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The development of the Namib dune field according to sedimentological and geomorphological evidence

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ABSTRACT. The Post-African planation surface of the Namib Plain also developed on the sandstone beneath the Namib dune field. On this ancient land surface five river systems have been active. After an erosional stage, decreasing run-off led to the accumulation of large alluvial fans. These were the main source of sand and the centres of erg development. Since the End-Pleistocene the wind regime shifted southward, only minor remodelling of the dune field has taken place.

INTRODUCTION

This paper is a brief summary of extensive research carried out mainly during 1976 and the following years and published in a monograph in German (Besler 1980). In view of the limited extent of the paper the presentation of techniques and methods of investigation is neglected in favour of results. However, as the Namib dune field covers an area of 34 000 km this cannot be more than a first attempt and much remains to be done.

PREREQUISITES FOR THE DEVELOPMENT OF THE DUNE FIELD

The Post-African Planation Surface

Ground control during the investigation of the Namib dune field (= Namib Erg) in 1976 (Besler 1976/77) revealed that the sand cover in the interdune valleys is not very thick and that the underlying Namib Sandstone (Besler and Marker 1979) can be found everywhere. Occasionally even the high dune ridges, where these embrace large dune pits, show sandstone at the base of the pits. It is particularly in the southern erg that the Namib Sandstone is exposed over large areas.

Based on the only available preliminary contour maps (1:100 000 and 1:250 000) 38 cross-sections were drawn from west to east at a distance of 10 km. These profiles show the base of the dunes to be slowly rising towards the east. As the ground control had shown, the levels of the interdune valleys can be connected by straight lines to roughly represent the underlying sandstone surface. The inclination of the land surface was calculated from the cross-sections and transferred onto a map (Fig. 1.).

