GEOGRAPHY AND THE SCHOOL
GEOGRAFIE IN DIE SKOOL

(1) ASPECTS OF DESERT GEOMORPHOLOGY

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Arid, or desert, geomorphology has great relevance for Southern Africa. Over two thirds of the subcontinental area receives under 500 mm average annual rainfall, an amount that is erratic; 26% variance being quite usual. Furthermore two of the world's major deserts, the Namib and the Kalahari, lie within the subcontinent. In the past, active desert environments were even more extensive. Vegetated linear sand dunes extend through Wankie Game Reserve to Victoria Falls in Rhodesia, to the Langeberg and across the Orange river in Northern Cape Province, RSA. Desert processes have left an imprint over much of central and western southern Africa.

Yet despite advantages of first hand experience, glacial landscapes, at least theoretically, remain more familiar than arid. Even when arid landforms are discussed, a tendency remains to select western American or Saharan examples drawn by teachers from overseas advanced texts. Only very recently has adequate coverage using southern African examples become available at school level (Barnard & Nel, 1976; Swanevelder et al., 1975). A further problem hinges on the fact that research in arid terrain remains at the reconnaissance level (Cooke & Warren, 1973). This paper sets out to discuss salient aspects of arid geomorphology, to consider the effects of process, to emphasise the dominant, but not necessarily the most photographed, landforms and to provide a suite of examples drawn chiefly from the central Namib. The objective is to provide, in a readily accessible form, information essential for teaching relevant arid geomorphology.

According to Meigs (1953), who includes polar arid regions, over 30% of the world's surface can be considered to be desert (Fig. 1). Of these areas, he classes 14,6% as semi-arid (much of western USA), 15,0% as arid and a further 4,0% as hyper-arid. Parts of the coastal Namib are included in the hyper-arid class.

As a desert in geomorphological terms requires an area with little or no vegetation cover, actual mean annual rainfall totals are less significant than edaphic and anthropomorphic factors. Southern African deserts tend to be better vegetated than those of North Africa and Asia where grazing pressure has been longer sustained. But even in the hyper-arid Namib, long-return heavy rain falls can cause marked changes in vegetation cover (Fig. 2).

By definition therefore, water loss must exceed precipitation for a desert to exist. Over much of SWA this is true, yet a transect from Windhoek to the coast reveals that only when mean annual precipitation falls below 100 mm p.a. do true desert conditions supervene (Fig. 3). As the rainfall diminishes, woody vegetation becomes shorter and grows further apart until it can no longer exist and ephemerals, that germinate only after rain, and stunted bushes along dry water courses, supersede as the vegetation cover. On this basis much of the Kalahari is too well vegetated to be classed as being genuine desert. It is a desert only in its lack of surface water.

Climatic Considerations

High temperatures and low precipitation combine to create tropical, *"hot"*, deserts where arid processes give rise to characteristic landforms. The extent of southern Africa's arid zone is a function of its position astride the Tropic of Capricorn within a high pressure zone, combined with the precipitation inhibition effect, most marked in Namib, of the cold Benguela current. The Kalahari is furthermore an interior desert.

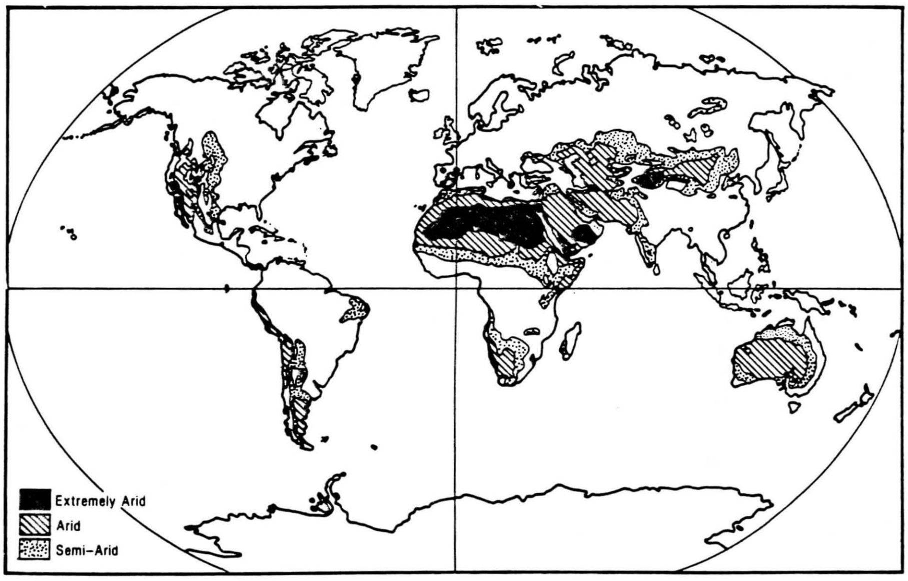

Figure 1: World arid areas (after Meigs, 1953)

