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Inselbergs of the Namib Desert
Processes and history

by

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with 3 figures and 2 photos

Zusammenfassung. In der zentralen Namib ist die Verwitterung charakterisiert durch Schalenablösung, Abschuppungen, Felsblasen, Abgrusung, Trockenrisse, Tafoni, Höhlen, Verebnungen im Flächenniveau und andere untergeordnete Prozesse. Das Fehlen von Anzeichen einer subterranen Verwitterung und anderer Indizien der Tiefenverwitterung läßt auf eine lange Dauer des Wüstenklimas mit fehlendem Grundwasser schließen, das schon im Mesozoikum eingesetzt haben kann. Eine vom Verwitterungsmantel bestimmte Einebnung ist heute aktiv, wobei wahrscheinlich die Inselberge durch selektive Verwitterung entstanden sind, da sie mit dem Ausbiß widerständiger Gesteine übereinstimmen. Dieser Prozeß wird „selective mantle controlled planation" genannt. Im südlichen Dünengebiet stehen einige Inselberge auf der Namib-Diskordanzfläche (? prä-Oberkreide) und ragen durch den Tsondab-Sandstein (? Kreide). In der Steinwüste könnten Kalkkrusten äquivalent zu dem Basiskonglomerat der Namib-Diskordanz sein oder aber zu dem zementierten Schutt auf der Tsondab-Verebnung (? Mittleres Obertertiär). In jedem Fall haben die Namib-Inselberge ein hohes Alter und sind Teil eines exhumierten Reliefs. Eine haltbare geomorphologische Deutung muß die geomorphologische Geschichte ebenso einbeziehen wie die aktuellen Prozesse.

Summary. In the Central Namib Desert unloading slabs, flaking, rock blisters, granular disintegration, dirt cracking, tafoni, caves, ground level platforms and other minor processes characterise the weathering assemblage. The absence of subsoil weathering features and other evidence of deep weathering suggests a great longevity for the desert climate with lack of groundwater, which may go back to the Mesozoic. Mantle controlled planation is in operation now and selective mantle controlled planation is the process likely to have given rise to the inselbergs which coincide with resistant rock outcrops. In the southern dune area, some inselbergs project from the Namib Unconformity Surface (? pre-Upper Cretaceous) through the Tsondab Sandstone (? Cretaceous). In the stony desert, calcretes on the plains may be equivalent to the Basal Conglomerate of the Namib Unconformity or to cemented gravels on the Tsondab Planation Surface (? mid-late Tertiary). In either case the Namib inselbergs are of great age and are part of an exhumed topography. Sound geomorphic interpretations require the study of geomorphic history as well as of modern processes.

Résumé. Dans le désert central de Namibie, des dalles dues à la décharge et à l'exfoliation, « rock blisters », des débris provenant de la désintégration granulaire, «dirt cracking », des tafonis, des grottes, et d'autres faits mineurs caractérisent l'altération. L'absence de traces d'altération souterraine et autres évidences d'altération profonde suggèrent que le climat désertique persiste depuis très longtemps, climat sous lequel n'existe pas d'eau souterraine. Ces conditions d'aridité pourraient bien remonter au Mésozoique. Les processus de « selective mantle controlled planation » sont actifs de nos jours et sont sans doute responsables des inselbergs qui coïncident avec les affleurements de roches résistantes. Dans la partie sud de la région dunaire, quelques inselbergs se dégagent de la surface de discordance de Namibie (antérieure au Crétacé supérieur?) à travers le grès Tsondab (Crétacé?). Dans le désert caillouteux, des croûtes calcaires apparues dans les plaines peuvent correspondre au conglomérat basal de la discordance namibienne ou des graviers cimentés sur la surface d'aplanissement Tsondab (Tertiaire moyen ou supérieur?). Dans l'un ou l'autre cas, les inselbergs namibiens sont anciens et constituent une part de la topographie exhumée. Des interprétations géomorphologiques valables ne peuvent être avancées qu'après l'étude de l'évolution morphologique antérieure ausi bien que celle des processus actuels.

One of the greatest landscape contrasts on earth is in the Central Namib Desert where the Kuiseb River gorge, incised into bedrock, separates the stony desert with inselbergs to the north from the mainly sandy desert to the south. This diversity is clearly visible from space and provided one of the classical space photographs. The area is illustrated in fig. 1.

The contrasting sandy and stony deserts offer scope for separate studies of geomorphic processes and history, but clearly the history of either cannot be considered in isolation – despite different processes and landforms at present the histories of the two areas must be related, and further historical clues come from the Kuiseb Valley itself.

This desert area is not only full of intrinsic interest, but it provides illustrations of several points of principle. SELBY (1977) used the inselbergs of the stony desert to illustrate the concept of convergence, whereby the same ultimate landform (inselbergs) may be created by different processes (stripping of deep regolith; scarp retreat across bedrock). In this paper I shall describe weathering processes on the stony desert, outline the geomorphic history of the region using evidence largely drawn from the sandy desert, and illustrate a further point of principle.

Weathering in the stony desert

A number of common weathering processes are found on the plains and inselbergs of the stony desert, and a few common ones are conspicuous by their absence. It is the total assemblage of weathering features rather than any individual mechanism that makes this desert distinctive.

