On the Antiquity of the Namib

J. D. Ward
Department of Geology and Mineralogy, University of Natal, P.O. Box 375, Pietermaritzburg 3200, South Africa.

M. K. Seely and N. Lancaster
Desert Ecological Research Unit, P.O. Box 1592, Swakopmund 9000, SWA/Namibia.

The Namib has been considered both a 'young' and an 'old' desert. We have reviewed the literature and present here an outline for further discussion on this topic, which has been influenced by our field experience in the Namib. The current arid to extreme-arid regime is a geologically youthful feature which has developed, probably progressively, from the Late Tertiary. However, the Late Mesozoic-Cenozoic stratigraphic record reveals a dominance of arid to semi-arid conditions throughout the history of the Namib, which dates back to the Cretaceous. An Early to Middle Tertiary desert sand sea is inferred for the Southern and Central Namib, pre-dating the full establishment of the Benguela Current system in Late Miocene times. The main Namib Sand Sea, which overlies much of the palaeo-desert arenities, has probably developed from the Pliocene through the Pleistocene to its present status. Geological and biological field observations strongly advise of a cautious approach to palaeo-climatic interpretations of the history of this long, narrow and dynamic desert tract.

Die Namib is al as 'n 'ou' en as 'n 'jong' woestyn beskou. Die literatuur is nagegaan en 'n oorsig oor die onderwerp — wat deur die skrywers se ervaring in die Namib beïnvloed is — word vir verdere bespreking voorgelê. Die huidige droë tot besonder ariede regime is 'n geologies jong kenmerk wat — waarskynlik toenemend — uit die Laat-Tersiêr ontwikkel het. Uit die Laat-Mesosoïese-Senosoïese stratigrafieverslae blyk dit dat daar dwarsdeur die Namib se geskiedenis, wat tot die Kryttyd teruggaan, oorwegend droë tot half-ariede toestande geheers het. Die bestaan van 'n Vroeë tot Middel-Tersiêre woestyn word vir die Suid- en Sentraal-Namib afgelei. Dit vervroeg die volledige vestiging van die Benguelastroomstelsel tot 'n tydperk in die Laat-Mioseen. Die hoof- Namibsandsee, wat groot dele van die paleowoestynareniete oordek, het waarskynlik van die Plioseen af deur die Pleistoseen tot die huidige ontwikkel. Geologiese en biologiese waarnemings ter plaatse, saam met anomale dier- en plantverspreiding, maan tot 'n versigtige benadering tot die paleoklimaatvertolking van die lang, smal, dinamiese woestynstreek wat die Namib genoem word.

Background

The Namib Desert of southwestern Africa, which currently has an arid to extreme-arid climte, is one of five west coast deserts lying within subtropical latitudes.[1] The age of the Namib has interested scientists in many disciplines, particularly since the early 1960s when the late Dr Charles Koch, entomologist of the Transvaal Museum, publicised the idea of a very great age for this desert.[2,3] In these two papers, he discussed the richness and endemism of the Namib fauna, notably the tenebrionid beetles, and ascribed this development to the long and undisturbed existence of these specialized biota. Koch recognised the importance of the Benguela Current to this desert climate, which, in following Kaiser,[4] he attributed to the Cretaceous. As a result the Namib was dubbed 'the oldest desert in the world'.

In 1975, van Zinderen Bakker Sr published a synthesis[5] describing the factors pertaining to the 'origin and palaeoenvironment of the Namib Desert biome'. Although supporting the 'old age of the desert' (p. 5), he proposed that the Namib could have developed only after cold water from the Southern Ocean was able to penetrate northwards; a situation which he considered possible from the Early Oligocene (*c.* 35 Myr ago), i.e. some 30 – 40 million years younger than the Cretaceous age postulated by Koch.[2,3] However, three papers on this topic appeared in 1978; two rejected a great age for the Namib[6,7] and proposed a Plio-Pleistocene, or even younger, age, while a third[8] concluded that the Namib may not be much older than other deserts of the world. These three publications made use of recent information, available from many disciplines, to update ideas concerning the origin of the desert climate and yet were consistent with Koch's[2,3] earlier observations on the richness of the Namib biota.

A number of reports had been published prior to 1978, many predating the early 1960s, which discussed geological aspects of the Namib Desert and often included tentative interpretations of palaeoenvironmental conditions in that region.[9-20] The information contained in these papers has apparently been overlooked (many of these publications are in German[9,12,13,15] or Portuguese[17,19]), or their significance not readily appreciated, especially if the issue of the age of the Namib was approached from a non-geological point of view. The age of the Namib was the theme of a panel discussion at the biennial conference of the South African Society for Quaternary Research, held in Pretoria in May, 1981.[21] The discussion revealed that this topic is still a matter for dissension and controversy.[22,23]

We attempt here to summarize the points which we consider important in the history of the Namib. Our presentation is based mainly on published geological information but also includes those of our own recent field observations which we consider pertinent. We hope that this material will provide a framework for future consideration of the antiquity of the Namib Desert.

Definition of the Namib Desert

The Namib comprises the relatively narrow tract of land, some 2 000 km long and mostly less than 200 km wide, lying west of the Great Escarpment between the Olifants river (Cape Province, South Africa) and the Carunjamba river (Mocamedes District, Angola) (see Fig. 1). The climate of the central section, which lies mainly within Namibia, is arid to extreme-arid, whereas the area north of the Kunene river is considered a summer rainfall desert and that south of the Orange river, a winter rainfall desert.[24,25] Although a number of workers have attempted to subdivide the Namib,[4,25-35] it is not our intention to comment on these divisions, which are based on climatological, geomorphological and/or botanical criteria. It is important, however, to recognise that the Namib Desert includes a wide variety of environments, notably sand seas, dunes, plains, inselbergs, ranges of low hills, coastal salt flats, pans, ephemeral rivers and streams, and even the lower

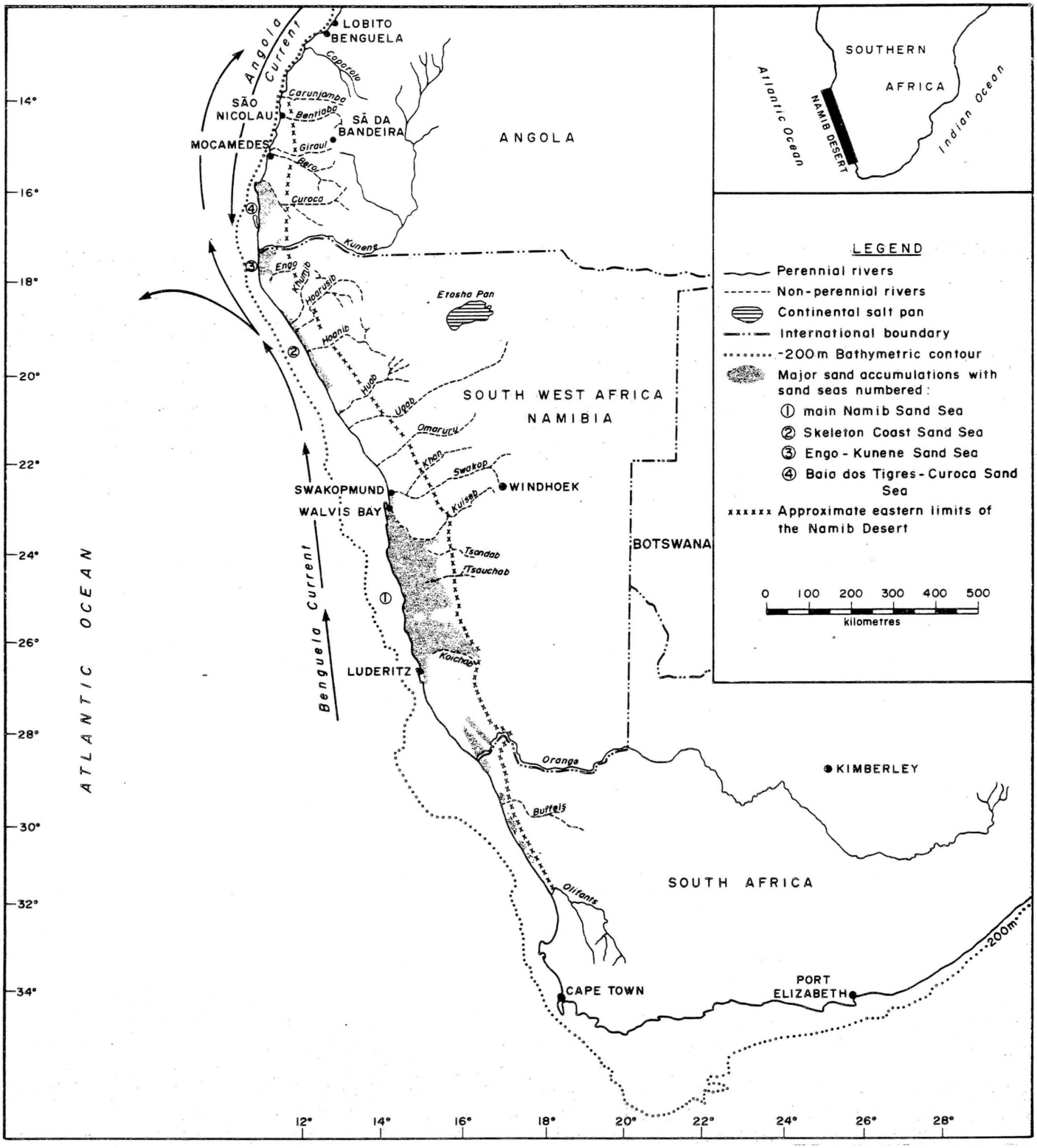


Fig. 1. Locality map of the Namib Desert.

reaches of two usually perennial rivers — the Kunene towards the north and the Orange towards the south. Therefore, it can be readily appreciated that the Namib Desert involves a much broader geomorphological character than merely the main Namib Sand Sea between Chameis Bay and the Swakop river, which, although spectacular, has often been the sole focus of attention in previous discussions.

