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Aridity in southern Africa: Age, origins and expression in landforms and sediments

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ABSTRACT. Today, arid and semi-arid climates have a wide distribution in southern Africa. Late Cenozoic landforms and sediments from the Namib suggest that although the area has experienced periods of increased humidity, these have been of limited extent and duration and that the region has experienced no climate more humid than semi-arid since the end-Miocene. Trends in the character of sediments and landforms suggest that there has been a progressive increase in aridity during the Late Cenozoic. The sedimentary record from the Kalahari is less clear, but similarly implies a long history of arid and semi-arid climates in this region. Thus, palaeolakes record periods of considerably increased humidity, whilst extensive systems of linear dunes, now fixed by vegetation, point to at least three periods when aridity was both more intense and of greater extent than at present.

INTRODUCTION

Today, the climates of southern Africa are dominated by seasonal or permanent aridity. Some 74 % of the area of the subcontinent is classified as arid or semi-arid (Paylore 1979) in a series of concentric zones of increasing aridity centered on the hyperarid Namib Desert along the west coast (Fig. 1). Two main sub-tropical arid regions can be distinguished on the basis of climate and physiography (Fig. 2): the hyperarid Namib Desert along the west coast and the arid to semi-arid Kalahari in the interior.

In recent years, there has been considerable interest in the age and Late Cenozoic history of aridity in southern Africa. Most of this has concentrated upon events in the Namib Desert and has been stimulated by considerations of the character and evolution of its distinctive fauna and flora (Koch 1961, 1962; Van Zinderen Bakker 1975; Seely 1978; Tankard and Rogers 1978; Endrody Younga 1978, 1982). Interest in the subject continues at a high level, as witnessed by the panel discussion at the 1981 SASQUA conference (Vogel, Rogers and Seely 1981) and recent papers by Ward et al. (1983) and Van Zinderen Bakker (in press). In contrast, discussion of palaeoenvironments in the Kalahari has concentrated on the Late Pleistocene and the chronology of periods of humid climates (Heine 1978, 1982; Lancaster 1979a, b).

The aim of this paper is to discuss the evidence contained in landforms and sediments for long-continued and persistent Late Cenozoic aridity in the Namib and the Kalahari.

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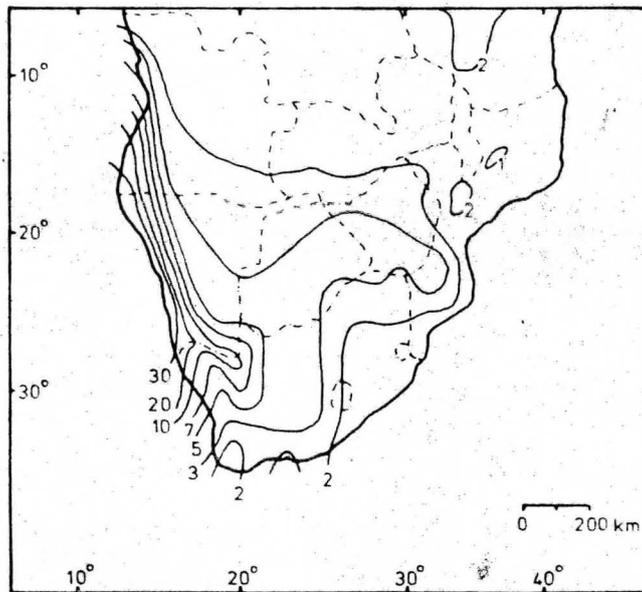


Figure 1. Distribution of arid climates in southern Africa, as shown by isolines of the Budyko-Lettau dryness ratio (the number of times the mean annual net radiation is able to evaporate the mean annual rainfall). Areas with values of 2 - 7 are considered semi-arid, 7 arid and 20 extremely arid.