Unloading. Unloading produces thick slabs, parallel to the sides of inselbergs, which later break down into boulders. Slabs resulting from this process are commonly over a metre thick and could not have resulted from any minor weathering process. Unloading is evident at Mirabib where one unloaded slab is

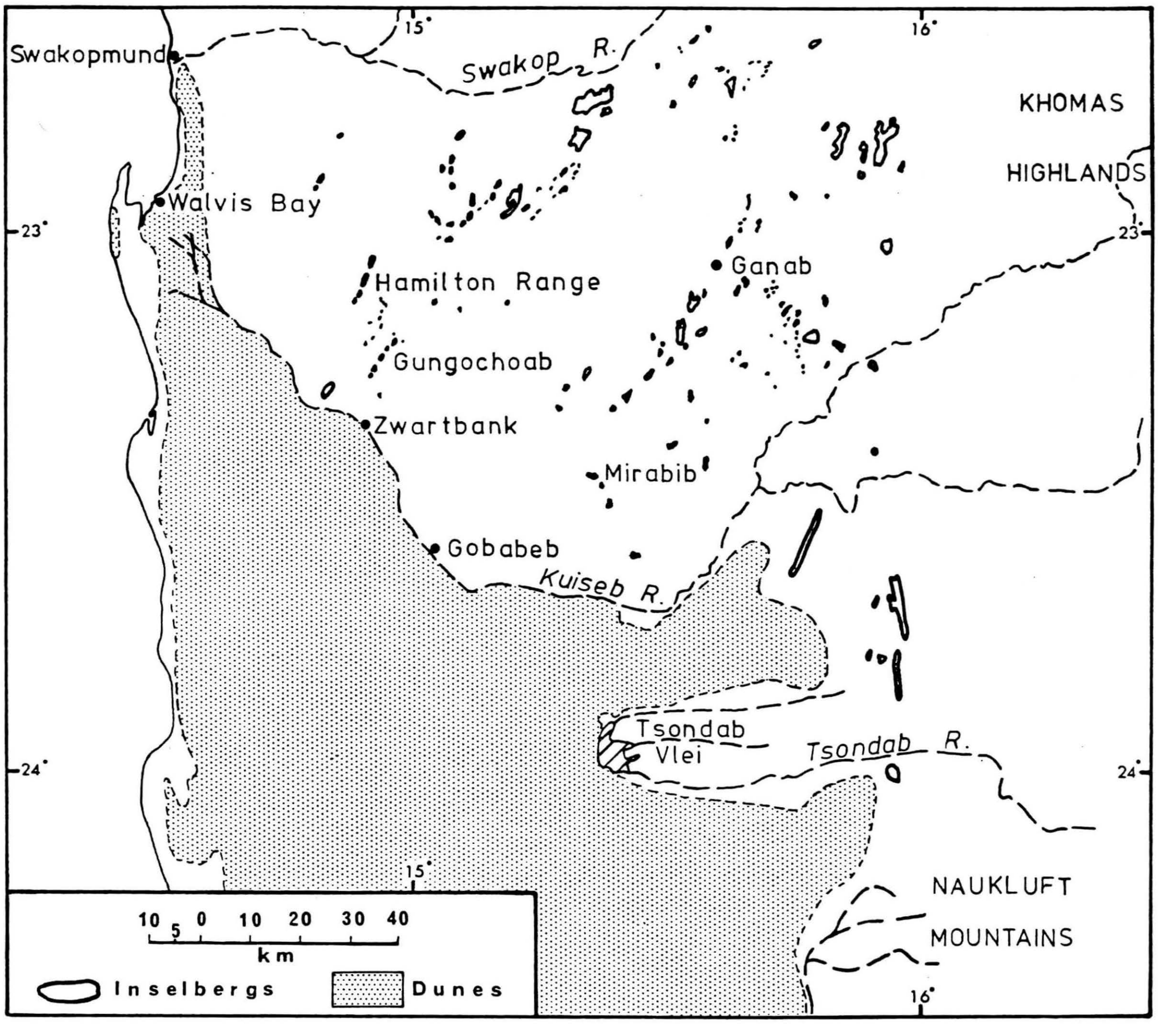

Fig. 1. Map of the Central Namib Desert.

present on the north side of the inselberg, and the base of an earlier, outer slab remains as a penitent rock (fig. 2 a). Structural directions in the granitic gneiss at Mirabib are not parallel to the curved unloading cracks. In other places, such as Gungochoab, unloading slabs may be present on the gneiss but it is difficult to distinguish possible unloading cracks from cracks parallel to rock structure.

Flaking. Flaking is a term for those weathering processes that produce thin sheets of rock on the surface of solid rock. These round off boulders, as corners and edges are particularly prone to weathering. Flaking was observed to affect gneiss, schist, granite, sandstone and marble. Most isolated boulders appear to be coated by a number of somewhat detached flakes, and have a litter of old flakes around the base.