Outline of the geological history of the Namib Desert (Table 1)

Late Mesozoic record

By definition, the potential maximum age of the Namib as a distinct physiographic region dates back to the formation of the narrow coastal tract between the South Atlantic Ocean and the Great Escarpment, following the break-up of West Gondwana. Evidence from palaeomagnetic, radiometric and palaeontological studies, summarized by Simpson[37] and, more recently, by Tankard *et al.*,[38] indicates that the South Atlantic Ocean initially opened from the south *c.* 130 Myr ago, with fully marine conditions established by *c.* 80 Myr ago. This development was paralleled, from *c.* 127 Myr ago, by the formation of the Great Escarpment by headward erosion, enhanced by epeirogenic uplift of the subcontinent, and grading of the coastal tract to the new base level formed by the evolving South Atlantic Ocean.[20,39,40] This process, dominantly of pediplanation, was augmented by the sediments of the Orange river, and led to the concomitant deposition of a sedi-

ment wedge, up to four kilometres thick in the Orange Basin, offshore in the Southern and Central Namib tract.[20,41-43] In contrast, marine deposition dominated the extreme Northern Namib during the Cretaceous[10,17,19] with a phase of terrestrial sedimentation recorded some 100 – 110 Myr ago by the Giraul Conglomerates, coarse alluvial-cone deposits some 200 m thick, derived from the escarpment.[17]

Remnants of some of the earliest terrestrial deposits in the Namib are recorded in the southern sector by the Pomona Beds (*sensu* Stocken[44]), dominantly fluvial sediments which are preserved sporadically in the hollows of the Cretaceous landscape and bevelled by the End Cretaceous land-surface.[44] Beetz[9] considered this succession indicative of deposition under conditions of increasing aridity, an interpretation he also considered valid for the early sediments of possible Cretaceous age in the Kunene Valley.[10] More recent work in the Sperrgebiet[44] has found nothing to contradict Beetz's views on the Pomona Beds.[9] The surface from the end of the Cretaceous is impressively level in the Southern Namib[44] and may be tentatively correlated with the well-planed bedrock platform in the Central Namib.[11,14,46-48] From the Upper Cretaceous, the sediment accumulation rates offshore in the Orange Basin were greatly reduced.[42,49] Although this has been attributed to stabilisation of basement subsidence[39] or a marked decrease in continental discharge rates,[50] it should be noted that these offshore sediments, from the Late Mesozoic, were a potential source of sediment for areas to the north, in a manner similar to that suggested for the much younger Quaternary sediments.[25,51,52] It therefore appears that the stage was set for Cenozoic terrestrial sedimentation, at least in the Southern and Central Namib, by the end of the Cretaceous with some evidence of arid conditions prevailing during the formtion of the Great Escarpment.[9,10,11,44,46]

Tertiary record

In the extreme Northern Namib, the Early to Middle Tertiary sediments indicate mostly marine conditions along the coastal tract from the vicinity of Porto Alexandre northwards.[10,17,19] In the Southern Namib, notably in the Sperrgebiet, the earliest Tertiary terrestrial sediments comprise the Chalcedon-Tafelberg Silcrete Formation of probable Palaeocene age.[53] These silicified superficial deposits are distinct from the Cretaceous Pomona Beds[9,44] and have been referred to as the Tafelberg Quartzites by Stocken,[44] an informal term which is preferred here. This succession is very similar, lithologically and stratigraphically, to the 'Basal Breccia' described by Ollier[45,46] in the Kuiseb Valley of the Central Namib, although the latter is intensely calcified (and even dolomitized) as opposed to the widespread silicification of the Tafelberg Quartzites.[44] There is evidence, however, that calcretization preceded silicification in the Tafelberg Quartzites,[44] and these deposits, comprising aeolian sands, pans and sheetwash debris, are generally interpreted as having accumulated under arid to extreme-arid conditions.[11,12,44] There is widespread deep leaching of the bedrock underlying the Tafelberg Quartzites,[44] in contrast with the Central Namib deposits where the lack of deep chemical weathering under both the 'Basal Breccia' and in the formation of inselbergs is striking,[46,48] which supports the belief in the existence of dry conditions at that time. Similarly, the Blaubock Gravels[44,53] in the Southern Namib are interpreted as 'sheetflood deposits reflecting episodic torrential rains under arid or semi-arid climatic conditions'[44] (p. 17) post-dating the Tafelberg Quartzites (End Cretaceous-Palaeocene) but older than the Eocene marine transgression.[44]

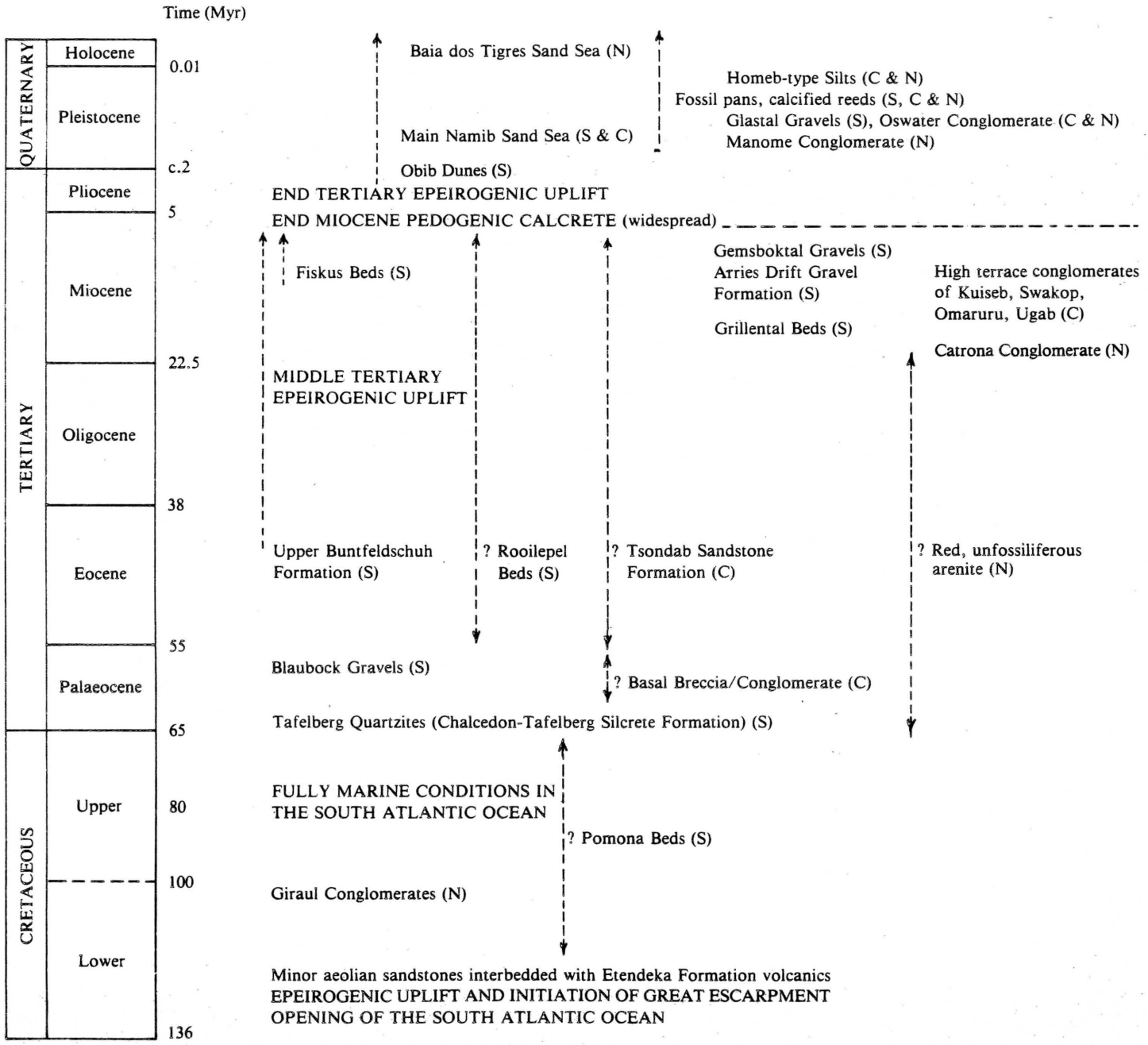
Widespread accumulation of terrestrial, mostly red-brown arenaceous sediments occurred throughout the Namib in the Early to Middle Tertiary, generally overlying an almost ubiquitous basal breccia.[14] The upper Buntfeldschuh Formation[53] in the Southern Namib comprises 55 – 57 m of cross-bedded aeolian sands resting on probable Eocene marine sediments and truncated by the main Namib calcrete,[9,14,18,44] a palaeosol[54] probably from the end of the Miocene.[53] These green to red-brown fossil dune sands have been equated with similar sediments in the higher terraces of the Kuiseb, Swakop, Omaruru, Ugab and Kunene Valleys,[10,14] with possible association as far north as the red arenites underlying the Lower Miocene Catrona Conglomerate near Mocamedes.[10,17] Between the Kuiseb Valley and the Lüderitz-Aus railway, similar deposits correlate closely with the limits of the present main Namib Sand Sea[14,28,33,45,48,53,55,56] and are considered typical desert sediments, including fossil dunes[14,29] and sand sheets, which have been called the Tsondab Sandstone Formation.[53] Northwesterly to northeasterly dip directions are recorded for large-scale aeolian cross-bedding along the northern limits of the Tsondab Sandstone Formation.[28,56] Similar dip directions are noted in the palaeo-dunes of the Rooilepel Beds,[18,44] which may be southern equivalents of the Tsondab Sandstone Formation. Recent studies in the Central Namib have shown that the internal sedimentary structures of the dunes closely reflect contemporary wind regimes,[57] which further substantiates the interpretation of a southerly quadrant palaeo-wind regime at that time. These arenaceous sediments thus apparently represent the accumulation of an Early to Middle Tertiary sand sea in the Southern and Central Namib under a dominantly southerly palaeo-wind regime which was similar to the present day wind pattern.[24]