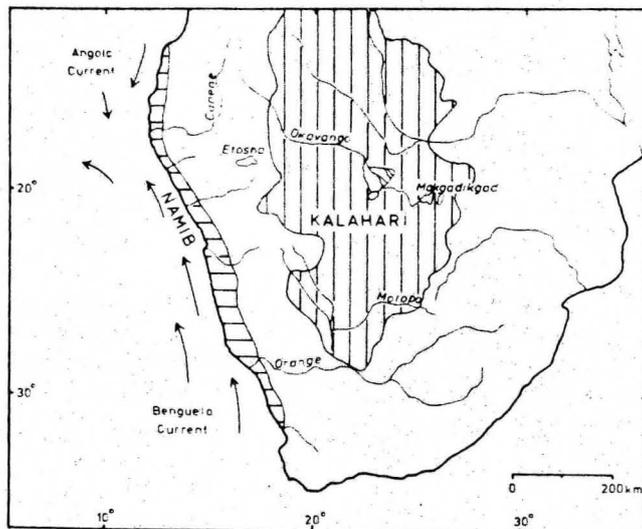


Figure 2. Major physiographic divisions of the subtropical and tropical arid zone in southern Africa.

TERTIARY ARIDITY IN THE NAMIB AND KALAHARI

The Namib

The evidence for the antiquity of aridity in the Namib has been fully discussed by Ward et al. (1983), who put forward the view that the character of most Tertiary sediments in the Namib suggests that they were deposited in arid or semi-arid conditions. The most striking evidence of Tertiary aridity in the region is contained in the thick red brown sandstones of the Tsondab Sandstone Formation and its probable equivalents, which are widely distributed in the central and southern Namib (Besler and Marker 1979; Ward et al. 1983). The sandstones contain both dune and sand sheet structures with large scale cross bedding dipping towards the northeast and northwest, implying deposition by winds from southerly directions (Besler and Marker 1979; Ward et al. 1983). They represent the accumulation of a major sand sea in the central and southern Namib over a period of some 20 to 30 m.y., prior to the Mid- to Late Miocene.

Although the Lower to Mid-Miocene fluvial gravels of the southern Namib appear to indicate a more mesic climate and savanna vegetation 12 to 18 m.y. ago (Corvinus and Hendey 1978), the sediments suggest deposition by seasonal or ephemeral streams (Ward et al. 1983). Further, in the central Namib at least, the upper members of the Tsondab Sandstone Formation were accumulating at the same time as gravels of apparently similar age to those which contain the Arrisdrift and Luderitz faunas were being laid down in the adjacent valleys (Yaalon and Ward 1982).

The Miocene fluvial gravels and the upper parts of the Tsondab Sandstone Formation and its equivalents were extensively calcreted during the end Miocene (Martin 1950). These thick pedogenic calcretes were interpreted by Yaalon and Ward (1982) as indicating some 500 000 years of landscape stability and a semi-arid climate with a summer rainfall of 350 to 450 mm. However, this evidence for more mesic climates in the Later Miocene represents an interval of no more than semi-aridity in the region and it appears that aeolian sand accumulation continued throughout the period, albeit possibly at a reduced level.

It appears that during the Pliocene, a climate of modern affinities was developing in the region. Seisser (1978, 1980) reports a variety of sedimentary, palaeontological and geochemical data from DSDP cores from the Walvis Ridge, which indicates that upwelling intensified significantly from the Late Miocene (7 to 10 m.y. BP) onwards and that the Benguela current developed progressively thereafter. The aridity of the Namib in the Pliocene appears to be confirmed by pollen from cores in the Walvis Ridge area, which indicate a hyperarid climate similar to that of today throughout the Pliocene (Van Zinderen Bakker, in press). Towards the end of the Pliocene, the Obib dunes of the southern Namib were formed and the main Namib Sand Sea began to accumulate (Ward et al. 1983), possibly aided by the Pliocene regression (Seisser and Dingle 1981).

The Kalahari

The Kalahari has acted as a major sedimentary basin since the Cretaceous (Tankard et al. 1982) and contains a considerable thickness (up to 500 m) of terrestrial sediments, mainly sands and marls, with playa

Proto-Namib

Pluvial phase

Pedogenic phase

deposits in some areas as described by Rogers (1934); Du Toit (1954); Boocock and Van Straten (1962); Money (1972); Smit (1977); Wright (1978); SACS (1980). Many of the sediments have been calcreted or silicified (Watts 1980; Summerfield 1983).