Flaking on concave surfaces tends to eat into a rock and produce hollows or caves lined with flakes. The hollows often grow upwards as well as inwards

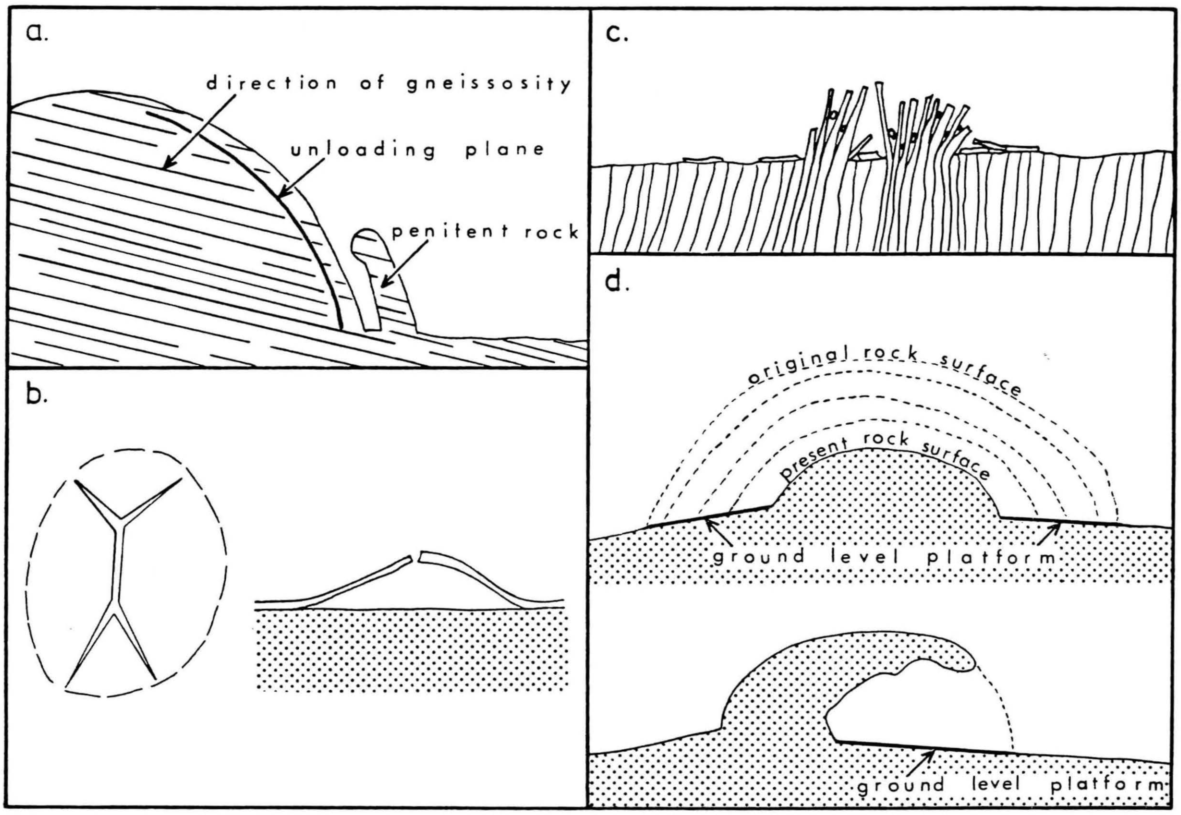

Fig. 2. a: Unloading at Mirabib. – b: Rock blister about 1 metre across shown in plan (left) and section (right). – c: Dirt cracking on steeply dipping schist. – d: Formation of ground level platforms by reduction of a boulder to general ground level.

but they never grow down below general ground level. Hollows growing from opposite sides of a boulder can make a hole through it.

A special kind of flaking feature is here called a rock blister. An elliptical flake of rock, usually one or two centimetres thick, blisters away from the rock mass, cracking in the process (fig. 2 b). The ultimate cause of blistering may vary (as with flaking generally) but undoubtedly expansion of the flakes causes it to heave away from the bedrock. The uplifted flakes of a blister eventually fall away, leaving an elliptical blister scar on the rock surface. What appears to be a larger scale version of the same phenomenon has been called A-tent weathering (JENNINGS & TWIDALE 1971).

In the Central Namib Desert spheroidal weathering is important because of its absence. True spheroidal weathering takes place in all directions around a corestone, and differs from flaking in that, while flaking produces flakes only on exposed surfaces, spheroidal weathering produces flakes on the underside of a corestone in the subsoil as well (OLLIER 1976). Spheroidal weathering is a good sign of deep weathering, which probably requires more abundant water than has been present in the Central Namib area for a long time. With few trivial exceptions only surface flaking occurs in the Central Namib, and spheroidal weathering is absent.

Granular disintegration. Granular disintegration is important on coarse grained rocks, especially granite and granite gneiss which break down into small fragments roughly equivalent to the original mineral grains in the rock. Like flaking, granular disintegration can lead to the formation of several landforms, but it produces a rough surface and a debris of granular material rather than flakes

Dirt cracking. Dirt cracking (OLLIER 1958) is a kind of insolation weathering that occurs when small fragments of sand, rock or any "dirt" fall into initial cracks in a rock. Temperature changes cause the fragments to expand on heating, wedging the host crack wider. When the fragment cools it can fall deeper into the crack, so the next time it expands it widens the crack further, enabling more dirt to fall in the crack, and so on. In the Central Namib this process is particularly effective on the steeply dipping gneiss and schist, where the abundant cracks facilitate rock breakdown (fig. 2 c). The process only works on projecting rock – it is ineffective once the general ground level is reached. Very good examples can be found between Gobabeb and Zwartbank.