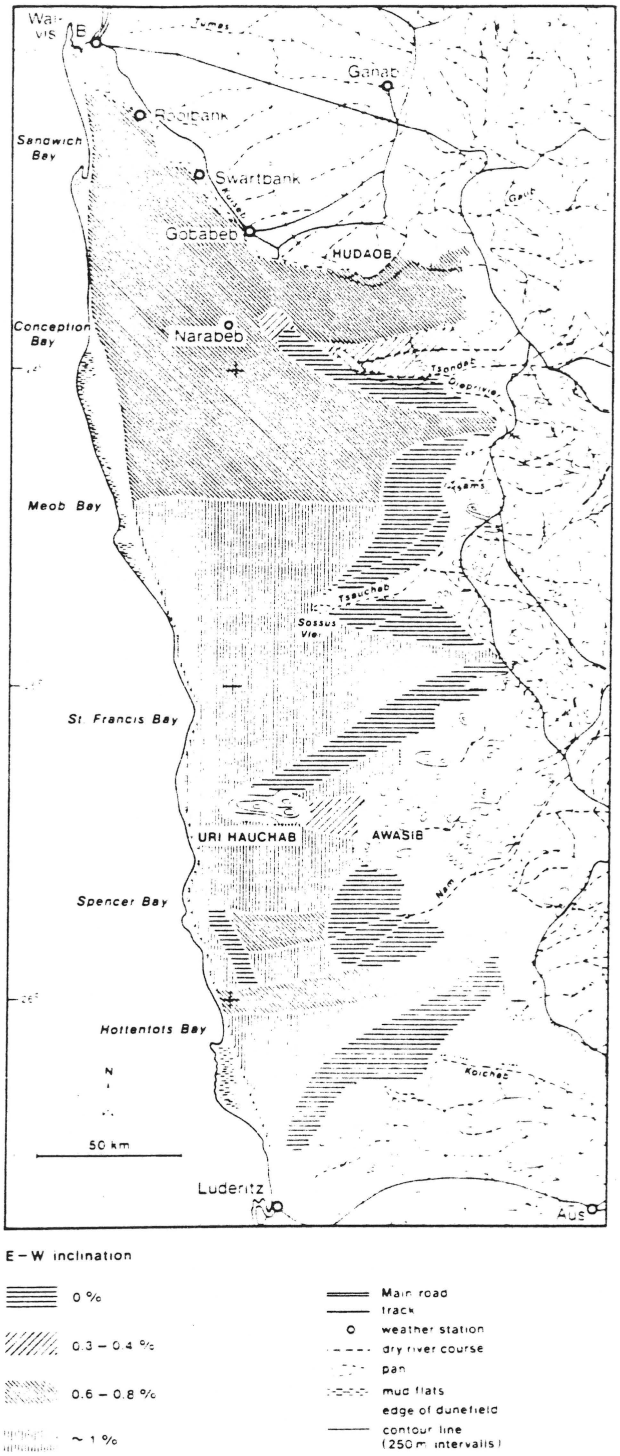

Figure 1. Gradients of the Namib Sandstone surface beneath the dune field calculated from 38 cross-sections (from Besler 1980).

Several points of interest should be noted:

1. The Namib Sandstone rises cliff-like up to 200 m above the crystalline basement near the coast (for example, near St Francis Bay and west of the Uri Hauchab inselberg) and up to 200 m above the foreland of the Great Escarpment in the east (for example, near the Tsauchab river and Nam Vlei). This sandstone pedestal gives the dune field its elevated appearance, exaggerating the heights of the dunes.

2. The Namib Sandstone thins out towards the north where the Kuiseb river approximately follows the contact between sandstone and crystalline rocks. It also thins out towards the south where the Koichab river marks the southern border.

3. With the exception of the northernmost part, the gradient of the sandstone surface is 1 % almost everywhere. This value is also given for the Namib Plain outside the dune field which according to King (1962) represents the Post-African Denudational Landsurface. Later King (1976) distinguished between Rolling = Post-African I Land surface (Mio-Pliocene) and Widespread = Post-African II Land surface (Plio-Pleistocene). Ollier (1978) suggests that this is the older Moorland Planation Surface (King 1976) because of the partly existing calcrete cover. But according to King (1962) the Moorland Surface is equivalent to the African Planation Surface which is characteristic for the South West African Highland. The important fact, however, is that the same planation surface is spread across the Precambrian of the Namib Plain and across the younger Namib Sandstone. The gradient of the crystalline basement beneath the sandstone is much lower and does not correspond to the Post-African Land surface.

4. Several marine benches are eroded into the coastal sandstone cliff. Unfortunately they cannot be traced everywhere and correlated because of the dune cover. Terraces were found at 25 m, 40 - 50 m, 80 - 100 m, 130 - 150 m, and even at 200 m. As King (1976) places the greatest uplift of the continent after formation of the Rolling Land surface in the Pliocene the Namib Sandstone surface beneath the dunes seems to represent the Post-African I erosion surface.

5. Lithologically the Namib Sandstone consists of only slightly cemented aeolian deposits that are reworked in some places. The dominating quartz grains are mostly subangular-pitted and poorly to moderately sorted, their mean grain size ranging from 0.08 mm to 0.38 mm with a frequency maximum around 0.2 mm. A high percentage of grains shows coatings of iron oxide.

Fluvial activity: the erosional stage

The gradient map shows horizontal parts of the sandstone surface near the eastern margin of the dune field and in the vicinity of still existing rivers. These surfaces either truncate the eastward rising sandstone or are incised into it. Whereas their westward inclination is zero, the gradient following the direction of probable former discharge is mostly 0.7 %. Especially near the Tsondab, the Tsauchab and the Nam rivers, the interpretation as ancient fluvial terraces is compelling. According to the gradient map five fluvial systems have thus been active on the Namib Sandstone surface in addition to the bordering rivers Kuiseb and Koichab. These are

1. the very complicated Tsondab-Dieprivier system
2. the Tsauchab-Tsams system with double terraces
3. the Bushman Hill-Uri Hauchab system without a visible river chan-

4. the Nam system with double terraces
5. the Koichab northern branch reaching the bordering Koichab near Koichab Pan.

