Z. Geomorph. N. F.	21	1	1–13	Berlin · Stuttgart	März 1977

Bornhardts of the Namib Desert

by

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with 1 figure and 4 photos

Zusammenfassung. Ein geomorphologisches Gesetz darf erst dann als gesichert betrachtet werden, wenn eine Hypothese sich wiederholt als nachprüfbar erwiesen hat. Eine solche Überprüfung erfordert eine umfassende Untersuchung vieler Beispiele. Im Falle der Theorien über die Bildung von Granitinselbergen haben zahlreiche Untersuchungen ergeben, daß die Freilegung des Gesteins durch Abtragen des Verwitterungsmaterials hervorgerufen wird. Diese Glockenberge verdanken ihre Form chemischer Verwitterung, und zwar in Zonen eng beieinanderliegender Klüfte in der Umgebung sowie geringerer Verwitterung in Zonen weitständigerer Klüftung innerhalb der Erhebung. Es sind schon so viele Beispiele für eine solche Entwicklung beschrieben worden, daß die Hypothese L. C. KINGS (1949, 1966) über die Bornhardt-Entwicklung durch Pediplanation und das Zurückweichen der Hänge über dem Anstehenden wohl eigentlich widerlegt worden ist. Es werden hier aber Beweise dafür angeführt, daß in der Namib-Wüste in Südwestafrika die Hypothese KINGS doch zutrifft, und daß nichts darauf hinweist, daß eine chemische Tiefenverwitterung je zur Bildung der Bornhardts beigetragen hat. Dieses Beispiel demonstriert die Bedeutung der Konvergenztheorie sowie auch die Gefahren, die dem Versuch anhaften, die kausalen geomorphologischen Prozesse aus der Untersuchung der Formen des Reliefs herzuleiten.

Summary. A geomorphological law can only be deemed to be established when an hypothesis is consistently found to be verified. Such verification requires extensive study of many examples. In the case of theories of the evolution of granitic bornhardts numerous studies have shown that the rock exposures result from the stripping of regolith and that these domes owe their form to chemical weathering in zones of closely spaced joints around the dome and shallower penetration of weathering in areas of massive jointing within the dome. So many examples of such development have been described that L. C. KING's (1949, 1966) hypothesis of bornhardt development by pediplanation and scarp retreat across bedrock has been virtually rejected. Evidence is offered, however, that in the Namib Desert of South West Africa KING's hypothesis does apply, and that deep chemical weathering has never contributed to the evolution of the bornhardts. This example demonstrates the importance of the concept of convergence, and the dangers inherent in attempts to deduce the causative geomorphic processes from a study of the morphology of landforms.

Résumé. Une loi géomorphologique peut seulement être considérée comme établie quand elle est vérifiée très fréquemment. Une telle vérification demande l'étude extensive d'un très grand nombre d'exemples. Dans le cas de théories sur l'évolution des bornhardts granitiques, de nombreux travaux ont montré que la mise à nu de la roche résultait de l'enlèvement de produits d'altération et que c'était le développement différentiel de l'altération chimique qui était responsable de la forme des dômes. Entre les dômes, l'altération chimique est profonde et intense parce que la roche est découpée par des joints très proches les uns des autres; l'altération est beaucoup moins développée dans les dômes car la roche y est beaucoup plus massive. Les exemples où cette règle peut être appliquée, sont si nombreux que l'hypothèse de L. C. King expliquant le développement des bornhardts par la pédiplanation et le retrait de l'abrupt sur la roche en place peut être virtuellement rejetée. Il est cependant évident que l'hypothèse de King est applicable dans le désert du Namib au sud-ouest de l'Afrique car l'altération chimique profonde n'a jamais contribué en cet endroit à l'évolution des bornhardts. Cet exemple démontre l'importance du concept de convergence et combien il est dangereux de déduire les processus géomorphologiques de la seule étude de la morphologie.