Minor processes. A few small solution grooves are present on the marble at Zwartbank and in the Hamilton Ranges, though wind erosion grooves tend to mask the solution effect. Solution could easily result from the small amount of rain and dew of the present climatic regime. I have seen no definite examples of salt weathering, though salt crystallisation probably enhances granular disintegration. No unequivocal examples of insolation weathering (other than dirt cracking) have been found.

Tafoni and caves. Tafoni, small hollows created by either granular disintegration or flaking, are common on both inselbergs and on boulders on the plains. They range in size from tiny holes a few centimetres in diameter to large caves several metres deep and high. In the Central Namib hollows seem to grow equally well on the shady side or the sunny side of rocks. Some boulders have been case-hardened before tafoni formation. Whether produced by flaking or granular disintegration the hollows never grow down below the general ground level on the plain, though on inselbergs some weathering pits are found. Sometimes cave formation by weathering reaches a stage where the mass of the overhanging roof exceeds the mechanical strength of the rock. The roof then collapses and usually shatters into angular blocks, a good example being at Ganab.

Ground level platforms. Flaking and granular disintegration are processes that are only effective above ground level. As weathering by these processes reduces the size of a boulder a new platform is created at ground level, and the ground level platform grows at the expense of the boulder until the latter is entirely consumed (fig. 2 d).

Significance of weathering features of the Central Namib Stony Desert. In many parts of the world weathering reaches depths of hundreds or even thousands of metres (for examples see OLLIER 1969), and such deep weathering requires the presence of a body of groundwater. Many deserts have remnants of deeply weathered rock suggesting former wetter periods when such a body of groundwater caused subsurface weathering. A very significant feature of the Namib Desert is the absence of deep saprolite, spheroidal weathering, or any other features of sub-surface weathering (cf. SELBY 1977). The total absence of such evidence in the Namib leads me to think that the area has had an arid climate for a prolonged part of its history since the first planation evident in the landscape.

In the Central Namib most of the weathering processes described are only effective on any bit of rock that sticks up above the general ground surface. Such projections tend to be levelled off, and a plane surface littered with debris is produced. This process of landscape levelling by weathering and debris accumulation is similar to what MABBUTT (1966) called mantle planation. It seems that weathering virtually stops in the Namib stony desert when a metre or so of weathered rock mantles the plain, and there is no deep chemical weathering. The plains are thus virtually cut across fresh rock, as described by SELBY (1977).

Remaining ridges, both large and small, are being reduced by weathering to the level of the surrounding plain. Strike ridges and cuestas are found on more resistant rocks such as the marble of the Hamilton Range and the quartzite of Gungochoab. Inselbergs, rising very abruptly from the surrounding plain, are restricted to resistant rock with low fissility and develop best where the topographic boundary coincides with a sharp geological boundary, as around a granite intrusion.

Weathering and the formation of inselbergs. How do these observations on active weathering processes affect ideas on inselberg formation?

Firstly I must agree with SELBY (1977) that stripping of regolith to leave residual inselbergs appears to be out of the question in this area.

But scarp retreat does not appear probable either, for with scarp retreat the slopes of the inselbergs should have retreated back from geological contacts, yet the distribution of inselbergs, ridges and hills corresponds closely to geological outcrops. Elsewhere in the world there are places where parallel retreat of slopes can be demonstrated, and the sharp junction between pediment and steep slope is demonstrably not at a geological contact but is within homogeneous unjointed rock. This is not the case in the Namib, and although unloading and other processes are now reducing the inselbergs, they do not appear to have originated them.

From the observations recorded here it would seem more likely that successive bevellings by mantle controlled planation would reduce the level of the plain, and the more durable rocks, especially those with little fissility, might be lowered less and in the course of time be left as high standing residuals rising above the plains, their borders corresponding with geological boundaries.

If this were so there would be a third mechanism of inselberg formation, selective mantle planation, to add to the two discussed by SELBY and the concept of convergent landforms becomes even more important.

However, before accepting this third mechanism of inselberg formation, we must consider the history of the inselbergs so far as it can be deciphered, since it is possible that present day processes did not prevail in the past.

Geological and geomorphic history of the Central Namib Desert

The stony desert and inselberg area north of the Kuiseb River provides very little information for a geomorphic history, but important data come from the Kuiseb Valley and the sandy desert to the South. The area is not well known, but the following account is based on observations by MARKER (1977), OLLIER (1977) and SELBY (1976). The geological features are shown on fig. 3.