In southwestern Angola, Beetz[10] considers the 'dune sandstones filling in all valleys of the old land surface; a thickness of over 150 m having been observed on the banks of the Cunene River and in gullies leading down to that river' (p. 146), to have accumulated under arid (desert) conditions, similar to the situation he observed in the Southern Namib.[9] His views are supported by Martin's conclusion that the upper Buntfeldschuh aeolianites, and their probable equivalents to the north, indicate dominantly arid conditions which may have spanned some 20 – 30 million years.[14,15] Mabbutt,[16] after studies in the Ugab Valley, supports Martin's interpretation, as do most investigators who have worked on the Tsondab Sandstone Formation[28,33,45-47,53,55,56,58] or the Southern Namib equivalents.[18,44] Martin[14,15] suggests that wetter periods must have been interspersed with the dominantly dry regime during that time because of the presence of 'root casts' in the arenites. These structures, or pedotubules,[59] could be groundwater solution phenomena[60,61] or biogenic features, possibly even termite chambers or burrows which could have acted as conduits for $CaCO_3$-precipitating solutions.[57] The reddened horizons in the Tsondab Sandstone Formation sediments in the Kuiseb Valley have been tentatively called palaeosols, representing minor stillstands under at least semi-arid conditions during the accumulation of the 'consolidated red desert sands'.[48] Fossil evidence from the Eocene marine transgression implies warm-water conditions in the South Atlantic Ocean during the Early to Middle Tertiary,[10,17,19,63,64] in contrast with the present situation.[5,62,63] Therefore, it is particularly significant that the Blaubock Gravels, the upper Buntfeldschuh Formation, the Tsondab Sandstone Formation, and their probable equivalents preserved throughout the Namib tract, accumulated under arid to semi-arid, mostly desert, conditions with a dominant southerly palaeo-wind regime before the full development of the Benguela Current in the Late Miocene.[63,64]

Martin[14] records calcified conglomerates, often as two discrete depositional units, lying directly over the red and brown arenites (described above) in the major river depressions of the Namib with equivalent thick calcrete layers on the arenites in the interfluvial areas. In the Central Namib, he notes that the high terrace conglomerates overlie fossil dunes of the Tsondab Sandstone Formation south of the Kuiseb river.[14] The Catrona Conglomerate near Mocamedes in the Northern Namib, a continental deposit which overlies red, unfossiliferous arenities, has been dated as Lower Miocene.[17] In the Southern Namib, a terraced suite of conglomerates, referred to as the Arries Drift Gravel Formation, occurs along the lower Orange river.[53] At Arrisdrif, a rich Middle

Table 1. Stratigraphical summary of Late Mesozoic-Cenozoic terrestrial sedimentation in the Namib.

Note: (i) Geological time subdivisions not to scale; (ii) S = Southern, C = Central, N = Northern regions of the Namib



Miocene (*c.* 12 – 18 Myr) fauna has been found[65] and the terrace formation, with subsequent gravel deposition, is thought to have occurred *c.* 20 – 8 Myr ago after the widespread epeirogenic uplift of the subcontinent in the Middle Tertiary.[50,66] At the Namex Mine, the Upper Terrace could represent the Post-African I geomorphic event (*c.* 20 Myr ago) and the Lower Terrace, the Post-African II episode (*c.* 8 Myr ago)[66]; although the vast accumulation of coarse alluvium is attributed to a single aggradational phase following the world-wide Miocene transgression.[44] In the Northern Namib, this transgression is well preserved and the fossil marine fauna reflects warm-water conditions at that time.[10,17,19,63] The fossil beaches D, E, and F in the southern Sperrgebiet have been re-interpreted recently as Miocene deposits on the basis of their warm-water fauna[67] and it is likely, therefore, that the Rooikop Gravels[53,68] are the Central Namib equivalents of the Miocene transgression. Within the Sperrgebiet north of the Orange river, Lower to Middle Miocene (16 – 18.5 Myr) fossils[69,70] have been recorded from fluvial sediments known as the Grillental Beds,[44] or the Grillental Clay Member of the Elizabeth Bay Formation.[53] These deposits are thought to be 'pan accumulations along river courses or in valley bottoms'[44] (p. 18) with the presence of standing water implied from the remains of *Brachyodus,* a primitive hippopotamus-like animal. From recent mapping in that area, the formerly Pleistocene Gemsboktal Gravels[44,53] have been re-assigned a Miocene age, post-

dating the Grillental Beds but pre-dating the End Miocene Namib calcrete (Stocken, personal communication). The high-lying conglomeratic terraces of the Swakop and Khan rivers are possible equivalents of the Lower Miocene fluvial sediments in the Sperrgebiet.[11] More recently, Martin (personal communication) has cautiously suggested that the high terrace conglomerates in the Kuiseb Valley[14,15] may be Miocene equivalents of the Arries Drift Gravel Formation.[53]