There are few exposures of these sediments, termed the Kalahari Group by SACS (1980), and even fewer detailed studies of their lithology and stratigraphy. Consequently, the age and depositional environments of the Kalahari Group remain uncertain. Cahen and Lepersonne (1952) and Mabbutt (1955) have attempted to assign ages to its members by correlating their occurrence with land surfaces of different antiquities. In the southwestern Kalahari, Mabbutt (1955) suggested that the pre-Kalahari Group surface was Cretaceous in age and that the Kalahari limestone and underlying calcareous sandstones were of Early Tertiary age, with the surface Kalahari sands predating the end-Tertiary incision of the River valleys. However, as Netterberg (1969) points out, the age given to the Kalahari limestone, and thus the age of the whole sequence, is based on slender palaeontological evidence. Martin (1950) has tentatively suggested that the Kalahari Group may be correlated with the Tsondab Sandstone Formation and its equivalents, with the Kalahari limestone possibly being equivalent to the end Miocene pedogenic calcretes of the eastern Namib. Most workers (e.g. Poldervaart 1957; Baillieul 1975) have suggested that the surface Kalahari sands are Late Tertiary to Recent in age, although Korn and Martin (1957) firmly assign them a Pliocene age.

Interpretation of depositional environments for the Kalahari Group is hampered by the lack of exposures, but there seems to be general agreement that its sediments accumulated in arid to semi-arid environments (Smit 1977; SACS 1980). This interpretation is supported by the widespread occurrence of calcretes, often with a high dolomite content (Watts 1980), which represents a series of episodes of pedogenesis in semi-arid climates since the Pliocene. Silcretes are also widely found (Summerfield 1983) and their distinct chemistry and mineralogy indicate that they were formed in alkaline pan margin environments. Late Tertiary stromatolites from Etosha Pan (Martin and Wilczewski 1972) indicate widespread saline lacustrine environments in this area.

Although the precise provenance of the surface Kalahari sands is uncertain, most workers have accepted that they have been redistributed by the wind a number of times during the Late Cenozoic (Poldervaart 1957; Grove 1969; Binda and Hildred 1973; Baillieul 1975). Thus, their widespread distribution in southern and south central Africa (Fig. 3) points to a number of periods of very extensive aridity in the Late Cenozoic.

THE QUATERNARY RECORD

The Namib

The Quaternary sedimentary geomorphic record for the Namib is one of continued aridity or extreme aridity, with considerable evidence to suggest that Quaternary climatic fluctuations in the region were of low magnitude and extent and were superimposed upon a trend of increasing aridity, as originally suggested by Korn and Martin (1957).

Accumulation of the Namib Sand Sea continued, with sand derived mostly from southern and western coastal source areas (Rogers 1977; Lancaster and Ollier 1983), fed ultimately by the sand fraction of the sedi-

ment load of the Orange River. This process was probably facilitated by eustatically lowered sea levels and higher wind speeds during Glacial Maxima. Further small sand seas and dune fields accumulated during the Late Pleistocene and Namaqualand (Tankard and Rogers 1978) and the Holocene in the northern Namib (Lancaster 1982). This process is still continuing. Stages in the development of the Namib Sand Sea are marked by wedges of dune arenites with steeply dipping large scale fore sets intercalated with fluvial conglomerates of probably Mid-Pleistocene age on the south bank of the Kuiseb river. These were interpreted by Ward (1982) as the deposits of large linear type dunes which abutted the river in a manner similar to those adjacent to the river today. Dune bedded sands are also present on the margins of a pan in the eastern Namib, the deposits of which contain remains of the Mid-Pleistocene *Elephas reckii* (Shackley 1980).