Introduction

In geomorphological studies it is seldom possible to define a "geomorphological law". Exceptions to this statement are provided by obvious situations such as "water flows downhill". Laws can seldom be established from study of a particular case and are most likely to be deduced from general studies and from sufficiently detailed observations of individual features. Once an hypothesis is consistently found to be verified it will ultimately become regarded as a law. A danger for the geomorphologist seeking laws is that he is often not in a position to travel sufficiently widely to observe a great variety of examples and so will reach a general conclusion — establish a law — before it is justifiable to do so. A number of writers have warned against the procedure of seeking a single explanation of similar forms which may have converged towards an equilibrium shape from separate origins through the operation of different processes. This principle of "equifinality" (von Bertalanffy, 1950) or convergence has been emphasized by White (1945), Wilhelmy (1958), Cunningham (1969) and Thomas (1974) amongst others.

In his list of generally accepted premises of the nature and origin of granitic landforms Thomas (1974) includes the following.

> "The establishment of rock exposures in the form of tors and domes (bornhardts) results from the stripping of regolith from areas of shallower weathering." (i. e. shallower than neighbouring basins of deep weathering).
>
> "In the development of tors and perhaps domes long periods of weathering penetration have to be followed by relatively short phases of rapid surface erosion or stripping. This two stage hypothesis of tor development advocated by Linton (1955) is generally considered to result from climatic changes".
>
> "Variations in the frequency of joints are, together with the effects of composition and texture, largely responsible for positive and negative elements in the relief and for the appearance of distinctive rock landforms which represent the less jointed rock masses".

> "Although linear erosion may be guided directly by major fractures, the susceptibility of granite to chemical alteration provides the main key to the understanding of granite landforms except perhaps under conditions of extreme cold or aridity".

Thomas thus clearly recognises the possible exceptions to general premises which may be found in conditions of extreme aridity, but an example of these from the Namib Desert will now be described so that the exceptions may not be overlooked and a general law come to be regarded as confirmed.

That such a general law could be regarded as virtually established may be seen from the words of Cotton (1962, p. 270):

> "Mounts that stand out from wash plains are inselbergs in the strictest sense (Bornhardt 1900). The origin of such inselbergs is still a subject for discussion, but the opinion is gaining ground that they are residuals of rocks that are resistant to high temperature chemical weathering and that they emerge, notably in a tropical humid-savanna or monsoon climate, when the regolith over other rocks that are most susceptible to such weathering — and may in some cases have been weathered a very long time ago (Ollier 1960, p. 47) — is eroded away in a new cycle . . . or is at any rate worn (strictly washed) down to form the wash plains that surround the inselbergs".

In contrast to this view is that of King (1966, p. 98) who considered that such an hypothesis

> . . . "fails utterly to account for the great bornhardt fields of Africa and South America with their many hundreds of feet of relief".

King argued for bornhardt formation as a result of pediplanation and scarp retreat and has held to this view (1957, 1966, 1975). According to his hypothesis domes develop when

> . . . "after the incision of retreating streams, the lateral scarps or valley walls standing steeply in the hard homogeneous rocks, retreat parallel to themselves, maintaining that steepness of flank for which bornhardts are notorious. The retreat is sometimes by spalling, when the base of the bornhardt is littered with debris, and sometimes by chemical weathering" (1949, p. 85).

King (1949, 1966) thus supports an hypothesis for bornhardt origin of pediplanation and scarp retreat across bedrock. Most other writers support concepts either of pediplanation and scarp retreat across deeply weathered rocks (Ollier 1960; Mabbutt 1961; Twidale 1964; Ojany 1969) or of differential weathering and multicyclic downwearing (Büdel 1957; Thomas 1965). The work of Boyé & Fritsch (1973) and Boyé & Seurin (1973) describing the removal of deeply weathered regolith from around a buried dome appears to establish beyond doubt that some bornhardts do originate as resistant masses within a deep weathering profile. It will be contended below that bornhardts of the central Namib Desert, South West Africa (Namibia), have developed according to King's hypothesis and thus that bornhardts may be produced by at least two distinctive sets of processes.