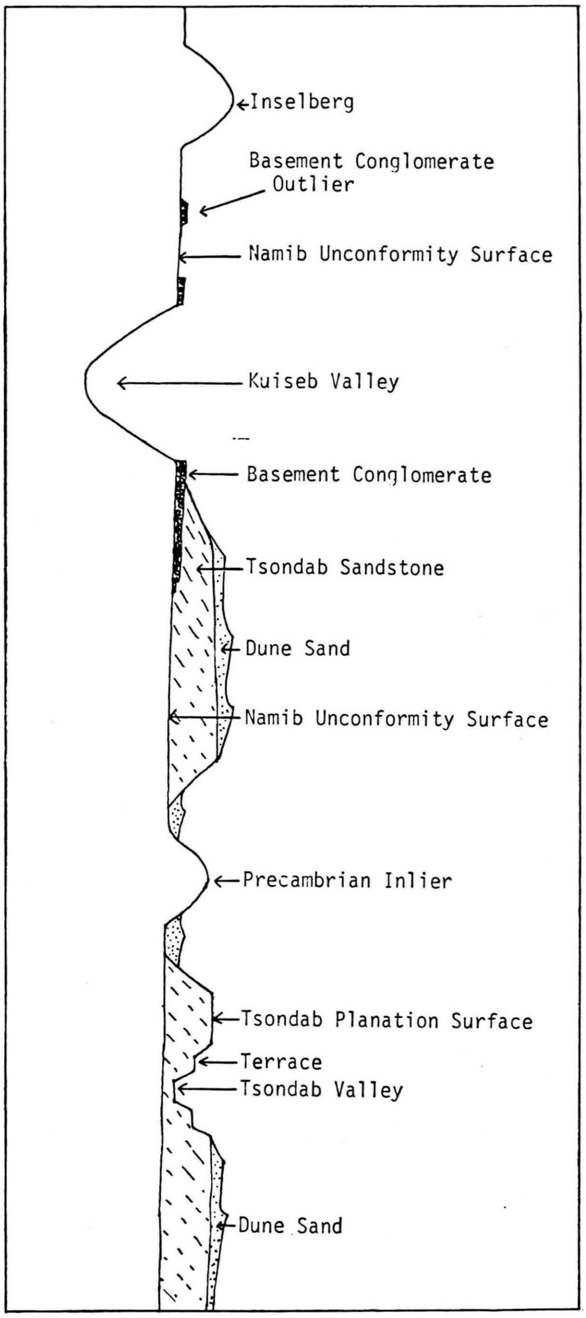

Fig. 3. Diagrammatic cross section of the Central Namib Desert showing the units that must be incorporated in a geomorphic history.

1. *Precambrian.* Shales, sandstones and limestones were metamorphosed to schists, gneisses, quartzites and marbles. These were injected by veins of quartz, aplite and pegmatite, sills of dolerite (Zwartbank) and in places converted to, or intruded by granite.

2. *Namib Unconformity Surface.* Long continued erosion across the Precambrian rocks formed a plain – the Namib Unconformity Surface – which is a fundamental datum in the area, separating the metamorphic bedrock from all younger deposits. Although generally flat, the surface has some irregularities which rise as hills, strike-ridges or inselbergs.

3. *Basal Conglomerate.* Overlying the Namib Unconformity Surface on the south side of the Kuiseb Canyon is a carbonate-cemented Basal Conglomerate. In some places the included fragments are very angular and clearly of very local derivation: in others it is a true conglomerate with rounded pebbles, and there are places where the equivalent rock has no included pebbles and would be more properly termed a limestone. Probable equivalents of the Basal Conglomerate occur also north of the Kuiseb River.

4. *Tsondab Sandstone.* At Tsondab (and at many other localities) there is a red, carbonate-cemented quartz sandstone called the Tsondab Sandstone. In places it is cross-bedded, elsewhere it is plane bedded. There do not appear to be any pebble bands and most authors have assumed that it is a consolidated dune sand. However, it should not be confused with the much younger unconsolidated sand dunes of the present day. The two episodes of dune formation in the Namib may be separated by a time span extending over whole geological periods. SELBY (1976) called the Tsondab Sandstone "consolidated red desert sands" which tends to link the Tsondab Sandstone with the modern sand dunes, but it is in fact a distinct unit.

There is no good indication of the age of the Tsondab Sandstone, but it may be equivalent to the Kalahari System of Botswana and the Republic of South Africa. A description of the Kalahari deposits by TRUSWELL (1970) may illustrate this: "Rivers draining into this region, ... deposited clay, more calcareous marls, sands and occasional gravel bands in the basin to form the primary Kalahari beds. Covered by the ubiquitous later sands as they are, information on these beds comes largely from boreholes. Their age is uncertain, but generally believed to be early Tertiary. They are capped by one or more sheets of calcrete and silcrete ... The age of these deposits is again uncertain, and made more so since they appear to have formed at several different times ... Subsequently the underlying material was reworked to produce the widespread blanket of Kalahari sands." According to HAUGHTON (1969: 427) the lowest horizons of the Kalahari System may be of Lower Cretaceous age, and this could apply to the Tsondab Sandstone.

5. *Tsondab Planation Surface.* After deposition of the Tsondab Sandstone a new erosion surface was cut across the sandstones. This was probably in the form of a vast pediment stretching from the Naukluft Mountains to the sea, and was traversed by drainage flowing from east to west (as indicated by the petrology of

derived pebbles) which deposited a conglomerate up to 30 m thick. This planation surface is a second fundamental surface in the history of the area, separating the period of accumulation of the Tsondab Sandstone from the later history of fluvial erosion and wind deposition. Presumably this activity, which predates the modern dunes, would also have affected the area north of the Kuiseb.

Again we can find a comparison with the Kalahari, where the geomorphic history according to GROVE (1969) appears to be similiar to that of the Namib. There the deposition of the lacustrine and terrestrial Kalahari Beds with numerous calcretes was succeeded by a period of river incision, and later renewed phases of wind dominance created the present dunes.

The Tsondab Planation Surface is best preserved as the upper terrace at Tsondab Vlei, where it is about 100 m above the vlei (valley bottom). The age of the planation surface is not known.