Continuing aridity in the Namib is also evidenced by the surface survival of calcareous palaeosols (Yaalon and Ward 1982) and calcareous lacustrine deposits (Selby et al. 1979). Quaternary pollens from DSDP cores on the Walvis Ridge are suggestive of a vegetation cover similar to that of today, with indications that the periods of increased humidity which occurred were not sufficient to change the composition of the vegetation (Van Zinderen Bakker, in press). The terrigenous sediments from the same cores indicate a dominance of aeolian inputs and thus arid climates in the region over the last 200 000 years (Diester Haas, pers. comm.)

The valleys of the major Namib rivers from the Tsondab northwards contain sequences of deposits which record periods of aggradation of gravels and silts during the Pleistocene, with intervening periods of incision (Gevers 1936; Mabbutt 1952; Korn and Martin 1957; Ward 1982; Vogel 1982). Whether or not these sequences reflect climatic or eustatic changes in the Namib and its hinterland (Ward et al. 1983), it seems clear from the sedimentary character of the deposits that they were laid down in arid conditions, as suggested by the presence of large dunes on the southern bank of the Kuiseb during the deposition of the Oswater conglomerate (Ward 1982). Silt deposits accumulated in the Kuiseb valley 23 000 to 19 000 BP in conditions of reduced stream discharge and competence (Vogel 1982) which may have been accentuated by the blocking of the valley by dunes (Rust and Wienecke 1974; Marker and Muller 1978). Red sands contained in many marginal facies again suggest the close proximity of dunes to the Kuiseb river (Ward et al. 1983).

Deposits from the Uis river, in the central Namib, suggest a decline in stream competence from the Late Tertiary which is independent of tectonic and basin area changes (Korn and Martin 1957). A similar situation obtains in the Tsondab Valley, where an episodic decline in stream discharge and competence seems to have occurred throughout the Quaternary (Seely and Sandelowski 1974; Lancaster 1983). These changes in fluvial deposits suggest a progressive desiccation of the Namib region during the Quaternary.

Calcified reed bed and pan margin deposits with C14 ages clustering around 32 000 to 31 000, 29 000 to 27 000, 22 000 to 21 000 and 12 000 to 10 000 BP (Vogel and Visser 1981) are scattered through the central Namib. Although suggestive of moister conditions, their occurrence in proximity to modern groundwater seepages and river valleys suggests low amplitude climatic changes.

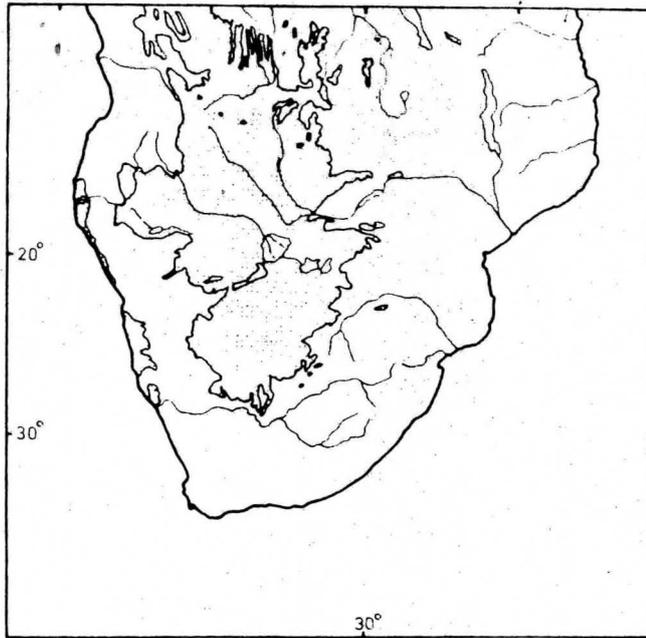


Figure 3. Distribution of sands of Kalahari type in southern Africa and major sand seas in the Namib.