The Namib Desert

The Namib Desert extends from Mossamedes (15° S) in Angola southwards for nearly 2000 kilometres to the mouth of the Olifants River (32° S) in Cape Province, South Africa. The central Namib north of the Kuiseb River (fig. 1) is a virtually bare rock platform rising from the Atlantic coast, where its altitude is within a few metres of sea level, inland to an extensive escarpment whose foot is about 1000 metres altitude. The escarpment may be abrupt, but is more commonly a zone of dissection some 30 km wide forming the western edge of the Khomas

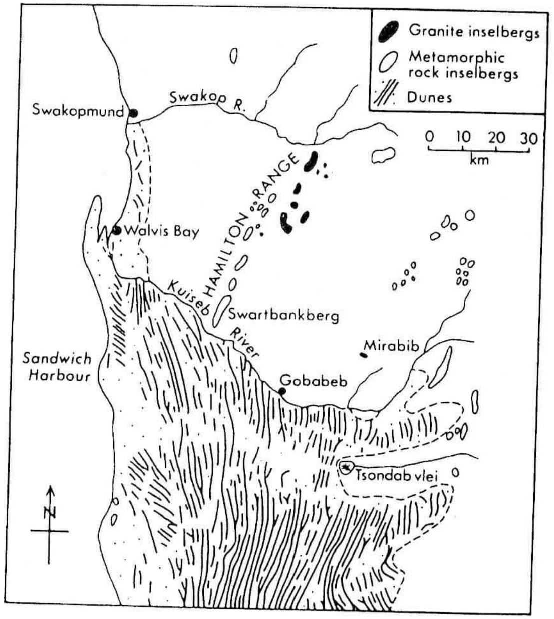

Fig. 1
The Central Namib Desert.

Highlands which vary in altitude from 1200 to 1800 m above sea level. The desert platform is about 130 km wide and is cut across late Precambrian rocks of the Damara system. These rocks are very varied metamorphics which include mica schists, marble, granitic gneiss and quartzite; into them are intruded Salem Granites (Smith 1962; Martin 1965 a, b; Clifford 1967). The granites are generally pale pink to grey porphyritic biotite granites which contain large phenocrysts of orthoclase and microcline feldspar.

In his study of African erosion surfaces L. C. King (1967, ch. 9) has postulated that the main Namib platform was cut by pediplanation processes in the late Cenozoic (Miocene and Pliocene) post-African cycle of erosion, and that the Kuiseb canyon was cut below this surface by Quaternary incision. The coastal

zone of the desert platform, however, must have originated earlier than the Miocene as in the southern Namib the Pomona quartzite of pre-middle-Eocene age, as shown by overlying fossil-bearing beds, appears to represent the intensely silicified surface, formed in an arid climate, of a terrestrial erosion surface (Gevers 1936). Kaiser (1926) has expressed the view that the coastal plain of the Namib was formed in late Cretaceous times. It would thus represent the coastal downwarped part of the surface now bevelling the Khomas Highlands.

The Kuiseb River, like all of the other major rivers of the Namib, rises in the interior highlands and its channel only carries water as far as the coast after unusually wet seasons in the highlands. Between 1837 and 1963 the Kuiseb reached the Atlantic fifteen times (Stengel 1964). The tributaries of the river which rise in the desert carry water even more infrequently and only after rare convectional storms. The extreme aridity of the desert is evident from the fact that less than 10 mm of rain is received in 50 percent of the years for which records are available (Schulze 1972).

Granite inselbergs of the central Namib

Granites outcrop in a number of places in the central Namib and are particularly prominent as inselbergs of various forms (photos 1, 2). In the escarpment zone they can be seen protruding from long spurs which are predominantly of schist. The lower flanks of these protrusions are of metamorphic rocks; the granite inselbergs rising above the metamorphics have the morphologies so frequently ascribed to bornhardts and which fit the original definition by Willis (1936, p. 117). They have bare surfaces, dome-like summits, precipitous sides becoming steeper towards the base, and an absence of talus or soil cover. It is apparent from aerial reconnaissance that the larger domes are delineated by major joints (photo 3) and hence that the dominant control on their form is structural. In general the height of the bornhardts declines with distance from the escarpment – suggesting that the Namib platform is being widened by scarp retreat and that the oldest, and most reduced, bornhardts are to be found at the greatest distance from the foot of the escarpment.

Of primary importance to the present argument is the complete absence of a chemically weathered regolith and the ubiquitous presence of schist bedrock forming the lower slopes between the flanks of the bornhardts and the surrounding pediments. The bornhardts are clearly inselbergs of position, or will become so when more of the schist is removed by erosion.