There is some evidence therefore for widespread fluvial activity in the Namib tract during the Miocene. Caution, however, is needed in any palaeo-climatic or environmental interpretation of these deposits, particularly in view of the general epeirogenic uplift of the subcontinent in the Middle Tertiary.[50] From the fossils in the Grillental Beds, Hopwood[71] invoked a wooded grassland palaeoenvironment with riparian woodland along the watercourses in the Sperrgebiet during the Lower Miocene. Similarly, the Arrisdrif faunal assemblage was thought to represent a well-developed riparian woodland along the lower Orange river with widespread savanna conditions throughout the Southern Namib.[65] These interpretations are possibly further substantiated by the subtropical to tropical pollen assemblages recorded in Miocene sediments in the southwestern Cape Province.[72] However, these deductions should 'be treated with considerable reserve in the face of the lithological evidence'[44] (pp. 21-22), and Stocken[44] proposes that the Grillental Beds reflect semi-arid conditions increasing in aridity and leading to the subsequent accumulation of aeolian Middle to Late Miocene Fiskus Beds,[44] or the Fiskus Sand Member of the Elizabeth Bay Formation.[53] He also suggests, on geological grounds, that the Arrisdrif 'faunal assemblage though varied represents a restricted riparian community confined within narrow limits to the valley of the proto-Orange river'[44] (p. 22). This necessity for caution was recently reiterated by Seely,[22,23] who cited the occurrence of large mammals, including elephant, black rhinoceros, giraffe and lion, well within the current extreme-arid section of the Skeleton Coast. These anomalous distributions are often related to the major river courses, for example, the Hoanib, Hoarusib, Khumib, Sechumib, Nadas, Engo and Kunene rivers, which traverse the Namib and thus provide potential fossil assemblages associated with fluvial sediments within an arid environment. Further noteworthy anomalies concerning animal distribution are mentioned briefly. The lower Kunene river, including the Foz do Kunene (mouth), has a population of the Nile Crocodile throughout the inhospitable Namib tract[73] (Costa, personal communication; Viljoen and Brits, personal communiction; personal observation 1973/75). A resident population of rock hyrax (*Hyrax capensis*) can be found near Gobabeb, some 60 km from the coast, in the Kuiseb river where there is no permanent surface water. Leopards have been recorded in the Kuiseb Canyon, as in the Namib tract of south-western Angola. Spotted hyaenas can be found in the Kuiseb Valley of the Central Namib, as well as farther north in the Skeleton Coast and Angolan tracts of the Namib. Cheetah have also been observed in these last two areas, adding to the list of unusual distribution records. The occurrence of Chacma baboon, e.g in the Kuiseb Canyon, within the arid desert strip is also interesting, particularly as the Arrisdrif faunal assemblage was noticeably lacking in primate fossils.

It is likely, therefore, that these fluvial Miocene deposits and their probable equivalents reflect the Post-African erosion cycle and Miocene marine transgression, during which time more mesic conditions than at present were dominant. However, the palaeoclimate was probably never more than semi-arid and even though the rainfall was, at times, considerably higher than now, 'a torrential rainy season and a long dry winter seem to have been the rule'[13] (p. 14). In the Southern Namib, the fluvial Grillental Beds are overlain by aeolian Fiskus Beds of Middle to Late Miocene age,[44,53] which may correspond to the uppermost Buntfeldschuh Formation and Rooilepel Beds, as well as the reddish sandstone exposed in the Kalkrucken Valley.[44] The Fiskus succession suggests considerable aridity at that time, but with possibly seasonal rainfall maintaining pans in some inter-dune areas.[44] A dominant southerly quadrant palaeo-wind regime is deduced from aeolian cross-bedding in the Fiskus sequence (Stocken, personal communication). A similar trend can be deduced for the Central Namib, where palaeo-dune sands persisted on the interfluvial areas of the Kuiseb after the deposition of the Miocene equivalent high-terrace conglomerates until affected by widespread calcrete formation.[54]

As mentioned earlier, many of the probable Miocene conglomerates are often intensely calcified,[14] with the thick deposits (*c.* 60 m and more) being cemented by a fluctuating but steadily dropping water-table under semi-arid conditions.[74] The interfluvial areas, particularly where the arenites are present, are often capped by a thick calcrete[14] or surface limestone (up to 5 m thick on fossil dune sands[54]), which also forms the uppermost section of the fluvial deposits. In the Central Namib this calcrete is interpreted as a palaeosol which developed over a period of some 500 000 years of landform stability under semi-arid, summer rainfall (?350 – 450 mm/yr) conditions.[54] This calcrete pre-dates the Plio-Pleistocene incision of the larger rivers traversing the Namib[54] and has been assigned an End Miocene age[53] (*c.* 6 Myr ago). Although best developed in the eastern areas,[75] the calcretes are widespread in the Namib, capping the Buntfeldschuh Formation palaeo-dunes,[14] the aeolian Rooilepel Beds and the Gemsboktal Gravels in the Southern Namib[44] (Stocken, personal communication). The thick Tertiary succession in the Ugab Valley is capped by a surface limestone,[16] as are many sedimentary sequences in the northern Skeleton Coast, e.g. the Sechumib, Munutum and Engo Valleys. Significantly, the calcretes are less well-developed, or even absent, westwards across the Central Namib, suggesting a decline in rainfall in that direction, similar to present-day conditions. This observation is further supported by the very well-preserved aeolian cross-bedding in palaeo-dunes of the Tsondab Sandstone Formation east and southeast of Sandwich Harbour, which in places are overlain by mere lag gravels, the unconsolidated thin equivalents of the Kuiseb high-terrace cemented conglomerates farther east.[14]

This widespread pedogenic calcrete development marks the upper limits of the various arenite sequences, namely, the Tsondab Sandstone Formation and its probable equivalents, as well as the fluvial deposits attributed to the Miocene. They therefore provide an important stratigraphic marker, tentatively dated as End Miocene at present,[44,53] approximately coinciding with the full development of the Benguela Current in Late Miocene times[63,64] and pre-dating river incision in the Plio-Pleistocene.[13-15,54]

The Benguela Current System, with its cooling and upwelling features, plays a major role in determining the current arid to hyper-arid regime in the Namib Desert[5,7,24,63] as well as influences advective fog formation and maintains a steep climatic gradient[32] between the Atlantic Ocean and the Great Escarpment. Recent sedimentological, palaeontological and geochemical data obtained from deep-sea cores on the Walvis Ridge, strongly suggest an intensification of cold-water upwelling and the full development of the Benguela Current in early Late Miocene times (*c.* 10 Myr ago).[63,64] These observations suggest that the aridification of the Namib Desert was initiated, or at least greatly intensified, at that time,[65] and support the conclusions of both earlier workers, such as Korn and Martin,[13] Martin,[20] and Carvalho,[17] and more recent interpretations[7,8] of the Late Cenozoic conditions in the desert tract.

Late Tertiary – Quaternary record

In Namibia, the Late Tertiary was characterized by arid to extreme-arid conditions which resulted in the widespread mobilization and deposition of aeolian sands in the Kalahari and Namib.[13-15] The Obib dunes, a seif dune complex with distinctive orange sands, in the Southern Namib are considered to be Pliocene equivalents of the Kalahari sands and were probably deposited by south-

southeasterly palaeo-winds.[44] It is likely that the main Namib Sand Sea had its origins at that time and traces of the southern limits of this sand sea found in the Lüderitz-Elizabeth Bay area are considered Pliocene remnants (Stocken, Jamieson and Talbot, personal communication).

These environmental conditions in the Late Tertiary were then affected by Plio-Pleistocene epeirogenic uplift of the subcontinent,[38.50.60] 'bequeathing to the Pleistocene a big, unused potential of erosion'[13] and initiating the incision of the major rivers traversing the Namib Desert, e.g. Kuiseb, Swakop, Ugab, Kunene and Curoca.[10.11.13-15.60] Their development, however, was aided by the 'return of pluvial conditions'[13] (p. 14) in the Early Pleistocene but the overall trend has been one of progressive aridification throughout the Quaternary[7.13.38.64] on which the climatic and eustatic fluctuations of the last approximately two million years have been superimposed. The margins of the Namib Desert may have been affected by latitudinal shifts of the climatic belts during glacial/interglacial cycles, but the main arid to hyper-arid core of the desert was probably never eliminated.[5.7] Furthermore, Korn and Martin[13] suggest that the general distribution of rainfall in Namibia during the Quaternary followed a pattern resembling the present-day trends,[24] with the lowest rainfall in the Namib tract. Thus Miocene marine deposits near Port Alexandre (Angola) show signs of only the typical desert/arid weathering[17] and in the Central Namib, the well-preserved calcrete palaeosols from the end of the Miocene preclude a later sustained humid climate which would have resulted in their dissolution.[54] Similarly, the survival of calcareous pan deposits containing Middle Pleistocene *Elephas reckii* and other fossils[76] implies the dominance of arid conditions since that time, as does the Narabeb calc-lacustrine deposit dated at 240 000 – 210 000 B.P.[77]

Fluvial deposits in the Uis river, which runs parallel to the 100 mm/yr isohyet and Atlantic coast in the northern Central Namib, reflect a general decrease in stream competence from the end of the Tertiary – Early Pleistocene to the present,[13] a trend which is independent of continental upwarping, increased run-off from a source area on the interior plateau and tributary capture.[13] This model exemplifies Korn and Martin's thoughts in the early 1950s on the Quaternary sequence which 'seems to show, right through the Pleistocene, a decline in rainfall on which the pluvial and interpluvial fluctuations are superimposed'[13] (p. 21).