All fluvial terraces have been confirmed by aerial photographic interpretation. As the gradient in the direction of former discharge is 0.6 - 0.8 % in each case, it seems possible to explain the inclination of the northernmost part of the sandstone surface in terms of general fluvial truncation not confined to channels. The coincidence between the extent of the less inclined area and the relatively high undissected part of the Great Escarpment between the rivers Gaub and Tsauchab is remarkable. There also seems to be sedimentological evidence that the eroded sandstone of the east was redeposited fluvially on Namib Sandstone in the coastal area.

Further evidence is derived from pebble analysis on the fluvial terraces. The river systems of Tsondab-Dieprivier and Tsauchab-Tsams partly have their catchment areas in the Schwarzkalk Formation of the Escarpment, supplying conspicuous dark pebbles. These can be found everywhere on their terraces and even appear as dark patches on aerial photographs. In fact, some Schwarzkalk pebbles were also found on a terrace near Uri Hauchab, supporting the inference of a Bushman Hill-Uri Hauchab river system. The Kuiseb, on the other hand, has its catchment area in the Damara System and had no contact with the Schwarzkalk Formation. The majority of pebbles of the Kuiseb consists of quartz. Between Gobabeb-Narabeb and the highest marine terrace (200 m) quartz and Schwarzkalk pebbles are found together, indicating the existence of a formerly combined discharge, most probably in a very shallow and braided channel system.

The fluvial history was investigated in more detail in the more easily accessible northern erg. Incised into the described surface with an inclination of 0.6 to 0.8 % are the separate high terraces of the Kuiseb and Tsondab with the same gradient in the direction of discharge. They are covered by calcretes which supplied a series of C14 dates of 33 350 ± 2960 BP (subsoil) to 24 480 ± 720 BP (surface) for the Tsondab High Terrace east of Tsondab Vlei and of 26 930 ± 915 BP (subsoil) for the Kuiseb High Terrace near Gobabeb. Here mixed pebbles of quartz and Schwarzkalk indicate that the Tsondab seems to have been a tributary to the Kuiseb at one stage. At this time there was enough local run-off on the Namib Sandstone to erode numerous small channels leading from the watershed between the Kuiseb and Tsondab (east of Tsondab Vlei) onto their respective high terraces. When local run-off ceased, the Kuiseb lost its southern tributary but could incise farther due to allochthonic water. This lower Kuiseb terrace branches off near Homeb where C14 dates ranges from 25 040 ± 475 BP (subsoil) to 22 770 ± 635 BP (surface). Farther west near Gobabeb the calcretes on the lower Kuiseb terrace contain rolled pieces of calcrete from the High Terrace and were dated 19 860 ± 590 BP (subsoil). Unfortunately radiocarbon dates for calcretes are difficult to interpret, but the main erosion of the Kuiseb valley - especially east of Gobabeb - must have occurred after the calcrete formation.

Distinct channels of local run-off are also found on the high terraces of the Dieprivier, Tsams and Tsauchab where they lead into space and have no connection with the lower terraces. At this stage obviously only discharge from the Highland area provided the water. Yet the erosive capacity reached its maximum, cutting deep but narrow valleys into the sandstone and at the same time broadening the erosional moat below the Escarpment. As a consequence the broad high terraces of the river systems were cut off from their hinterland (with the exception of the Tsondab). Local run-off was only effective on crystalline bedrock outcrops which were separated from the surrounding sandstone by small erosional moats draining towards the tributaries of the greater river systems.

Fluvial activity: the aggradational stage

The application of sedimentological techniques to sand samples from the recent dune field and the interpretation of the results led to the conclusion that with decreasing discharge the rivers no longer reached the ocean but, during retreat, accumulated large alluvial fans on the formerly eroded Namib Sandstone surface. These fans can still be traced in the dune field because here the granulometric and morphoscopic qualities of sand grains are distinctly different, providing enhanced evidence for fluvial transport, although the sands were later incorporated into the dunes. Judging from these differences in the sand, the size of alluvial fans decreased from north to south. The combined Kuiseb and Tsondab accumulated the largest fan, reaching from west of Tsondab Vlei to the coast and from Walvis Bay to Conception Bay. The smaller Tsauchab alluvial fan still reached the coastline but the Nam river only deposited an interior fan. Practically no sands were accumulated in the Bushman Hill-Uri Hauchab system and in the Koichab northern branch. Both these systems seem no longer to have been active after the erosional stage. The Bushman Hill-Uri Hauchab system does not even possess lower terraces.