On the surface of the central Namib platform granite outcrops in a number of places. Around Gobabeb (fig. 1), for example, the granite has been planated and it forms prominent features only where tributaries of the Kuiseb River have cut into the platform and exposed bedrock to subaerial processes. Here small knobs and low cliffs have been etched by weathering processes.

Of greater prominence are the inselbergs, of which those around Mirabib are good examples (photo 4). These outcrops are varied in their morphology. They range from broad gently sloping domes with abundant large rounded slab-like boulders on their crests, to very steep sided bare monolithic domes rising over 40 m above the surrounding pediment.

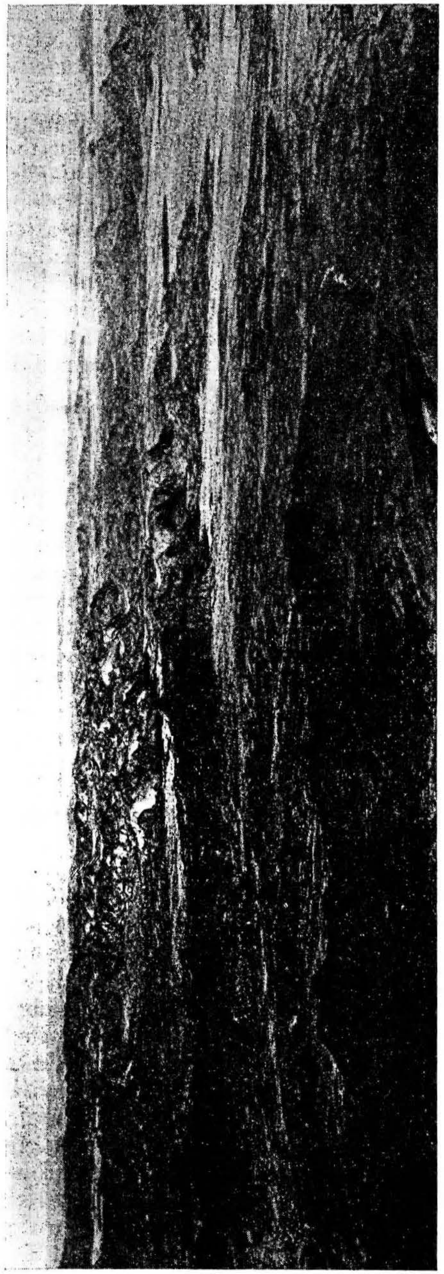

Photo 1. Spurs of the Namib escarpment extending into the desert. The rounded granite domes can be seen protruding from the surrounding schists.

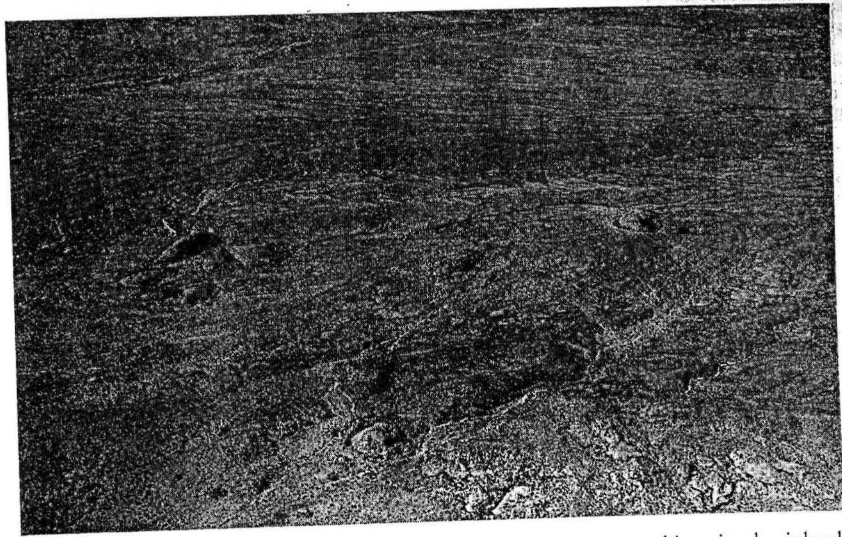

Photo 2. Granite inselbergs surrounded by pediments cut across schists, in the inland central Namib.