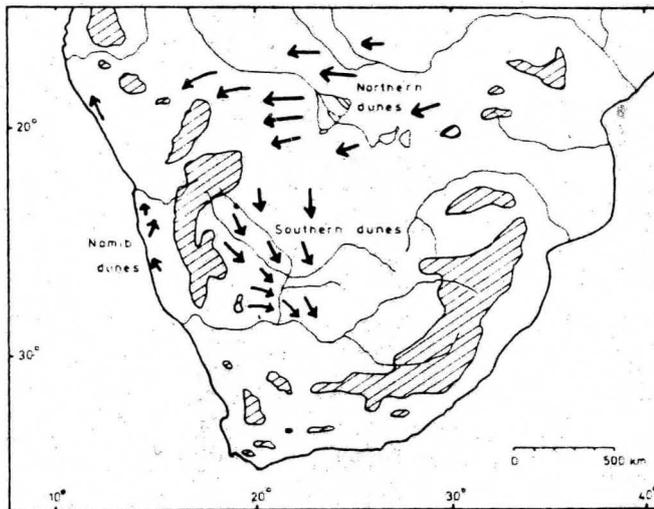


Figure 4. Generalized trends of major dune systems in southern Africa.

The Kalahari

The Quaternary sedimentary and geomorphic record for the Kalahari suggests that climates in the region fluctuated about a semi-arid mean. Periods of aridity of very considerable geographical extent alternated with widespread formation of pedogenic calcretes in intervals of semi-arid climates in the Mid-Pleistocene, Upper Pleistocene and Late Pleistocene - Recent (Netterberg 1969; Watts 1980). There were limited periods of sub-humid climates, as evidenced by shallow lakes in valleys and pan depressions (Lancaster 1979b; Helgren and Brooks 1983) and the deposition of sinter in caves (Cooke 1975). The palaeoclimatic significance of large palaeolakes in the Makgadikgadi Depression is uncertain, given the tectonic instability of the Okavango delta region and the exoreic nature of most of its drainage (Cooke 1980).

Microcosms of Late Quaternary climatic change in the southern Kalahari are contained in the deposits and landforms of the pans (Lancaster 1978), with periods of deflation in sub-arid to arid conditions alternated with shallow seasonal or permanent alkaline lakes formed in sub-humid climates. A rather similar record of alternating arid and sub-humid climates is provided by the alluvial, colluvial and lacustrine deposits of the Dobe and Xangwa valleys in Ngamiland (Helgren and Brooks 1983).

Extensive systems of parallel, mostly linear, dunes now fixed by savanna vegetation, occur throughout the Kalahari from the Orange river to southern Angola and southwestern Zambia (Lancaster 1981), forming an arc which corresponds approximately to the pattern of outblowing winds around the South African anticyclone (Fig. 4). The existence of dunes fixed by savanna vegetation and occurring in areas which today receive 450 - 650 mm of rainfall annually is a graphic illustration of the former extent of aridity in southern Africa. Currently active dunes are restricted to the Namib Desert where rainfall is less than 100 mm per year; whilst dune crests are active in some areas of the southwestern Kalahari where rainfall is between 100 and 150 mm. Comparisons of the present position of the 100 mm isohyet with the distribution of fixed dunes (Lancaster 1981) indicate that it lay up to 1000 - 1200 km northeast of its present position when the northern dunes were formed. Formation of the southern group of dunes involved a 200 to 300 km northeastward shift of the 100 mm isohyet.

On the basis of the alignment patterns of dunes of different morphologies, Lancaster (1981) identified three patterns of palaeosandflows and winds, whilst Mallick et al. (1981) identified two. It appears that periods of aridity and dune formation were associated with, and probably caused by, a larger and more intense anticyclonic circulation and higher windspeeds (Lancaster 1981).

Assigning ages to the periods of aridity is difficult. In the north-western Kalahari Helgren and Brooks (1983) suggest that the large linear dunes were formed during the Early Pleistocene or even the Late Tertiary. Although it is difficult to credit the survival of recognizable dune forms from this length of time, these dunes are of some antiquity, as they are cut by one of the faults which forms the western boundary of the Okavango Delta (Mallick et al. 1981). The latest period of aridity recognized from the sedimentary and geomorphic record at Ci postdates a valley-wide lake in the Dobe valley and may span much of the Last Glacial Maximum period (Helgren and Brooks 1983). It may be tentatively correlated with the aeolian sand invasions of caves in

the nearby Kwihaba Hills, which occurred prior to a period of extensive sinter deposition 17 000 to 13 000 (Cooke 1975).