6. *Fluvial Incision Period.* The broad plain that existed after the formation of the Tsondab Planation Surface was later cut into by the major rivers crossing it from east to west to form major valleys. Downcutting was at times replaced by lateral erosion and rockcut terraces were carved across the Tsondab Sandstone. At Tsondab Vlei a terrace about 50 m above the present valley bottom and 50 m below the Tsondab Planation Surface marks a major break in downcutting. The terrace has a cover of carbonate-cemented gravels, and both size of the valley and the roundness of the pebbles indicate that the Tsondab River had a high flow, at least intermittently, at the time of downcutting and terrace gravel deposition.

South of Gobabeb an old course of the Kuiseb is preserved within the dunes. The terraces have carbonate-cemented gravels, but are essentially rockcut terraces eroded across both Precambrian bedrock and already indurated and jointed Tsondab Sandstone.

Regional Variation. From this point on, the geomorphic history of the area is best considered by areas – the Kuiseb Valley, the sand dune area to the south, and the stony desert to the north.

(a) *The Kuiseb River Valley:* Details of the geomorphology of the Kuiseb Valley are given by MARKER (1977) and OLLIER (1977), but the history may be summarised as follows (numbered from oldest to youngest):

8. Formation of minor terraces and the present flood plain.
7. Formation of the lower terraces of the Kuiseb.
6. Re-excavation to bedrock, leaving remnants of Homeb Silts.
5. Deposition of Homeb Silts.
4. Erosion to bedrock at present river level.
3. Deposition of gravels of Ossewater Conglomerate to form a terrace. Cementation.
2. Cutting of canyon, almost to present level; tributaries form badlands on north bank.
1. Initiation of Kuiseb course on the Namib Unconformity Surface or on the Tsondab Planation Surface.

This sequence of cut-and-fill may reflect climatic changes, but two things are important for the present purpose. Firstly the Kuiseb River derives almost all its water from the highlands beyond the Namib Desert, and so does not necessarily reflect local climatic changes, and secondly the whole history recorded in the Kuiseb is post-Tsondab Planation Surface in age.

(b) *The Sand Dune Area:* The area south of the Kuiseb River has been covered by sand dunes since some unknown time in the past. The main mass of sand is in north-south linear dunes and these are essentially fixed, and only the crests and minor dunes are active.

The dunes cross the Tsondab River, the valley of which is now exposed only in patches. To form the Tsondab valley the river had to be large (at least in flood time) and it could not be simultaneously eroding its bed and blocked by sand. The sand dunes postdate the terraces and the lower course of the Tsondab.

The dunes terminate abruptly at the Kuiseb River and it would seem that the Kuiseb carries away any sand deposited in its bed and prevents the dunes crossing its valley.

The present dunefield is therefore relatively young, and is separated from the Tsondab Sandstone by (a) the planation of the Tsondab Planation Surface and the spread of gravels on the resulting pediplain, and (b) the incision of the Tsondab and Kuiseb valleys, with the complications of terrace formation, river course change from the prior-Kuiseb to the present course, and probably the various depositional terraces of the Kuiseb. The time gap between the formation of the Tsondab Sandstone and the modern dunes is therefore great – probably millions or tens of millions of years.

(c) *The Stony Desert:* The gravel plains north of the Kuiseb yield little evidence to reveal their history.

However, there are common remnants of an indurated cover of surficial materials – calcrete up to 30 m thick – which is apparently equivalent to the Basal Conglomerate of the south side of the Kuiseb (photos 1 and 2). No remnants of the Tsondab Sandstone are known north of the Kuiseb.

The impression is that the present day processes are doing little more than bevel a pre-existing plain (the Namib Unconformity Surface) which is being exhumed from a calcreted cover of younger rocks.

The history in brief appears to be:

5. Modern pedimentation and minor river and wind action
4. Erosional stripping of younger rock to re-expose the Namib Unconformity Surface
3. (Possible deposition of equivalent of Tsondab Sandstone)
2. Deposition of "calcrete" equivalent to the Basement Conglomerate
1. Erosion of the Namib Unconformity Surface.

The Kuiseb River runs along the geological contact between the Precambrian rocks of the gravel plains and the Tsondab Sandstone of the dune area to the south. It is possible that in its middle course the river moved south by uniclinal shifting down the slope of the Namib Unconformity Surface as it stripped the cover rocks. Now, however, it is incised in Precambrian rock and such movement, if it ever occurred, has stopped.