These climatic and eustatic changes facilitated terrace formation along many of the major river courses[13.15] crossing the Namib, generally with Early to Middle and End Pleistocene phases discernible.[13] It is appreciated that most of these rivers rise outside the Namib in regions of generally higher rainfall and therefore the terrace development may not reflect conditions in the Namib. However, along the lowermost canyon reaches of the Kuiseb river, wedges of linear palaeo-dunes are interbedded with fluvial deposits of probable Early to Middle Pleistocene age.[78] These sediments represent the earliest aggradational phase, post-dating river incision in the Kuiseb Valley, and are called the Oswater Conglomerate.[45.46.58.78-80] The palaeo-dunes, found only in outcrops on the left bank, imply the presence of large, linear-type dunes along that reach of the Kuiseb during the aggradational phase,[78] during which time the general northwesterly course from Natab had also been established. The Oswater Conglomerate reflects a regional trend[13.78] and the Glastal Gravels in the Sperrgebiet (Stocken, personal communication), the terraces in the Swakop, Omaruru and Ugab rivers,[13.16] and the Manome Conglomerate in southwestern Angola[17] are probably equivalent deposits.

The presence of dunes in the Central Namib during the Middle Pleistocene is further supported by the Namib IV fossil site, where an Acheulian assemblage, with *Elephas reckii* and antelope remains, led Shackley[76] to postulate savanna conditions at that time. These fossils are associated with a pan palaeo-environment and a recent personal investigation revealed a red dune sand rim, probably the base of a dune or dune edge, on the northwestern side of the palaeo-pan margin. In view of this observation and the anomalous distribution of the larger animals in the Namib Desert, cited earlier, a re-interpretation of the postulated savanna conditions is needed. Reed imprints, probably of *Phragmites* sp., were also observed in the pan carbonate at Namib IV and are indicative of at least temporary standing water. There are a number of localities within the Namib where fossil reeds, or their leaf imprints, occur often in association with pan/lacustrine carbonates, e.g. Khommabes, near Gobabeb, Meob and Conception Bays,[81] and Koichab Pan, or with calc-tufa spring deposits, e.g. Hudaob (Kuiseb river) and Gemsenwasser (northern Koichab river). These calcified traces of former reed beds reflect conditions when more surface water was available but not necessarily sustained wetter conditions. For example, at Khommabes, about 6 km west of Gobabeb, calcified reed-like and sedge-like stalks (probably *Phragmites* sp. and *Juncellus* sp.) are preserved in a palaeo-pan setting, indicating relatively moist conditions, yet the southern margin of the pan is bordered by fossil dune remnants containing calcified root casts of *Acanthosicyos horrida* (!Nara). Radiocarbon dates for !Nara root, termitaria and reed casts imply varying ages of formation, namely, *c.* 21 000 – 22 000 B.P., *c.* 27 000 – 29 000 B.P. and 31 000 – 32 000 B.P.[81] The repeated occurrence of ^{14}C dates between 39 000 – 28 000 B.P. and *c.* 21 000 B.P. in the Central Namib 'strongly suggest two distinct moist periods during Late Pleistocene in Central Namib desert' (p. 77),[81] although the older dates should be treated with reserve and, if possible, checked against the local stratigraphy when used for sedimentological comparisons. This need for caution is demonstrated by the similar ^{14}C dates, *c.* 28 000 – 33 000 B.P., recorded for an Oswater Conglomerate outcrop and nearby pedogenic calcrete between Homeb and Oswater in the Kuiseb Valley of the Central Namib.[81.82] The former deposit post-dates the initial incision of the Kuiseb river[45.58] after the Plio-Pleistocene epeirogenesis and is probably from the Early to Middle Pleistocene,[13.78] whereas the pedogenic calcrete pre-dates the main canyon incision[54] and has been assigned an End Miocene age.[53]

The Homeb Silts,[83] fine-grained micaceous sediments which accumulated in the middle Kuiseb Valley during the Late Pleistocene, *c.* 19 000 – 23 000 B.P.,[81.82] also reflect palaeo-environmental changes in the Quaternary.[79] Some workers interpret these sediments as dune dam deposits[79.84] or river end-point accumulations,[82.83] indicative of arid conditions, whereas Ollier[45] considers them to represent floodplain sediments of an aggrading Kuiseb river. Whatever their origin, fluvially-deposited, unconsolidated red dune sands are intercalated with the silts, implying the presence of dunes along the left bank of the Kuiseb river at that time. Similar micaceous deposits in the Huab, Hoanib and Hoarusib rivers, although not yet dated, suggest a regional control in Central and Northern Namib river aggradation which may be related to either climatic or eustatic changes in the Late Quaternary.[85]

The finding of Stone Age implements in the Namib is interpreted as further evidence for Quaternary climatic fluctuations.[13] Early Stone Age artefacts are recorded in a palaeo-course of the Tsondab[86] and at Namib IV,[76] in the northern parts of the main Namib Sand Sea. Material attributed to the Middle Stone Age (MSA) is widely distributed through the 'driest parts of the Namib desert'[13] (p. 19) in Namibia, and, in southwestern Angola stone artefacts record the existence of early man in the now barren desert strip in the vicinity of Mocamades.[17] These occurrences imply that conditions were favourable, at least episodically, for early man in the Namib at intervals during the Middle and Late Pleistocene. The apparent restriction of Late Stone Age material to favourable sites, such as waterholes and springs, suggests a dominance of dry conditions during the late MSA.[13] However, ^{14}C dates at shelters in the Namib reveal intermittent occupation during the Holocene, e.g. at *c.* 9 000 B.P., *c.* 6 000 B.P. and A.D. 400 at Mirabib,[81.87] as well as

along the eastern fringe of the desert.[81] A ^{14}C date of 12 800 ± 140 B.P. from a site in the dunes between Gobabeb and Sout Rivier[88] 'shows unexpected stability of dune surface since Upper Pleistocene'[81] (p. 55).

Although the main Namib Sand Sea is attributed a Pleistocene to Recent age,[20] which is supported by other workers,[7.33.38.45] it is likely to have had its origins in the Pliocene, when conditions were very arid.[13.44] The sands are derived from southern and western coastal source areas[89.90] (Lancaster and Ollier, in press) of which the Orange river is probably the most important source of sediment,[25.52] as well as from the reworking of the Tsondab Sandstone Formation.[33.55.56] The development of the main Namib Sand Sea was probably facilitated by eustatically lowered sea levels during the Pleistocene,[25.90] and recent sand movement records[11.36.48.91-93] show that the main Namib Sand Sea is still a dynamic system. In the Southern Namib, the Namaqualand coastal dune systems are considered a Quaternary feature[7.25] and, in the northern sector, a Recent age has been proposed for the Skeleton Coast dunefield[94] and the Baia dos Tigres – Curoca Sand Sea.[17]

The observations of earlier workers,[10.11.13.14.16.17] supported by more recent studies,[7.33.45.17.63.64] strongly suggest that the current desert regime of the Namib dates from the Late Tertiary, with the Quaternary climatic and eustatic fluctuations superimposed on a dominant, and possibly progressive, aridifying trend.

Discussion

Emphasis has been placed on the Late Mesozoic and older Tertiary geology in the Namib. Suitable material for absolute dating, such as fossils and volcanics, are scarce. Reliance, therefore, has been placed on stratigraphy to aid in the interpretation of the geological history of the Namib Desert. Personal field experience has also helped us in evaluating the various correlations between units, particularly the fluvial deposits attributed to the Miocene and the widespread arenaceous sediments, including the Tsondab Sandstone Formation, the upper Buntfeldschuh Formation and similar deposits in the Northern and Southern Namib.

The cold upwelling conditions of the Benguela Current are often considered to be an important factor in maintaining the desert climate of the Namib.[2.3.5.7.24.25.26.63.64] We, however, have presented extensive lithological evidence for an Early to Middle (possibly even Late) Tertiary sand sea in at least the Southern and Central Namib, which was deposited by a predominantly southerly palaeowind regime similar to that of today. These conditions probably prevailed for at least 20 to 30 million years,[14] long before the full establishment of the Benguela Current in Late Miocene times.[63.64] Thus, we believe that the age of the cold Benguela Current, and its associated upwelling, cannot be used to establish the antiquity of the Namib. Nevertheless, the fully established Benguela Current is probably closely associated with the occurrence of advective fog.[24] As fog is an important source of moisture for a number of Namib dune plants[95.96] and animals,[97.98.99] the evolution of adaptations leading to its use may be supposed to have started only after the establishment of an effective Benguela Current. This does not, of course, preclude adaptation to the sand environment,[8] or to the desert conditions in general, in the absence of fog.

A steep climatic gradient is a conspicuous feature of the Namib climate and is often attributed to the presence of the Benguela Current and its associated upwelling.[32] Annual rainfall decreases approximately six- to tenfold over about 120 km in the Central Namib from the base of the escarpment to the Atlantic Ocean (Lancaster *et al.*, in press). A similar gradient exists in the Northern Namib, where average annual rainfall at Mocamedes on the coast is *c.* 75 mm in contrast with the *c.* 1 050 mm at Lubango (Sa da Bandeira) on top of the escarpment.[24] Although this gradient is reinforced by the Benguela Current System, the maintenance of low rainfall conditions is accentuated by the location of this narrow strip of desert in the rain shadow of the western part of Southern Africa below the Great Escarpment.[24] This is further accentuated by the high pressure system of the South Atlantic anticyclone, usually situated between Port Nolloth and Lüderitz.[24] These two factors have had the potential to influence the Namib throughout the period following the evolution of the South Atlantic Ocean and the concomitant development of the long, narrow strip of land west of the Great Escarpment — that is, for approximately the last 80 million years.