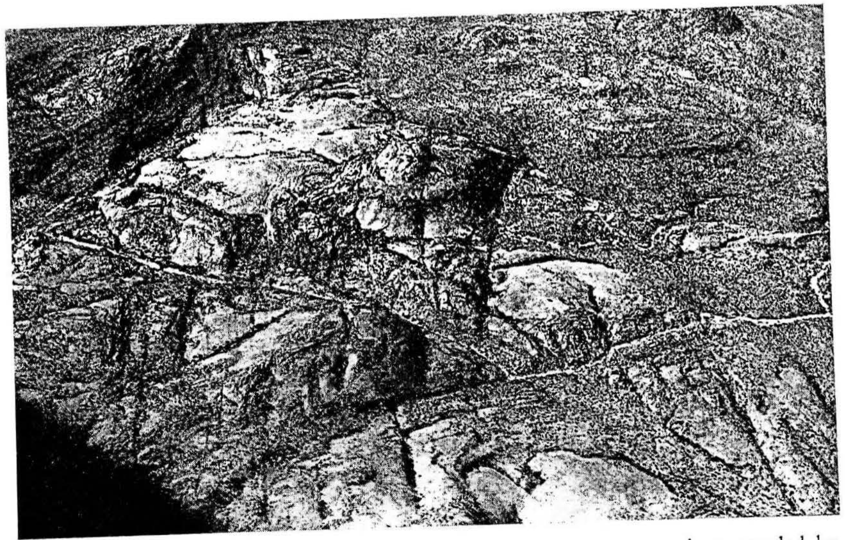

Photo 3. Rounded granite domes outlined by major joint systems and surrounded by schists; inland central Namib.

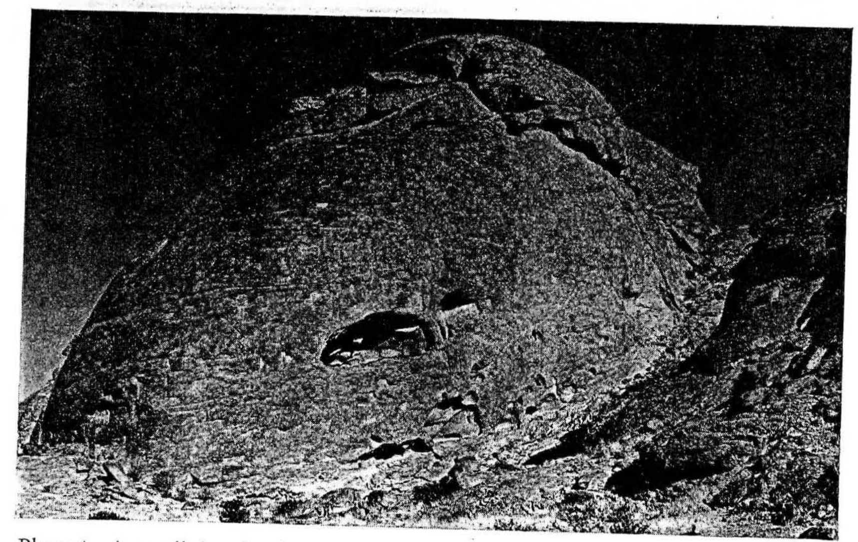

Photo 4. A small bornhardt near Mirabib. The surrounding pediment is cut across schists.