The history of the largest alluvial fan and the sand relations in the north were investigated in detail (Fig. 2).

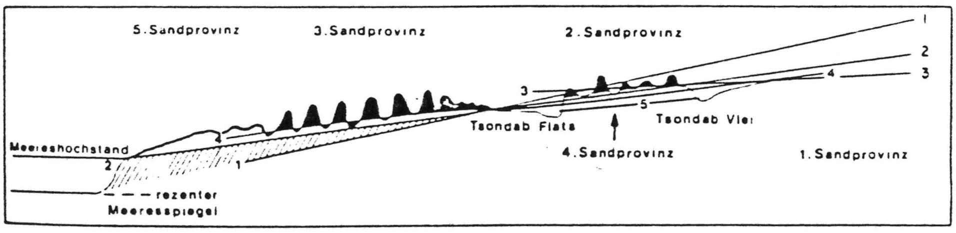

Figure 2 Sand provinces of the northern erg along the generalized cross-section no 8 (from Besler 1980)

Levels and gradients:

1. Post African Land surface (1.0%)
2. northern truncation surface (0.7%)
3. Tsondab Plain = High Terrace (0.3%)
4. ancient Tsondab (0.6%)
5. ancient Tsondab (0.6%)

Sand provinces:

1. red subangular sands from sandstone decomposition
2. brown rounded sands
3. brown mixed sands (1. and 2.)
4. grey calcareous sands from reworked calcretes
5. yellow mixed sands

1. The primary stage is represented by the Post-African Denudational Land surface with an inclination of 1 %.

2. The second surface with an inclination of 0.6 to 0.8 % consists of a truncated part in the east and an aggradational part near the coast.

3. Incised into the eastern part is the third surface with an inclination of 0.3 % still visible east of Tsondab Vlei where it is covered by calcretes. This is the High Terrace of the Tsondab river, the so-called Tsondab Plain. In this eastern part of the erg the modern red sands are simply weathered Namib Sandstone and therefore consist of subangular-pitted grains with a high percentage of iron oxide coating. These sands represent the first sand province. The river flowing on the High Terrace brought rounded sands from the Escarpment. These brown rounded sands were spread out west of Tsondab Vlei where they still form the second sand province.

4. The next stage of main valley erosion cut through the older deposits and deep into the Namib Sandstone. During river retreat the eroded sands were spread out west of the so-called Tsondab Flats in a large alluvial fan. They consist of subangular-pitted grains (from the Namib Sandstone) and rounded grains (from older deposits) and form the third sand province of brown mixed sands. These sands reach as far as the longitudinal dunes, that is, approximately to the highest marine terrace.

5. Another stage is represented by remnants of partly dune-covered fluvial terraces 10 - 20 m above the level of Tsondab Vlei. These terraces are covered by coarse grey calcareous sands representing the fourth sand province. The grey sands can be traced in a channel through the brown sands as far as north of Narabeb. They were derived from reworked calcretes of the High Terrace.

6. The sands in the coastal area covering the marine benches show the same qualities of grain shape and surface texture as the third sand province (brown mixed sands) but are better polished and lighter in colour. This could be due to the longer fluvial transport which destroyed the iron oxide coatings. Another reason could be the effects of the stronger aeolian mobility near the coast with grain abrasion. The yellow mixed sands represent the fifth sand province. There is no strong evidence for marine sands.

In fact, patina and the sorting of sand grains, increasing from the coast eastward, do not reflect aeolian transport from the coast but fluvial transport from the east, with increasing bleaching and mixing. During river retreat large alluvial fans were also accumulated in the moat between the Escarpment and the eastern sandstone cliffs, partly drowning the inselbergs. As a consequence, the lowest level (with small pans) is today found in basins close to the sandstone cliff sheltered from aggradation by inselbergs.