In the Makgadikgadi Depression, Cooke (1980) and Helgren (in press) suggest intervals of Lower to Mid-Pleistocene aridity, with deflation of pan and lacustrine deposits. A major arid phase, with extensive dune formation, took place in the later Upper Pleistocene, after the drying of the 920 m lake. This period is possibly equivalent to that which formed the Group 2 dunes of Lancaster (1981) and may tentatively be correlated with a period of aridity and dune formation recognized from the Makgadikgadi area for the period coeval with the Last Glacial Maximum by Heine (1978). Widespread dry climates in the Northern part of the Kalahari sands region are recognized at this time in southern Zaire. Blow outs and deflation hollows formed on the Kwango Plateau (De Ploey 1963), whilst there is a hiatus in the archaeological record for the period 25 000 - 15 000 BP (Cahen 1978).

In the southwestern Kalahari, organic soil horizons below the dunes have C14 dates of 28 000 + 4900 - 3200 BP (Heine 1982), implying stabilized dunes at this time. Heine (1982) puts forward a variety of stratigraphic and sedimentary evidence to indicate a period of dune formation and much increased wind speeds in this area during the Late Glacial. There is further evidence from this area for increased aridity and dune extension during the Holocene, some 4500 to 3500 BP (Heine 1982), as dune sands are interstratified with fluvial and colluvial deposits in the Auob river near Gochas.

DISCUSSIONS AND CONCLUSIONS

The Tertiary sedimentary record for the Namib and Kalahari strongly suggests that sedimentation in the region during this period has taken place mostly under conditions of arid to extreme arid and semi-arid climates. Dominant depositional environments have been sand seas and dune yields, with proximal and distal alluvial fan, ephemeral flood plain and pan or playa facies. Periods of geomorphic stability were characterized by extensive pedogenic calcrete formation. Such conditions appear to have prevailed probably for much of the last 20 m.y. and possibly for the last 50 to 80 m.y. This view follows Ward et al. (1983), but is contrary to that expressed by most previous workers in the region (Tankard and Rogers 1978; Seely 1978; Lancaster 1979a; Deacon 1980), but supports the tentative suggestions for an Oligocene age for aridity in southern Africa put forward by Van Zinderen Bakker (1975). Unlike the Tertiary sedimentary and geomorphic record for Australia (Bowler 1976; Kemp 1978), there is no published evidence for humid climates during the Cenozoic in the region of the modern Kalahari and Namib deserts. It appears that the antiquity of arid climates in southern Africa may parallel that from the Sahara, where Sarntheis (1978) suggests that intervals of aridity occurred 38 to 34, 23 to 20 and 13 to 12 m.y. BP.

Comparison of the Quaternary sedimentary and geomorphic record for the Namib and Kalahari suggests an essentially similar pattern, with climatic oscillations being superimposed on a mean of generally arid to hyperarid climates in the Namib, and semi-arid climates in the Kalahari. There is some evidence to suggest that aridity may have intensified in the Namib during the period in question. The amplitude and extent of the climatic oscillations varied between the Namib and Kalahari. In the Namib, they were of low magnitude and extent, whilst in

the Kalahari there is a much greater contrast between the massive expansions of aridity as evidenced by the distribution of fixed dunes and the widespread Late Glacial humid period in the southern Kalahari (Lancaster 1979b).

Whilst there is evidence for considerable expansions of the area of aridity at intervals, there is no reliable chronology of events, nor any agreement upon the nature of the changes in regional climatic patterns. For example, it is not known whether aridity and dune formation in the northern Kalahari resulted from a general expansion of the area of the arid zone as suggested by Lancaster (1981), or a latitudinal shift in the position of circulation patterns (Van Zinderen Bakker 1975; Tankard and Rogers 1978). A priority for future research in the palaeoclimatology of the arid zone in southern Africa should be to resolve these questions.

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