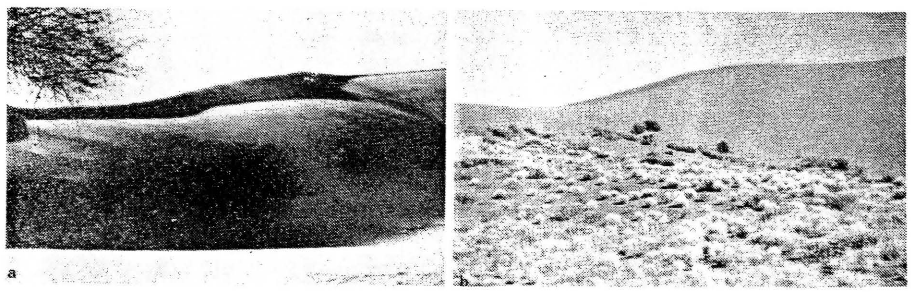

Figure 2. The effect of long-return rainfall events on dunes near Tsondab Vlei. (a) October 1975, (b) April 1976.

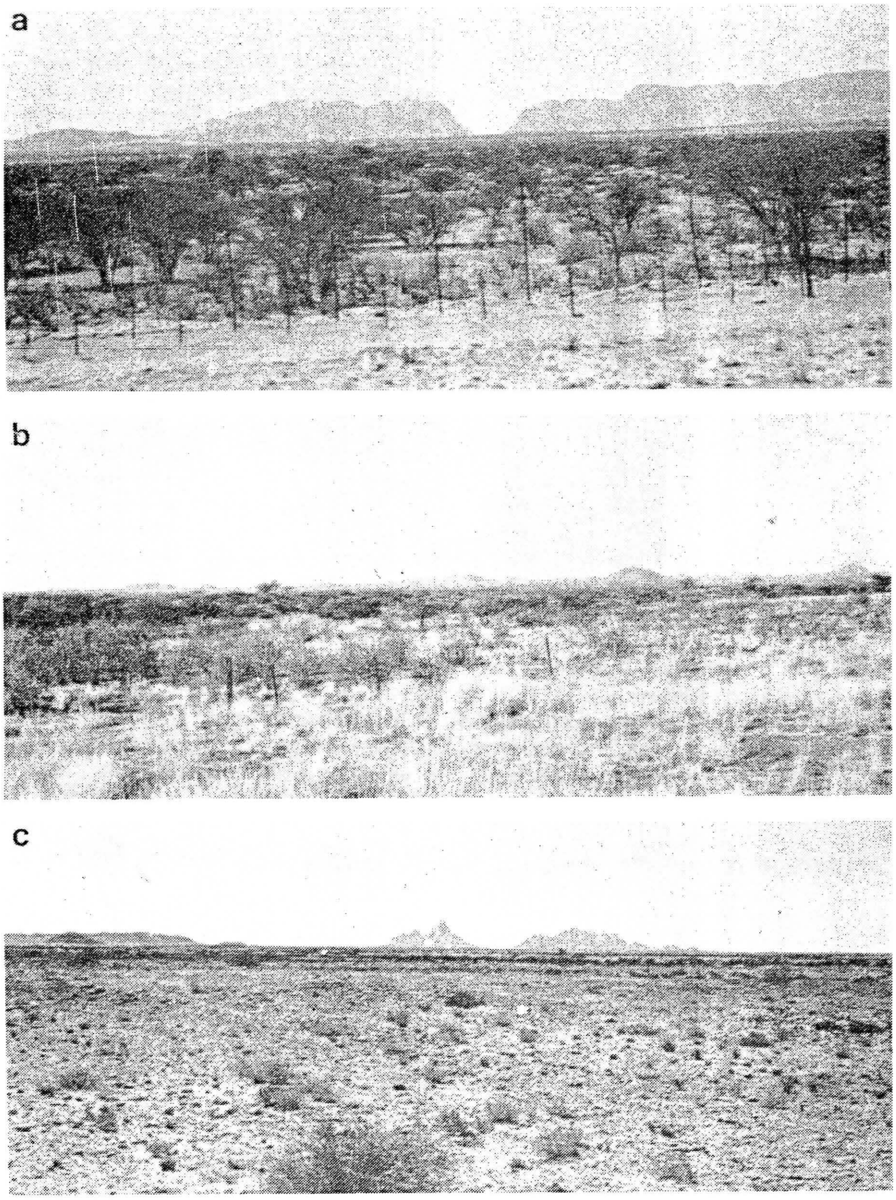

Figure 3. Vegetation diminution with rainfall (a) ± 350 mm p.a. (b) ± 250 mm p.a., (c) ± 75 mm. p.a. Note Spitzkop rising above a reg plain.