Pediments

The pediment around the inselbergs has a stony surface formed largely of quartz pebbles. Beneath the surface there is a layer of sandy gravel with small quantities of silts (< 1–5 % by weight) of variable thickness but nearly everywhere less than one metre. This may lie upon slightly altered schist which shows some evidence of hydration of the biotite, but more commonly the gravel lies upon a strongly indurated calcrete which consists mainly of fresh quartz gravel cemented by calcium carbonate. The calcrete becomes increasingly massive with depth and is of variable thickness. Coring during mining exploration has shown that the calcrete may be over 30 m thick but more commonly is 2 to 4 m thick. It reaches its greatest thickness where it occupies old stream channels which are cut into the schist bedrock. Nowhere in the drilling programme, nor in field excavations, has a zone of deep chemical weathering been found beneath the calcrete. In traverses carried out along the flanks of the Kuiseb canyon similar exposures of gravel or calcrete upon bedrock have been found, and again there are no indications of deep weathering. The only report of a strongly weathered profile is that of Scholz (1968) who at one locality near Gobabeb found, at a depth of 40 cm below the calcrete crust, an horizon of reddish-brown clay partly consolidated by gypsum and 40 cm thick; this horizon overlies a reddish-brown clay-gypsum crust on bedrock at a depth of 1 m below the surface.

The complete absence of deep chemical weathering cannot be confirmed without very extensive drilling and field exploration but the work already

carried out by mining exploration companies and a number of field scientists indicates that its presence is improbable. Furthermore the lack of field evidence for humid climates in late Cenozoic time, and the arguments in favour of long-term aridity in the Namib (see below) would seem to make it unlikely that a suitable environment for chemical weathering has existed during that time.

Causes of aridity in the Namib

The Namib is a desert area because of three interacting factors (Gevers 1936). (1) The persistence of a strong and stable anticyclone over the southern Atlantic causes persistent subsiding, diverging, and hence dry air to move as winds from the south and south-southwest for most of the year. The centre of this anticyclone moves seasonally over a latitudinal range of about 4 degrees, its southern position being at about 30° in summer (Schulze 1972). (2) The aridifying effect is intensified during most of the year by anticyclonic conditions over the southern continent. Only when this pressure system weakens can humid air of tropical or maritime origin penetrate into the interior of southern Africa, and even when it does the moisture carried by air from the Indian Ocean is lost in its passage over the interior plateaux, and on reaching the Namib katabatic airflow down the escarpment further reduces the possibility of precipitation. (3) The offshore Benguela Current is relatively cold (10–14 °C) and the rare, but chilled, onshore winds are warmed over the Namib and lose their capacity to release precipitation. The history of the Namib Desert is thus closely tied to that of the Benguela Current.

The Benguela current originates in the sub-Antarctic zone of the Atlantic where cold water sinks and moves northwards as Antarctic Intermediate Water (Moroshkin et al. 1970). It seems probable therefore that the Namib could not have become totally arid until the South Atlantic had become wide enough for the present ocean current system to be established, nor before Antarctica had developed a full ice sheet and thus become the cause of major cooling of the southern oceans. According to current seafloor spreading concepts the separation of South America and southern Africa was not completed until the Cretaceous and the ocean current system might not have become fully established until mid-Tertiary times (Deep sea drilling project, 1973). It now seems clearly established that East Antarctica had an ice sheet by early Miocene times and that a full Antarctic ice sheet had formed by mid-Miocene times (see Denton et al. 1971 and Selby 1973 for reviews of the evidence). The persistence of an Antarctic ice sheet since the mid-Miocene suggests that there is an a priori case for believing that the Benguela Current has existed since that time. The study by Kennett (1973) has shown that by the early Miocene a modern planktonic foraminiferal fauna had developed in the southern oceans with strong contrasts between polar and tropical faunas. King's (1967) belief that the Namib platform has been produced by scarp retreat in Miocene and Pliocene times thus coincides with the period in which there are reasonable grounds for believing that the Benguela current has existed, and that the Namib inselbergs have thus evolved under the same basic controls as exist at the present time.

A great age for aridity in the Namib was postulated by Koch (1960 a, b) to account for the remarkable endemism of the Namib flora and fauna. Koch particularly cited the beetle family of the Tenebrionidae with 30 endemic genera and 200 endemic species.

Clear evidence for climatic fluctuations in other parts of the world during Quaternary times raises the question of what happened in the Namib during such fluctuations elsewhere. Zinderen Bakker (1967, 1975) has suggested that during Quaternary glacial periods the southerly offshore winds extended further north and drove the Benguela Current with them. This extended the Namib Desert into Angola and Zaire. Aridification of the area around Kinshasa and the mouth of the Zaire River in glacial times seems to be substantiated on the stratigraphic evidence reported by Mortelmans & Monteyne (1962) and de Ploey (1965, 1969), and by the general movement northwards of the Kalahari sands. There is however little evidence of what happened in the southern Namib.