THE NAMIB ERG

Pleistocene formation

The alluvial fans of the retreating rivers were the source of blown sands and the centres of erg development. A rough mass-calculation comparing the dune volume west of the vleis and the volume of eroded sandstone in the Tsondab and Tsauchab channels showed that all the dune sands could have come from these river channels, without even considering erosion along the Escarpment. The separated sand provinces and distinguishable fan areas, in spite of the dunes, provide evidence for minimal aeolian sand movement over long distances. Otherwise the sands would have been mixed and show more typically aeolian qualities, such as pitted surfaces. This at first glance seems incompatible with the high dunes.

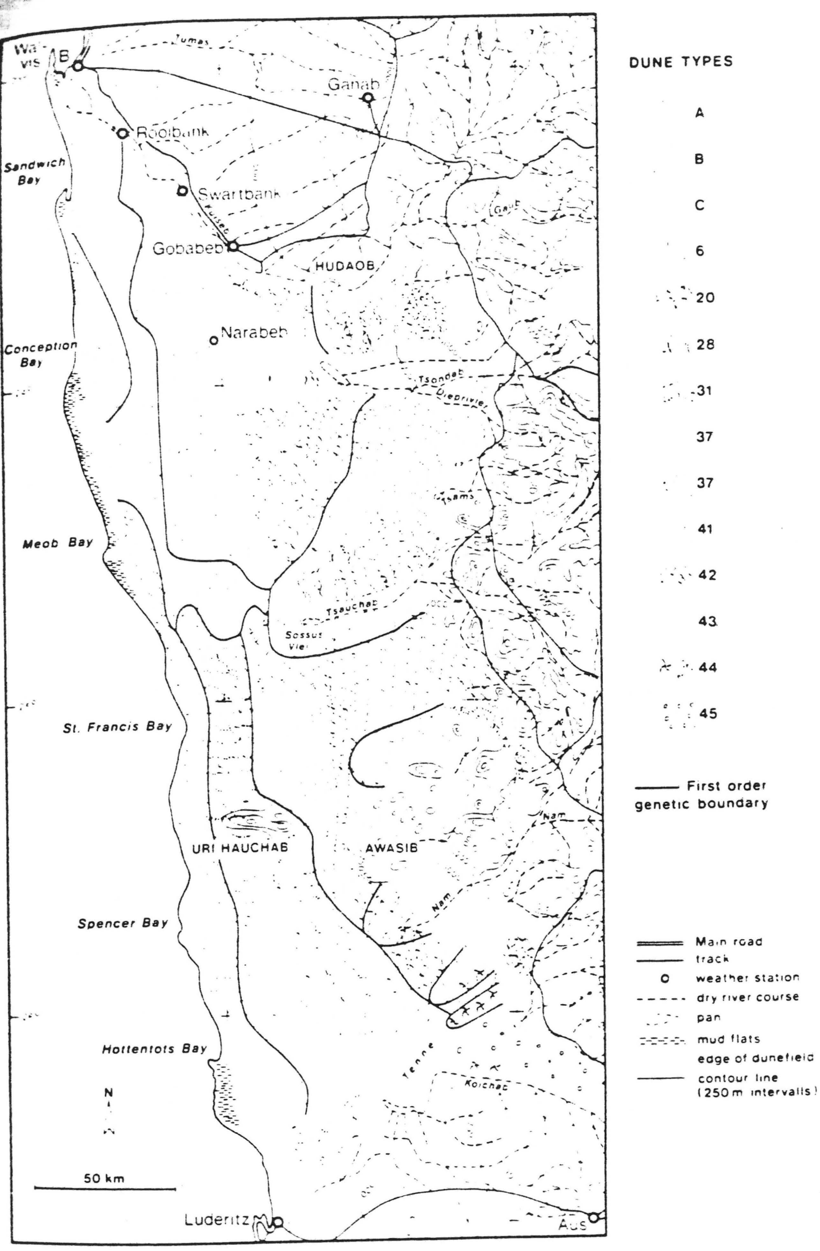

Figure 3. Dune types deduced from stereoscopic aerial photographs and ground control.