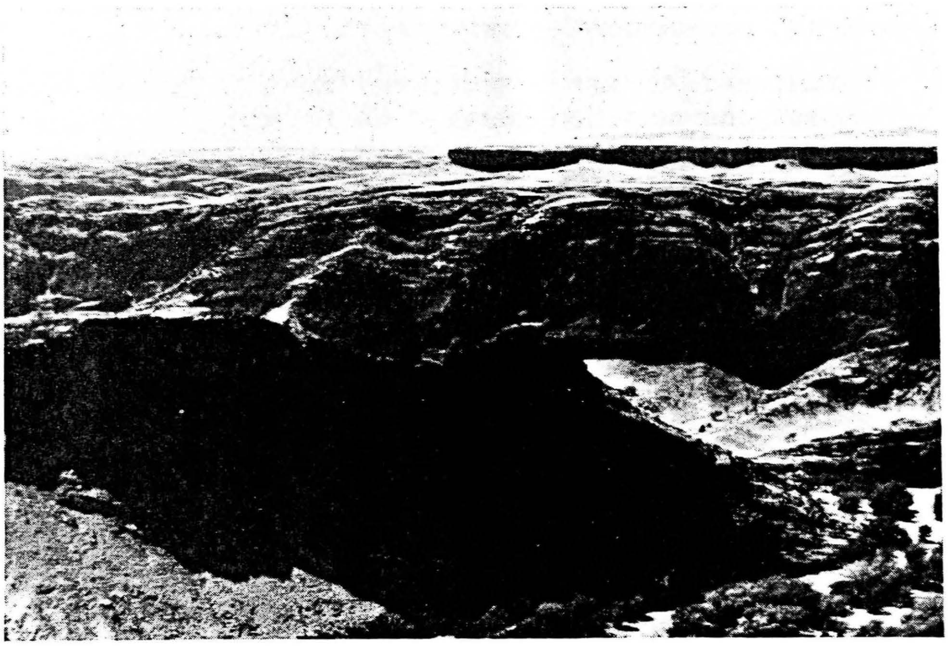

Photo 1. Basal Conglomerate with flat top and irregular base overlying Precambrian gneiss. Kuiseb Canyon.

Photo 2. An isolated mesa consisting of Basal Conglomerate overlying Precambrian gneiss. Near Kuiseb Canyon.

Summary of the geomorphic history of the Central Namib Desert

7. Formation of the north-south dunes (south of the Kuiseb), modern weathering and pedimentation (north of the Kuiseb).
6. Terrace history of the Kuiseb Valley (the terrace history of the Tsondab Valley may be this age or older).
5. Stripping of Tsondab Sandstone and most of the Basal Conglomerate in the area north of the Kuiseb River and re-exposure of the Namib Unconformity Surface.
4. Deposition of Tsondab Sandstone.
3. Deposition of Basal Conglomerate.
2. Formation of the Namib Surface, with inselbergs.
1. Formation of the Precambrian rocks.

The age of the erosion surfaces. As shown in Fig. 3 there are two erosion surfaces in the Central Namib area – the Namib Unconformity Surface cut across the Precambrian rocks and the Tsondab Planation Surface cut across the Tsondab Sandstone and possibly continuous with the bevelled surface where calcretes are being stripped from the gravel plains. What are the ages of these two surfaces?

KING (1969, fig. 119) shows the gravel plain of the Namib as part of Post-African Late Cainozoic landsurface. It is possible, however, that it is a downwarped part of the African (early Cainozoic) or even Gondwana (Jurassic) landsurface preserved on the Khomas Highlands.

In his latest terminology (KING 1976) the planation surfaces are called the Gondwana (Jurassic), Kretacic (early-mid Cretaceous) and Moorland (late Cretaceous to mid-Cainozoic). According to KING the Moorland surface is characterised by calcrete and silcrete, and on this basis is the one most likely to be equated with the Tsondab Planation Surface. Its postulated age is greater than that of the Post-African surface previously correlated with the gravel plain but would not conflict with any information currently available. The Namib Unconformity Surface would then be older still, either Gondwana or Kretacic.

Another approach to the age of the erosion surfaces (SELBY 1976) is to equate the gravel plain of the Central Namib with a similar plain in the South Namib where there is a silcrete – the Pomona sandstone – which is thought to be pre-middle Eocene. However, according to HAUGHTON (1969: 436), the Pomona sandstone is not dated by fossil evidence, so this approach is as speculative as any other.

The absence of deep weathering may be relevant to the age as well as the mode of genesis of the erosion surfaces. Either (a) there never was deep weathering, or (b) any deep saprolite has been removed during a later erosion phase. (a) If there never was any deep weathering, why not? Deep weathering requires the presence of a body of groundwater for a long time and aridity might prevent saprolite formation. On this simple assumption aridity may have prevailed in the Central Namib since formation of the Namib Surface. (It might be noted in passing that some deserts do have considerable groundwater, such as the large fresh groundwater resource discovered a few years ago near Alice Springs in Central Australia. It may be possible to have deep weathering even though the surface is arid.)

(b) If there was a saprolite and it has been stripped off, when was it formed and when stripped?

As HOLMES (1965) pointed out, apart from limited marine invasions across the coastal plains, much of Africa "has been a land area since the Ordovician, and much of it since the Precambrian." In this vast time span it seems probable that the climate would at some time have provided suitable circumstances for deep weathering almost everywhere.

My own belief is that a major period of deep weathering took place beneath the Gondwana Surface (e. g. OLLIER 1959), and despite minor episodes of weathering later the deep regolith has been generally stripped in subsequent cycles. If this were so in the Central Namib, then the Namib Surface must be one of the post-Gondwana surfaces. It could then correspond perhaps to the Kretacic or to the Moorland planation surfaces of KING (1976). If this is accepted, there is still the problem of the absence of deep weathering since Mid-Tertiary times.

In brief there is little evidence of the age of the erosion surfaces. My own guess is that the Namib Unconformity Surface is pre-Upper Cretaceous, and that the Tsondab Planation Surface is middle to late Tertiary.

Geomorphic history and climatic change. It is easy, though very superficial, to find climatic changes as causes for every change in geomorphic history, but with present knowledge this cannot always be done in a satisfactory scientific way. The various possible combinations of rainfall, vegetation growth, runoff, soil formation, and erosion are too complex to allow conclusions to be drawn from a single geomorphic event. Much more abundant, varied and accurately dated data are required to warrant more than the most general speculation.