The Namib cannot be considered a single climatic or geographic unit, and over its approximately 2 000 km length, the desert extends from a winter rainfall region at its southern extremity through an extremely arid central region to a summer rainfall area in the north. The Namib is also extremely narrow, mostly less than 200 km wide, thus the climates encountered at the periphery of the desert inevitably influence the arid centre. The effects of variations in rainfall on the Great Escarpment and interior plateau are very marked, particularly along the ephemeral and perennial rivers which, in rising in those regions, often form linear oases across the desert strip.[93] Such variations have probably persisted throughout the history of the Namib, thus any biological or archaeological evidence relating to the age of the desert must be interpreted cautiously with these variations in mind.

Examples of the influence on the local biology of linear oases coupled with the narrowness of the Namib are numerous[93] and some examples of anomalous animal distributions were cited earlier. Related vegetational discontinuities include the following.

In Angola, *Podocarpus* sp., the yellowwood (cf. *P. milanjianus*, C.J. Ward and J.D. Ward collection no. 53), grows on top of the escarpment in the Tundavala area west of Lubango (Sa de Bandeira), where an average rainfall of *c.* 1 050 mm is recorded.[24] The Great Escarpment is well defined there by the Chella quartzites[10] and drops steeply into the Northern Namib Desert. The vegetation components change rapidly from *Podocarpus* sp. near the summit through *Brachystegia* sp. woodland down to *Colophospermum mopane* woodland and scrub at the base of the escarpment. This, in turn, grades westwards through sub-desert scrub to true desert conditions over a distance of approximately 80 km. The potential pollen sources, e.g. *Podocarpus* sp., are therefore very close to the semi-arid and arid desert tract. Easterly 'berg' winds are recorded for that area,[24] thus there is the likelihood that parts of plants from adjacent, higher rainfall regimes could be incorporated in desert sediments. One vegetation distribution anomaly was recently recorded by two of us (M.K.S. and J.D.W.) in the Hauchab inselberg in the main Namib Sand Sea. On the east-southeast side of the dominant outcrop, a fern and a liverwort (M.K. Seeley and J.D. Ward collection nos. 40 and 41) were recorded in a small, well-protected overhang in what is generally regarded as an extremely arid section of the Namib. Their presence in a local fossil assemblage would, no doubt, suggest a less arid climate than at present. In the Kuiseb Delta, *Acacia albida*, *A. erioloba* and *Ficus sycomorus* trees have been recorded; these specimens were dwarfed (probably from the strong winds and harsh conditions) yet their leaves and pollen still provide a potential source of fossil material in an extremely arid part of the Cental Namib dominated by a *Phragmites* community. At present, normal-size trees of those species are found only upstream of Rooibank along the Kuiseb river.

These anomalous distributions of the fauna and flora of the Namib, particularly along the major river courses, provide a source of organisms which could colonize surrounding dunes, plains and hills if conditions were changed even temporarily. The Namib Desert is a dynamic system and an appreciation of even short-term changes is necessary in any attempt to understand past conditions from the fossil evidence. One dramatic event will be used to illustrate our point. In 1976 over 100 mm of rain fell in the Central Namib, about 50 km from the coast. This resulted in extensive germination of dune vegetation and a fifty-six times increase of standing crop.[100] This vegetation, in turn, supported a population of oryx and springbok which was estimated to be at least fifty times

greater than usually found in that vicinity. It is tempting to speculate that these conditions, in earlier times, could have supported a temporary movement of primitive man into the dune areas with the linear oases of the Kuiseb river (and possibly the Tsondab) never more than about 30 km away. In the wake of the same rainfall event, tenebrionid beetles, which usually occupy the riverine woodland along the Kuiseb river (in this case), were found at least 20 km into the dunes. The likely dispersal, therefore, of relatively small organisms over seemingly inhospitable tracts to isolated inselbergs, or other linear oases, on various occasions in the past, is great.

Another interesting aspect of the dynamic nature of the Namib is reflected in the large delta built up by the Swakop river in the exceptionally heavy floods of 1933 – 34, in which the shoreline prograded several kilometres from its present position.[11] Within a decade, however, these sediments were removed, probably by longshore drift under the strong south-southwesterly coastal wind regime,[24] and the shoreline attained its approximate present position. The dynamic nature of both long- and short-term events in this long, narrow tract of land must therefore be appreciated in any interpretation of palaeo-environmental conditions throughout the geological record of the Namib Desert for the Late Mesozoic and Cenozoic. Another factor to consider is the relative stability of the subcontinent in post-Gondwana times. The current relative position of the South Atlantic Ocean, Great Escarpment and narrow Namib date back to the Cretaceous; the subsequent latitudinal movement of Africa has been northwards, of the order of about 12°, relative to Eurasia.[46,101,102]

Conclusions

A review of Late Mesozoic-Cenozoic geology leads us to conclude that the Namib tract, which dates back to the Cretaceous, has not experienced climates significantly more humid than semi-arid for any length of time during the last 80 million years. Although not well-dated, the Tsondab Sandstone Formation, and its probable arenaceous equivalents, strongly suggest the existence of a major Early to Middle (possibly Late) Tertiary desert sand sea in the Southern and Central Namib, at least, which was more extensive than the current main Namib Sand Sea. These fossil-dunes were deposited by a dominant southerly palaeo-wind regime which was similar to the present wind system. Significantly, these early sand accumulations pre-date the full development of the Benguela Current in Late Miocene times.

Widespread fluvial deposits, attributed to the Middle Tertiary epeirogenic uplift of the subcontinent and the Post-African erosion cycle, are generally dated as Lower to Middle Miocene. Mesic conditions probably prevailed in the Namib at that time and the fluvial aggradation may also be related to a Miocene transgression. A period of geomorphic stability at the end of the Miocene resulted in widespread pedogenic calcrete formation, which may have occurred in a semi-arid climate with summer rainfall. The calcrete palaeosols, however, are best developed along the eastern sector of the Namib and provide an important Cenozoic stratigraphic marker.

Full development of the Benguela Current and its associated cold upwelling system in the Late Miocene accentuated the desertic conditions in the Namib during the Late Tertiary and has contributed to the unique character of the current desert ecosystem. The aridification of the Namib Desert from the Late Tertiary is apparently a progressive phenomenon, which has been affected by Plio-Pleistocene epeirogenesis and climatic fluctuations in the Quaternary superimposed on this aridifying trend. The main Namib Sand Sea probably dates from the Pliocene and was apparently maintained through the Pleistocene to the present day, possibly with minor expansion and contraction of its boundaries.

The unusual distribution of certain plants and animals, particularly in relation to linear oases crossing the desert strip, implies that caution is needed in palaeo-environmental reconstructions from fossil assemblages in the Namib.

These tentative correlations and interpretations of the Late Mesozoic-Cenozoic record will, we hope, broaden perspectives and provide an outline for further discussion on this fascinating topic, the antiquity of the Namib.

We gratefully acknowledge the CSIR for funding our various research projects and the Department of Nature Conservation, South West Africa/Namibia, for facilities at Gobabeb and permission to work in the various parks. We are grateful to the numerous colleagues who have discussed this topic with us over the years. We particularly thank L. Blom, C.K. Brain, D. Bühmann, G. Grantham, V. Gray, K. Hoffman, B.J. Huntley, H. Martin, R. McG. Miller, F. Netterberg, T. Partridge, J. Rogers, M.J. Selby, J.C. Vogel, V. von Brunn, C.J. Ward and D. Yaalon. J.D.W. acknowledges logistic support from the Geological Survey, South West Africa/Namibia, and thanks Dr C. Stocken and his field staff of C.D.M. for an enlightening trip in the Southern Namib.

Received 23 February; accepted 9 March 1983.

