (Figs. 1 and 4). All the travertine occurrences in the Sperrgebiet are located close to springs that are still active today, although they are all slightly saline. It is likely that this spatial relationship is not fortuitous, and that increased discharge during relatively cooler and more humid periods of the Quaternary led to the deposition of the travertines. If this is so, then the travertines and calcretes of the Namib would have formed at the same time, being different manifestations of the same underlying climatic processes related to glacial climatic regimes.

Littoral Marine Deposits (Raised Beaches)

Until recently, all the diamondiferous 'raised beaches' parallelling the Namibian and Namaqualand coasts were considered to be of Plio-Pleistocene age (Davies, 1973; Hallam, 1964; Pether, 1994). Various deposits have been mapped both north and south of the Orange River mouth, the number and altitude of the beaches varying from place to place and from author to author. Most researchers prior to Pether (1994) recognised three to six 'terraces' and various correlations to Plio-Pleistocene sea-level curves were proposed to account for their accumulation above present-day sea level. Pether (1994) recognised that the deposits accumulated during periods of regression rather than during transgressions as previously published (Carrington and Kensley, 1969). He proposed a nomenclature based on the altitude of sea level at which regression began. Thus the 90-metre package consists of all the sediment, regardless of its measured altitude, that accumulated as the sea regressed from the 90-metre contour. The 50-metre package, mapped as younger than the 90-metre package, consists of all the sediment, again regardless of its measured altitude, that accumulated as a result of the regression from the 50-metre high stand. Likewise for the 30-metre package and for three sub-10-metre packages. Pether's approach is essentially one of sequence stratigraphy but it is complicated by the fact that the sediments studied occupy the feather-edge of the basin in which they accumulated and have hence been prone to disturbance by sub-aerial and littoral marine erosive processes. Pether (1994) concluded that all these Namaqualand littoral marine sediment packages were of Pliocene to Pleistocene age, citing the discovery of several fossil mammals, in particular the horse, *Equus* and the suid, *Nyanzachoerus*.

The recovery of fossil mammals in the diamond mines at Hondeklip Bay and nearby at Ryskop, has radically changed the understanding of the timing of deposition of these littoral marine deposits (Figs. 1 and 2). At Ryskop, fossils from sediments assigned to the 90-metre package of Pether (1994) are of early Miocene age (Pickford, 1998; Pickford and Senut, 1997). The fossils from Ryskop are unlikely to have been derived from pre-existing sediments which locally crop out below the 90-metre package. This is because apart from plant remains, these sediments are unfossiliferous. It is more likely that they are contemporaneous with the deposits in which they were found and it should be noted that several of the specimens are unrolled and in mint condition, excluding reworking from pre-existing deposits.

Gravels below sediments assigned to the 50-metre package at Hondeklip Bay have yielded mammals of late Middle Miocene facies. Many of the fossils from these gravels are rolled and polished and could be reworked from pre-existing deposits but the main identifiable specimens are probably contemporaneous with the deposition of the gravels. It is likely that these gravels represent all that is left of a sediment package that was subsequently almost completely reworked during the transgressive phase of the 50-metre package.

The 50-metre package itself has yielded abundant fossils of latest Miocene to basal Pliocene age. These are unrolled and in much better condition (e.g. *Nyanzachoerus kanamensis australis*) than those from the underlying gravels and it is probable that the discordance between the underlying gravels and the 50-metre package spans several million years.

The 30-metre package at Hondeklip Bay contains Plio-Pleistocene mammals such as *Equus* (Pether, 1994; Pickford and Senut, 1997). The sub-10-metre beach deposits and associated dunes contain middle to late Pleistocene and Recent faunas and stone artefacts (Acheulean at Swartlintjies for example). Because altitude data has led to confusion in the past, a new nomenclature has been introduced, employing marker fossils to identify the various sedimentary units (Fig. 2).