For example, in Southeastern Australia where abundant dated stratigraphic material has been studied in detail, it has been found that periods of world glaciation were represented in southeastern Australia by more arid conditions, in the sense that vegetation was reduced, strong winds blew and dunes were active. But the rivers at that time were bigger than those of the present day and lakes were generally full. If only part of the data had been found who would have thought that full rivers correlated with arid periods?

In the Namib, until the geomorphic-stratigraphic evidence is much more detailed, climatic inferences are highly speculative. What does seem clear is that the area has been arid to some degree for a very long time. Periods of rivers downcutting clearly indicate the flow of rivers, but they may have been (like the present Kuiseb) rivers that collect their water outside the desert. The modern period of dune building may indicate greater aridity than before, or (for the sake of argument) it may result from greater flow of the Orange River bringing more sand to the source area.

Terrace cut-and-fill and calcrete formation reflect only minor changes in climate; the mobility of the present dunes may indicate a climatic change of Quaternary or Upper Tertiary times, but the absence of deep weathering apparently poses problems of climatic change on an even longer time scale, and the big question is how long has the area been generally arid. Palaeomagnetic evidence (MCELHINNY 1970, figs. 119 and 140) indicates that there has been very little change in palaeolatitude in the Mesozoic or since for this part of Africa and it has been either interior continental or west coast through this time also. Despite complications of atmospheric and oceanic circulation changes it seems possible that the area could have been dry since the Mesozoic.

ZINDEREN BAKKER (1975) suggests that the desert could date back to the Oligocene when the circum-Antarctic Current originated, but several other biogeographers prefer a younger Namib Desert. Work on the coastal region of South West Africa suggests many climatic fluctuations, and a late age for the onset of aridity. TANKARD & ROGERS (in press) suggest that the earliest evidence of semi-arid environment in the southwestern Cape dates to the Pliocene, and believe that in the Miocene there was a pan-African environment of dry wooded-grassland with summer rainfall.

There is also conflicting geomorphic evidence. AMARAL (1969) has described inselbergs from Angola that have deeply weathered rock and laterites around, and which he says "are not the result of a retreat of scarps, but rather the effect of the progressive down-wearing of the topographical sub-aerial surface and of the basal surface of weathering". He believes the landforms result from "many phases and processes" though ignorance of the extent of "climatic fluctuations which affected the tropical belt during the last million years" restricts more accurate explanation.

In the present state-of-the-art of climatic geomorphology I think that more direct conclusions are more likely to come from the study of lakes or sedimentary basins in or around the Namib than from the study of the relatively barren dunes and gravel plains. However, to establish the correlations necessary for a sound history, the stratigraphy, sedimentology and geomorphic history of the Namib needs to be known in greater detail than it is at present.

Significance of the geomorphic history

Even if the calcrete patches of the northern stone desert are equivalent to the later conglomerates deposited on the Tsondab Planation Surface, a considerable age must be accorded to the inselbergs. The view taken here, however, has been that they are to be correlated with the older Basal Conglomerate of the Namib Unconformity Surface. The significant point is that the stony desert plain is not simply being formed by present-day processes but is an exhumed plain. Present day weathering processes are concentrated on removing any upstanding features and making the plain even flatter by mantle planation, but the major features of the desert plain and its inselbergs are inherited from a period of landscape formation of great antiquity.

In the southern sandy desert occasional inselbergs project through the Tsondab Sandstone and the modern sands, suggesting that the early desert plain with inselbergs is preserved under the Tsondab Sandstone as one would except. Indeed it is quite likely that the Tsondab Sandstone extended farther to the north but has been totally stripped off.

Accepting this postulated history the Namib Surface is of great age, and the Namib stony desert is an exhumed topography. Contemporary processes are doing little more than bevel a pre-existing plain, and the absence of deep weathering noted by SELBY becomes even more remarkable, for it seems to indicate a very long period of aridity.

Weathering processes in the Namib Desert are causing mantle controlled planation of the surface. This removes irregularities on a small scale, and also leads to general surface lowering. This general surface lowering acts differentially, so some resistant rocks (dolerite, marble) stand up as strike ridges, and massive rocks with little fissility (especially granite) project as inselbergs. Topographic boundaries thus correspond closely with geological boundaries, a situation which is not consistent with parallel retreat of slopes. It is suggested that repeated and selective mantle-controlled planation may be a third mechanism for inselberg formation, the others being regolith stripping and parallel retreat of slopes. SELBY's contention that inselbergs provide an example of convergent landform evolution is thus supported and extended.

The concept of differential erosion of inselbergs by many small increments of mantle controlled planation is somewhat similar to the concept of the etchplain originally proposed by WAYLAND (1934), but physical weathering processes are dominant in the former rather than the intense chemical weathering of the latter.

However, although weathering features are consistent with continued formation of inselbergs, the geomorphic history of the region suggests that the inselbergs were formed long ago, have been buried by younger sediments, and are now being exhumed. Present processes are merely exhuming and slightly modifying an inherited landscape. The point of principle arising from this observation is that process studies alone are insufficient to explain how landscapes are formed, and without the parallel study of geomorphic history may lead to only partial or even incorrect interpretations.

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