1. Meigs P. (1966). Geography of coastal deserts. *UNESCO Arid Zone Res.* **28**, 1 – 40.
2. Koch C. (1961). Some aspects of abundant life in the vegetationless sand of the Namib Desert dunes. *J. S.W. Afr. Sci. Soc.* **15**, 8 – 34, 77 – 92.
3. Koch C. (1962). The Tenebrionidae of southern Africa XXXI. Comprehensive notes on the tenebrionid fauna of the Namib Desert. *Ann. Transv. Mus.* **24**, 61 – 106.
4. Kaiser E. (1926). *Die Diamantenwüste Südwestafrikas.* Dietrich Reimer, Berlin.
5. Van Zinderen Bakker E.M. Sr (1975). The origin and palaeoenvironment of the Namib Desert biome. *J. Biogeog.* **2**, 65 – 73.
6. Endrödy-Younga S. (1978). In *Biogeography and Ecology of Southern Africa,* edit. M.J. Werger, pp. 797 – 821. Junk, The Hague.
7. Tankard A.J. and Rogers J. (1978). Late Cenozoic palaeoenvironments on the west coast of southern Africa. *J. Biogeog.* **5**, 319 – 337.
8. Seely M.K. (1978). The Namib Dune Desert: an unusual ecosystem. *J. arid Environ.* **1**, 117 – 128.
9. Beetz W. (1926). In *Die Diamantenwüste Südwestafrikas,* edit. E. Kaiser. Dietrich Reimer, Berlin.
10. Beetz W. (1933). Geology of South West Angola, between Cunene and Luanda Axis. *Trans. geol. Soc. S. Afr.* **36**, 137 – 176.
11. Gevers T.W. (1936). The morphology of Western Damaraland and the adjoining Namib Desert of South West Africa. *S. Afr. geog. J.* **19**, 61 – 79.
12. Korn H. and Martin H. (1937). Die jüngere klimatische und geologische Geschichte Südwestafrikas. *Zentral-blatt für Minen* **11** (Sect. B).
13. Korn H. and Martin H. (1957). In *Proc. III Pan-African Congress on Prehistory, Livingstone,* edit. J.D. Clarke and S. Cole, pp. 14 – 22. Chatto and Windus, London.
14. Martin H. (1950). Südwestafrika. *Geol. Rdsch.* **38**, 6 – 14.
15. Martin H. (1961). AbriB der geologischen Geschichte Südwestafrikas. *J. S.W. Afr. Sci. Soc.* **15**, 57 – 66.
16. Mabbutt J.A. (1952). The evolution of the middle Ugab valley, Damaraland, South West Africa. *Trans. R. Soc. S. Afr.* **33**, 333 – 365.
17. Soares de Carvalho G. (1961). Geologia do deserto de Mocamedes. *Mem. Junta Invest. Ultram. 2. Sér.* **26**.
18. Stocken C.G. (1962). The diamond deposits of the Sperrgebiet, South West Africa. *Field excursion guide, 5th Ann. Congr. geol. Soc. S. Afr.* 1 – 16.
19. Antunes M.T. (1964). O Neocretacio e o Cenozoico do litoral de Angola. *Junta de Invest. Ultram. 2. Sér.*
20. Martin H. (1973). In *Sedimentary Basins of the African Coasts.* Part II: South and East Coast, pp. 7 – 15. Geological Survey, Paris.
21. Coetzee J.A. and van Zinderen Bakker E.M. Sr (Eds) (1982). *Palaeoecology of Africa* **15**, Balkema, Rotterdam.
22. Vogel J.C., Rogers J. and Seely M.K. (1981). Summary of SASQUA Congress May 1981. *Geol. Soc. S. Afr. Quart. News Bull.* **24**(3), 25 – 27.
23. Vogel J.C., Rogers J. and Seely M.K. (1981). Summary of SASQUA Congress May 1981. *S. Afr. J. Sci.* **77**, 435 – 436.
24. Meteorological Services of the Royal Navy and the South African Air Force (1943). *Weather on the coasts of Southern Africa,* vol. II(I). *The West Coast of Africa from River Congo to Olifants River,* 3 – 61. Cape Times, Cape Town.
25. Rogers J. (1977). Sedimentation on the continental margin off the Orange River and the Namib Desert. *Joint Geol. Surv./UCT Marine Geosci. Group Bull.* **7**. Cape Town.
26. Wellington J.H. (1955). *Southern Africa — a geographical study,* vol. 1. *Physical Geography,* 528 pp. Cambridge University Press, Cambridge.
27. Barnard W.S. (1964). 'n Terreintipekaart van Suidwes-Afrika. *S. Afr. Geographer* **2**(4), 66 – 72.
28. Barnard W.S. (1973). Duinformasies in die Sentrale Namib. *Tegnikon,* 2 – 13.
29. Spreitzer H. (1966). Beobachtungen zur Geomorphologie der zentralen Namib und ihrer Randgebiete. *J. S.W. Afr. Sci. Soc.* **30**, 69 – 94.
30. Giess W. (1971). A preliminary vegetation map of South West Africa. *Dinteria* **4**,