The association of phosphate nodules with some of the raised beach deposits of Namaqualand and Namibia (Watkins *et al.*, 1995) reveals that the main period of phosphogenesis in the southeast Atlantic occurred during the Miocene (Figs. 4 and 5) and that by the Pleistocene it was tailing off. It had ceased by the onset of the late Pleistocene when the Benguela upwelling cells moved close to the present-day coastline from their previous position some distance offshore. Molluscan evidence from the 50-metre and 30-metre packages indicates that Namibian coastal waters of the Miocene and Plio-Pleistocene (ca 12 Ma to ca 2.3 Ma) were relatively warm (Figs. 4 and 5). As cool, phosphate-charged waters upwelled offshore, they would mix with warmer coastal water thereby promoting the precipita-

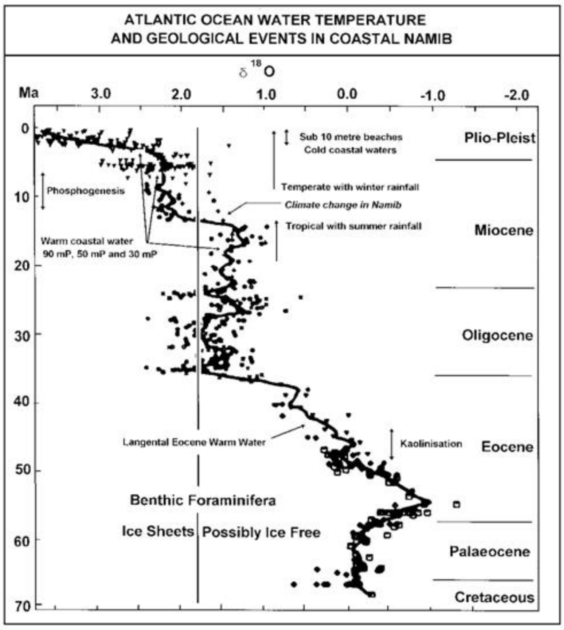

Figure 5 : Atlantic ocean water temperature and geological events in the coastal Namib.

tion of phosphates inshore (Watkins *et al.*, 1995). With the installation of cool-water molluscan faunas along the coasts of Namaqualand and Namibia during the late Pleistocene (the three sub-10-metre beaches) due to an inshore shift of the position of the upwelling cold-water cells, phosphogenesis in the region was greatly reduced or ceased altogether.

Comparison of the data now available about the raised beach deposits of the Namib and Namaqualand with evidence from other parts of the world, such as Western Australia (Quilty, 1977) reveals that there is a close correlation between sea-level events in the two regions (Pickford, 1998) (Fig. 6). It is likely therefore that the raised beach deposits of Namibia owe their formation to global-scale sea-level fluctuations during Miocene and subsequent times. Nevertheless, it is likely that the present-day altitude of the raised beaches has been altered by more recent epeirogenic uplift of southern Africa (Partridge *et al.*, 1995a, b).

Furthermore, comparison of the timing of littoral marine events with sedimentary episodes in the Orange River and other palaeovalleys in the Sperrgebiet indicates a one-for-one correlation between periods of high sea-level and periods of backfilling of the valleys to produce the Proto-Orange and Meso-Orange terraces (Fig. 2).

The new data and correlations have led to a reassessment of the timing of placer genesis in the region and thus to revised ideas of the rate of placer enrichment and other aspects which are crucial to the mining industry. It has also led to a revision of ideas concerning the genesis and timing of offshore diamond deposits.

Crater Deposits

Crater deposits are rare in Namibia. The best known example is Brukkarros, a late Cretaceous phreatomagmatic volcano with a fossiliferous crater infilling containing plant remains. Chalcedon Tafelberg and Graben are two deposits in the Sperrgebiet that accumulated in craters. The former has yielded abundant gastropods and plant remains, but the latter appears to be palaeontologically sterile. Unfortunately, none of the fossils found at Chalcedon Tafelberg yield any geochronological information but it is clear that the gastropods belong to extant genera (*Hydrobia*, *Lymnaea*). It should be pointed out here that Chalcedon Tafelberg has nothing to do with the Pomona Silcretes that form prominent mesas in the vicinity of Pomona in the northern Sperrgebiet. The latter are pedogenic in origin, whereas Chalcedon Tafelberg is a crater fill, originally consisting of clastic, carbonate and silicate deposits which accumulated in a crater lake.