A. transverse dunes
B. transition forms
C. longitudinal ridges undifferentiated
6. network complex
20. branching longitudinal ridges
28. honeycomb structure with stellate dunes
31. lace dunes
37. zibar and zibar-silk system
41. high chaotic dunes
42. warty ridges with stellate dunes
43. giant honeycomb structure
44. pyramidal dunes
45. sand plain with craters

The fifteen varieties of high longitudinal dunes in the interior northern erg (Fig. 3) can all be reduced to one original form, the primary longitudinal dune ridge with one sharp undulating crestline and symmetrical flanks with an inclination of about 20 degrees. The heights range up to about 100 m with crest separation of 1.8 to 2.4 km. At present only one model exists which explains their formation without any contradicting evidence, that is, the Taylor-Görtler-movement within the Planetary Boundary Layer of the atmosphere. Under certain conditions parallel double vortices develop in the boundary layer (1 km dia.), eroding sand beneath their sinking branches and accumulating sand between their rising branches (Hanna 1969; Wippermann 1973) without sand transport over long distances. All necessary boundary conditions are fulfilled in the Namib, with the exception of frequent strong winds with velocities higher than 36 km/h. Today these are found only south of the Namib dune field (Lüderitz, Alexander Bay). But for the Pleistocene a meridional shift of wind systems and a higher acceleration can be assumed due to pressure-belt compression (van Zinderen Bakker 1975).

In the southern erg, with less alluvial sands, dunes have always been lower, displaying a zibar-sief (Warren 1972) or zibar-silk pattern (Mainguet and Callot 1978), zibars being large, weak undulations transverse to the wind.

Near the coast where marine benches cut the sandstone, two boundary conditions for vortex development were lacking: the undisturbed surface and the steady southern winds. Here strong additional sea winds moulded the sands into smaller transverse dunes.

The complex dunes around and east of the vleis cannot be explained by aeolian activity only. Interpretation of aerial photographs, ground control, and sand sample analysis provide evidence that these structures on the erosional part of the sandstone surface east of the alluvial fans are based on a fluvial sandstone topography. The sand is supplied by decaying sandstone (first sand province) which renders the distinction between sandstone base and dune cover even more difficult. The fluvial origin is most conspicuous in the north-eastern corner of the erg where the curved "dunes" are simply sandstone ridges between fluvial channels draining from a common watershed towards the Kuiseb and Tsondab High Terraces. On the High Terrace of Dieprivier the sand cover is poorer and the channels can be traced more easily. The conspicuous pyramidal dunes, for example near Nam Vlei and at the beginning of the Koichab northern branch, are all sitting on the rim of river terraces with one arm falling onto a lower platform. This descending arm is exaggerated in the case of the high dunes spilling into the Tsauchab channel east of Sossus Vlei. The dunes thus appear higher than they actually are since they are partly hiding a 200 m sandstone terrace. In fact, the eastern erg is not of aeolian but of fluvio-aeolian origin.

Holocene remodelling

After the End-Pleistocene southward shift of the wind regime the erg is modelled by a weaker, bimodal wind system consisting of trade winds (S-SW), sea breezes (SW), and easterly bergwinds. The southerly trade winds decrease towards the north but, together with bergwinds, seem still to be effective for the small sief or silk dunes in the southern erg. The transverse coastal dunes are still in equilibrium with the sea winds. But the high longitudinal ridges of the interior northern erg are remodelled according to their position within the erg and their exposure to the winds (see also Lancaster 1980). Barchan-like secondary dunes, transverse to the SW winds, cover the eastern flanks in the western erg. Towards the east they are gradually replaced by small secondary sief or silk dunes which need two obliquely blowing winds to form (SW and easterly bergwinds). Still further east these secondary dunes decrease in size with diminishing wind velocities and now cover the original ridges like small worms. In the NW corner near Swartbank strong NE winds constitute an additional element, forming numerous dune hollows (Besler 1976/77). The eastern erg, however, is practically fossilized. Mobility is only recorded where the sands, following the laws of gravity, fall onto lower platforms.

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