31. Logan R.F. (1972). The geographical divisions of the deserts of South West Africa. *Mitt. Basler Afrika-Bibl.* **4 – 6**, 46 – 65.
32. Besler H. (1972). Klimaverhaltnisse und klimageomorphologische Zonierung der zentralen Namib (Südwestafrika). *Stuttgarter Geogr. Stud.* **83**, 1 – 209.
33. Besler H. (1980). Die Dunen-Namib: Entstellung und Dynamik eines Ergs. *Stuttgarter Geogr. Stud.* **96.**
34. Kayser K. (1973). Beiträge zur geomorphologie der Namib-Küstenwüste. *Z. Geomorph. N.F.*, **17**, 156 – 167.
35. McKee, E.D. (Ed.) (1979). A study of global sand seas. *Geol. Surv. Prof. Pap. 1052*, 429 pp.
36. Endrödy-Younga S. (1982). Dispersion and translocation of dune specialist tenebrionids in the Namib area. *Cimbebasia* (A) **5**, 257 – 271.
37. Simpson E.S.W. (1977). Evolution of the South Atlantic. *Alex L. du Toit Mem. Lect. 15*, 1 – 15. Geol. Soc. S. Afr. Annex. vol. LXXX.
38. Tankard A.J. *et al.* (1982). *Crustal Evolution of Southern Africa. 3.8 Billion Years of Earth History.* Springer-Verlag, New York.
39. Dingle R.V. and Scrutton R.A. (1974). Continental breakup and the development of post-Paleozoic sedimentary basins around Southern Africa. *Bull. geol. Soc. Am.* **85**, 1467 – 1474.
40. Martin H. (1975). Structural and palaeogeographical evidence for an Upper Palaeozoic Sea between Southern Africa and South America. *Proc. Pap. IUGS 3rd Gondwana Symp. 1973, Canberra*, 37 – 51.
41. Bryan G.M. and Simpson E.S.W. (1971). Seismic refraction measurements on the continental shelf between Orange River and Cape Town. *Inst. Geol. Sci. Rep. 70/16*, 186 – 198.
42. Dingle R.V. (1973). Regional distribution and thickness of post-Palaeozoic sediments on the continental margin of southern Africa. *Geol. Mag.* **110**, 97 – 102.
43. Van Andel T.H. and Calvert S.E. (1971). Evolution of sediment wedge, Walvis shelf, South West Africa. *J. Geol.* **79**, 585 – 602.
44. Stocken C.G. (1978). A review of the later Mesozoic and Cenozoic deposits of the Sperrgebiet. Unpubl. rep. Geol. Dept., Consolidated Diamond Mines of South West Africa (Pty) Ltd.
45. Ollier C.D. (1977). Outline geological and geomorphic history of the Central Namib Desert. *Madoqua* **10**, 207 – 212.
46. Ollier C.D. (1978). Inselbergs of the Namib Desert — processes and history. *Z. Geomorph. N.F.* **31**, 161 – 176.
47. Selby M.J. (1976). Some thoughts on the geomorphology of the central Namib desert. *Namib Bull.* Suppl. 1 of *Transv. Mus. Bull.* 5 – 6.
48. Selby M.J. (1977). Bornhardts of the Namib Desert. *Z. Geomorph. N.F.* **21**(1), 1 – 13.
49. McLachlan I.R. and McMillan I.K. (1979). Microfaunal biostratigraphy, chronostratigraphy and history of Mesozoic and Cenozoic deposits on the coastal margin of South Africa. *Geokongres 77, Geol. Soc. S. Afr. Spec. Publ.* **6**, 161 – 181.
50. Partridge T.C. (1982). A review of southern African geomorphology. *Geol. Soc. S. Afr. Winter Fieldschool* **7**, July 1982.
51. Hoyt J.H., Oostdam B.L. and Smith D.D. (1969). Offshore sediments and valleys of the Orange River. *Marine Geol.* **7**, 69 – 84.
52. Rogers J. (1973). Texture, composition and depositional history of unconsolidated sediments from the Orange-Lüderitz shelf, and their relationship with Namib desert sands. *IGS/UCT Tech. Rep.* **5**, 67 – 88.
53. South African Committee for Stratigraphy (1980). Stratigraphy of South Africa, Part 1, comp. L.E. Kent. *Handb. geol. Surv. S. Afr.* **8**, 578 – 609.
54. Yaalon D.H. and Ward J.D. (1982). In *Palaeoecology of Africa* **15**, edit. J.A. Coetzee and E.M. Van Zinderen Bakker. Balkema, Rotterdam.
55. Besler H. (1976/77). Untersuchungen in der Dunen-Namib (Südwestafrika). *J. S.W. Afr. Sci. Soc.* **31**, 33 – 64.
56. Besler H. and Marker M.E. (1979). Namib Sandstone: a distinct lithological unit. *Trans. geol. Soc. S. Afr.* **82**, 155 – 160.
57. McKee E.D. (1982). Sedimentary structures in dunes of the Namib Desert, South West Africa. *Geol. Soc. Am. Spec. Pap. 188.*
58. Marker M.E. (1977). Aspects of the geomorphology of the Kuiseb river, South West Africa. *Madoqua* **10**, 199 – 206.
59. Netterberg F. (1980). Geology of southern African calcretes: 1. Terminology, description, macrofeatures and classification. *Trans. geol. Soc. S. Afr.* **83**, 255 – 283.
60. King L.C. (1951). *South African Scenery*, 2nd ed. Oliver and Boyd, Edinburgh.
61. Coetzee F. (1975). Solution pipes in coastal aeolianites of Zululand and Mocambique. *Trans. geol. Soc. S. Afr.* **78**, 323 – 333.
62. Moroshnikov K.V., Bubnov V.A. and Butalov R.P. (1970). Water circulation in the eastern South Atlantic Ocean. *Oceanology* **10**, 27 – 37.
63. Siesser W.G. (1977). In *Antarctic Glacial History and World Palaeonenvironments*, edit. E.M. Van Zinderen Bakker, pp. 105 – 112. Balkema, Rotterdam.
64. Siesser W.G. (1980). Late Miocene origin of the Benguela upwelling system off northern Namibia. *Science* **208**, 283 – 285.
65. Corvinus G. and Hendey Q.B. (1978). A new Miocene vertebrate locality at Arisdrift in South West Africa (Namibia). *N. Jb. Geol. Paläont. Mh.* (1978) (*4*), 193 – 205.
66. Steyn M.V.R. (1982). Guide book to the Ochta Diamond Mine, Richtersveld, North West Cape Province. *Geol. Soc. S. Afr. Winter Fieldschool* **8**, October 1982.
67. Stocken C.G. and Campbell D. (1982). Some notes on the CDM raised beach complex. *Geol. Soc. S. Afr. Winter Fieldschool* **8**, October 1982.
68. Miller R. McG. and Seely M.K. (1976). Fluvio-marine deposits south-east of Swakopmund, South West Africa. *Madoqua* **9**(3), 23 – 26.
69. Stromer E. (1926). In *Die Diamantenwüste Südwestafrikas*, edit. E. Kaiser, pp. 107 – 153. Dietrich Reimer, Berlin.
70. Hamilton W.R. and Van Couvering J.A. (1977). Lower Miocene mammals from South West Africa. *Namib Bull.* Suppl. 2, *Transv. Mus. Bull.*, 9 – 11.
71. Hopwood A.T. (1929). New and little known mammals from the Miocene of Africa. *Am. Mus. Novit.* **344**, 1 – 9.
72. Coetzee J.A. (1980). Tertiary environmental changes along the south-western African coast. *Palaeont. afr.* **23**, 197 – 203.
73. Van Riet W. (1965). Canoe trip on the Cunene. *African Wild Life* **19**, 293 – 302.
74. Netterburg F. (1969). The interpretation of some basic calcrete types. *Bull. S. Afr. archaeol. Soc.* **24**, 117 – 122.
75. Blümel W.D. (1982). In *Aridic Soils and Geomorphic Processes*, Catena Suppl. 1, edit. D. Yaalon, pp. 67 – 82. Braunschweig.
76. Shackley M. (1980). An Acheulean industry with *Elephas reckii* fauna from Namib IV, South West Africa (Namibia). *Nature* **284**, 340.
77. Selby M.J., Hendy C.H. and Seely M.K. (1979). A late Quaternary lake in the central Namib Desert, Southern Africa, and some implications. *Palaeogeog., Palaeoclim., Palaeoecol.* **26**, 37 – 42.
78. Ward J.D. (1982). In *Palaeoecology of Africa* **15**, edit J.A. Coetzee and E.M. Van Zinderen Bakker. Balkema, Rotterdam.
79. Rust U. and Wieneke F. (1974). Studies on gramadulla formation in the middle part of the Kuiseb River, South West Africa. *Madoqua* **3**(*69 – 73*), 5 – 15.
80. Sawyer E.D. (1976). Provisional legend of field sheets 2315CA Gobobeb and 2315CB Gorob. Unpubl. Rep. Geol. Surv., Windhoek.
81. Vogel J.C. and Visser E. (1981). Pretoria radiocarbon dates II. *Radiocarbon* **23**(*1*), 43 – 80.
82. Vogel J.C. (1982). In *Palaeoecology of Africa* **15**, edit. J.A. Coetzee and E.M. Van Zinderen Bakker. Balkema, Rotterdam.
83. Marker M.E. and Müller D. (1978). Relict vlei silt of the middle Kuiseb Valley, South West Africa. *Madoqua* **11**(*2*), 151 – 162.
84. Scholz H. (1972). The soils of the Central Namib Desert with special consideration of the soils in the vicinity of Gobabeb. *Madoqua* **1**(*54 – 62*), 33 – 51.
85. Wieneke F. and Rust U. (1973). Variations du niveau marin et phases morphoclimatiques dans le desert du Namib Central, Afrique du Sud-Quest. *Finisterra VIII* **51**, 48 – 65.
86. Seely M.K. and Sandelowsky B.H. (1974). Dating the regression of river's end point. *S. Afr. Archaeol. Soc. Goodwin Ser.* **2**, 61 – 64.
87. Sandelowsky B.H. (1977). Mirabib — an archaeological study in the Namib. *Madoqua* **10**(*4*), 221 – 283.
88. Sandelowsky B.H. (1976). An ancient butcher site in the dunes of the Namib. *S.W. Afr. Ann. 1976*, 118 – 119.
89. Harmse J.T. (1980). *Die noordwaartse begrensing van die Sentrale Namib duinsee langs die Benede-Kuiseb.* Thesis, University of Stellenbosch.
90. Lancaster N. (1982). In *Palaeoecology of Africa* **15**, edit. J.A. Coetzee and E.M. Van Zinderen Bakker. Balkema, Rotterdam.
91. Besler H. (1975). Messungen zur Mobilität von Dünensanden am Nordrand der Dünen-Namib (Südwestafrika). *Würzburger Geographische Arbeiten* **43**, 135 – 147.
92. Barnard W.S. (1975). Geomorfologiese prosesses en die mens: die geval van die Kuiseb delta, S.W.A. *Acta geog.* **2**, 20 – 43.
93. Seely M.K. *et al.* (1980/81). Lower Kuiseb River Perennial Vegetation Survey. *J.S.W. Afr. Sci. Soc. XXXIV/XXXV*, 57 – 86.
94. Lancaster N. (1982). Dunes on the Skeleton Coast, S.W.A./Namibia: geomorphology and grain size relationships. *Earth Surface Processes and Landforms* **7**, 575 – 587.
95. Seely M.K., de Vos M.P. and Louw G.N. (1977). Fog imbibition, satellite fauna and unusual leaf structure in a Namib dune plant *Trianthema hereroensis*. *S. Afr. J. Sci.* **73**, 169 – 172.
96. Louw G.N. and Seely M.K. (1980). Exploitation of fog water by a perennial Namib dune grass, *Stipagrostis sabulicola*. *S. Afr. J. Sci.* **76**, 38 – 39.
97. Hamilton W.J. III and Seeley M.K. (1976). Fog basking by the Namib Desert beetle, *Onymacris unguicularis*. *Nature* **262**, 284 – 285.
98. Seely M.K. and Hamilton W.J. III (1976). Fog catchment sand trenches constructed by tenebrionid beetles, *Lepidochora*, from the Namib Desert. *Science* **193**, 484 – 486.
99. Seely M.K. (1979). Irregular fog as a water source for desert dune beetles. *Oecologia* **42**, 213 – 227.
100. Seely M.K. and Louw G.N. (1980). First approximation of the effects of rainfall on the ecology and energetics of a Namib Desert dune ecosystem. *J. arid. Environ.* **3**, 25 – 54.
101. Truswell J.H. (1977). *Geological Evolution of South Africa.* Purnell, Cape Town.
102. Dietz R.S. and Holden J.C. (1970). Reconstruction of Pangaea: Breakup and dispersion of continents, Permian to present. *J. geophys. Res.* **75**, 4939 – 4956.