Within what is now the central Namib some evidence can be interpreted as suggesting a limited increase in precipitation during parts of the Quaternary. Marked fluctuations of climate in the Kalahari have been demonstrated by Grove (1969), but it does not follow therefore that the Namib has undergone similar and simultaneous climatic changes. The major rivers of the Namib rise on the interior plateaux and have spread extensive gravels into the southern Namib – especially around and seawards of Tsondab Vlei (fig. 1), and the Kuiseb River is deeply incised in a canyon in its middle reaches; but such evidence of fluvial activity may only be evidence for greater precipitation on the inland plateaux. The gravel sheets of the Tsondab are now crossed by linear dunes which extend northwards from the Orange River. The consistent alignment of the dunes and yardangs of the southern Namib suggests that present wind directions have persisted through much of Pleistocene time. The large dunes are at present advancing northwards at rates of about 1 m per year. As many of the dunes are 40 to 60 km long such a rate of advance implies that the dunes have taken at least the whole of the last glacial and Holocene times to cross the gravel flats of the Tsondab. It is difficult, therefore, to believe that during the last glacial, at least, that the central Namib was notably more humid than it is now.

From the Erongo Mountains Martin & Mason (1954) have described tufaceous cave deposits and Korn & Martin (1955) have suggested that there was a widespread Middle Stone Age pluvial in the Naukluft – both mountains are close to the escarpment of the central Namib. The ages of the tufa and the Middle Stone Age culture are unknown, and the precipitation that would be required to support them is also unknown. On the limited evidence available either could have occurred at any time in the last million years.

The widespread presence of calcrete implies that a semiarid climate has persisted for a considerable length of time in the central Namib. Goudie (1973) has suggested that at the present time calcrete is mainly forming in semiarid areas where rainfall is around 400 mm per year. In southern Africa fresh calcretes around the wetter margins of the Kalahari exist in areas with a rainfall of 250–300 mm per year (Goudie 1972). In the central Namib at present calcrete is being altered to gypsum (Martin 1963) under a rainfall of about 10 mm per year, and the calcrete is thus regarded as being relict from a more humid climate.

Conclusions

With the exception of one very localised buried soil horizon 40 cm thick within a total regolith profile of only 1 m thickness, no strongly chemically weathered regolith materials have been found in the central Namib Desert. A variety of studies, including those of the age of the ocean basins and the age and origin of the Benguela Current, suggest that the Namib Desert has been in existence since early Miocene times. The widespread calcrete deposits indicate that semiarid conditions have occured for long periods during Quaternary times, and the existence of river gravels and incised dry stream channels in the desert indicate that on the interior plateaux, and probably in the escarpment region, that rainfall has been higher than at present during periods of the late Cenozoic. There are, however, no indications of climates more humid than semiarid and even these are not favourable to deep chemical weathering.

The extent of the southern dune fields, and the great size and length of the linear dunes indicates clearly that truly arid conditions have existed for much of late Cenozoic time, as does remarkable endemism of the flora and fauna. The lack of field evidence for chemical weathering and the clear evidence for physical weathering and erosion around emerging bornhardts, and their isolation on erosion surfaces cut across unweathered bedrock renders inapplicable an origin for the bornhardts through stripping of a chemically weathered regolith. The contention of Jessen (1936) and of King (1949) that bornhardts are produced during scarp retreat is supported by their emergence from surrounding schists forming long spurs of the main escarpment zone. Bornhardts can thus be formed under arid or semiarid conditions through physical processes. The hypothesis which proposes that bornhardts are exposed as a result of the stripping of surrounding or overlying chemically weathered regolith can thus not be regarded as a universal law. It is essential, then, that geomorphologists recognise the possibility of convergence of forms, and that they avoid the argument that a particular landform can result only from a single suite of processes.

Acknowledgements

I am indebted to the University of Waikato for study leave, and to Dr Mary Seely, Director of the Namib Desert Research Station for her help and guidance and to Dr Beatrice Sandelowsky-Pendleton for discussion in the field.

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