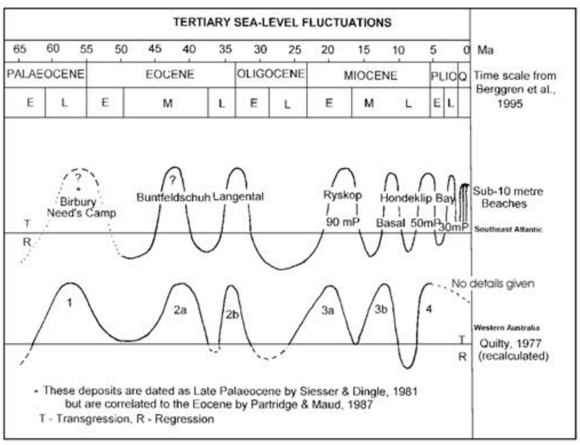

Figure 6 : Tertiary sea-level fluctuations. Note the close correspondence between the sea-level histories of Western Australia and the Southeastern Atlantic.

Discussion and conclusions

The past decade has seen a quantum leap in the quantity of geochronological data available from Cenozoic deposits of Namibia. Before 1990 fewer than a dozen localities could be dated but by 1999 well over 100 fossiliferous localities had been calibrated. Firstly, the discovery of fossil-rich breccias in the Otavi Mountains has led to the development of a local biostratigraphy based on micromammals (Fig. 3). This karstic time scale spans the late Middle Miocene to Recent and when added to a similar scale worked out for rodents from the Tsondab Aeolianites and the Sperrgebiet fluvial deposits, the scale spans the period ranging from the early Miocene (ca 21 Ma) to Recent. Biostratigraphic correlations with other African and even European sequences have been proposed (Fig. 3).

Secondly, study of the Tsondab aeolianites has resulted in the discovery of a long succession of bird egg shell types ranging in age from early Miocene (ca 17 Ma) to Recent (Fig. 3). The succession of egg shell varieties has been calibrated by using rodents and other mammals that occur in the same sedimentary levels. The commonest of these mammals belong to the spring hare family (Pedetidae) and it is clear from the series of fossils collected that in this lineage there were dramatic changes in cheek tooth hypsodonty with the passage of geological time. The pedetids are therefore of use for biochronology. Muroids have also been found in aeolianites of the Tsondab Sandstone Formation and these have permitted correlations to be made to other parts of the African fossil record, notably Kenya. Now that the egg biostratigraphic sequence of Namibia has been established and calibrated, it has been possible to estimate the ages of egg-bearing deposits in other parts of the Old World, including South Africa, Tanzania and Abu Dhabi.

Thirdly, it is evident that periods of sedimentation in Namibia were closely linked to global scale eustatic and climatic events (Figs. 4 to 6). The raised beach deposits of the southeast Atlantic and the fluvial deposits in the river valleys which drain into the Atlantic, including the Orange and Kaukausib, accumulated in response to sea levels higher than those of today. The aeolianites of the Namib Desert started accumulating when there was a global scale plunge in the temperature of ocean waters, probably brought about by the expansion of the Antarctic Ice Cap to cover the entire continent at 16-17 Ma. Prior to this the climate of the southern and central Namib was subtropical with summer rainfall but afterwards it became temperate with winter rainfall (Figs. 4 and 5). The calcretes and travertines of Namibia and neighbouring countries were evidently formed during the Quaternary (glacial) period (Fig. 4), probably due to regionally lower groundwater temperatures and higher surface humidity in the subcontinent than characterises the region today. The karst deposits of northern Namibia reveal no close link to regional or global geological or climatic events and they were presumably forming and eroding away more or less continuously throughout the Neogene. Rates of karstic downwasting of 15 metres per million years have been calculated for the Otavi Mountains and the Aha Hills, Botswana. Such rates mean that few of the sediment bodies that developed in karst settings will survive for extended periods of geological time, deposits such as Berg Aukas and Harasib 3a being exceptions because of their size and resistance to erosion.

Henno Martin made contact with the Namibia Palaeontology Expedition when the first paper on fossil eggs was published. He was especially interested in the succession of struthious egg shell types and it is clear that he fully grasped the importance of the fossils for geochronology. He passed away before the full results of the NPE's work could be published. Let this present article be a tribute to his contributions to Namibian Geology and to his lively mind which was active to the end.

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