Climatic data for Gobabeb on the Kuiseb river, can be taken as characteristic of the central Namib and indicative of conditions elsewhere (Fig. 4). Lying only 60 km. inland, Gobabeb is affected by mist humidity to perhaps a greater extent than other desert areas, but on the other hand, the cold current limits annual precipitation to a mere 16 mm p.a. (Seely and Stewart, 1976). Total precipitation is low. Evaporation in every month exceeds available moisture. Moisture derived from mist condensation is, however, an important additional component of the ecosystem, but such

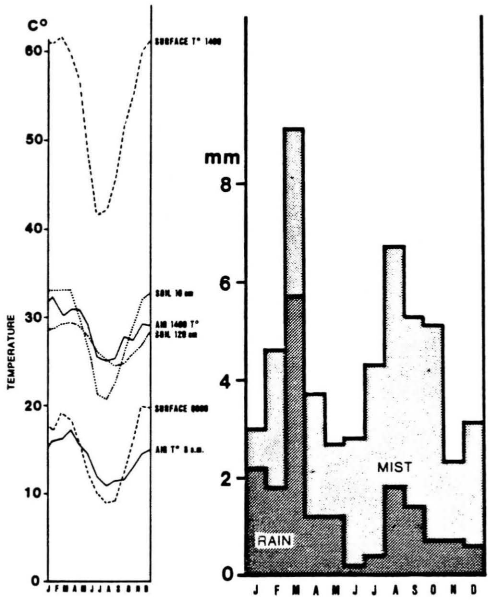

Figure 4. Climate of Gobabeb, Central Namib

additional moisture is not peculiar to coastal deserts. early travellers in North Africa and Asia commented on heavy night dews and farmers in the Negev maximise orchard yields by priling smooth dark stones round the base of trees so that they benefit from condensation.

Air (screen) temperatures exhibit extreme diurnal ranges exceeding mean annual variation. Dew point is reached as a result of low night temperatures. Still more marked diurnal effects are felt on the ground. Bare grounds heats up and cools down fast. Such marked temperature changes however affect only the surface few centimetres. At depth, temperature variation is buffered. Surface temperatures are also affected markedly by ground characteristics. Ground temperatures at Gobabeb are recorded over grey gravel.

Much higher day temperatures and at least as low night temperatures are recorded over bare rock and dark rocks such as basalt heat more readily than rough pale flecked granite. Winds at Gobabeb are not exceptionally strong. A Winter (easterly) and summer (westerly) wind regime is apparent (table 1)

TABLE 1

Percentage frequency of strong winds at Gobabeb (km/h) 1967— 72

(after Seely and Stewart, 1976)

	J	F	M	A	M	J	J	A	S	O	N	D
N	11	9				4	4			6	9	12
NNE	3			2	1	2	2					
NE				3	3	2	3	3				
ENE			*	1	2	$\boxed{3}$	$\boxed{2}$	1	1		*	
E			*	2	$\boxed{5}$	$\boxed{5}$	$\boxed{6}$	4	3	1	1	
ESE				7	9	10	10	8	4	3		
SE					16	17	17	13		3		
SSE			1	3		5	3	3	3	2	*	
S		2	4	5	5	5	6	7	6	4	2	2
SSW	2	2	4	4	4	4	4	4	5	6	3	3
SW	13	13	12	10	8	8	9	13	14	19	14	14
WSW	6	7	5	5	3	2		3	4	5	6	7
W	7	7	7	5	4			4	6	6	7	8
WNW	5	4	5	3	3			2	2	4	4	5
NW	19	17	11	7	6	6	6	6		11	18	20
NNW	20	18	11	3		3	3	4	6	9	13	13
Calm	7	13	19	24	21	18	18	20	20	16	13	9

km/ph = 10-15, ○ = 15-20, □ = 20+, * = Recorded wind.

but diurnal sea (west) and land (east) winds are also recorded at most seasons. Most tropical deserts are characterised by stronger winds than these and constant wind directions are more usual in the tropics.

Salient characteristics of process in arid environments

Arid environments are dry, therefore channel flow is minimised unless runoff is accentuated from bare rock. Precipitation falls as episodic, intensive showers that create localised channel flow in wadis but act chiefly as sheet wash to transport waste material. Floods associated with long return storms, carry out a disproportionate amount of water action. Large diurnal temperature ranges accentuate physical weathering, particularly exfoliation, since the rock surface is subjected to greater expansion and contraction than the underlying material. But chemical weathering, initiated by episodic showers and probably, more systematically, by nocturnal dews, is dominant. The lack of vegetation exposes the ground surface to the full impact of weathering. Rock break down in situ is dominant. Wind is unaffected by the friction effects of vegetation and thus is able to remove fine waste as it forms, exposing surfaces to weathering.

The lack of vegetation cover and waste mantle fine material implies that in desert environments geological structure is exposed. The bare bones of the landscape protrude and rocky deserts have structurally controlled landforms. The tabular landscapes of the Fish River canyon or the mesas and buttes of the Karoo owe their form to horizontal strata. In contrast, tors and knobbly inselbergs are characteristic of the basement rocks of the Namib margin. The silhouette of Spitzkop, near Usakos, is a function of its structure (Fig. 3).

In deserts geomorphological change is slow but cumulative. Aridity acts to preserve landforms, whether created by current process or during former wetter conditions. Southern African deserts are shield deserts like the Sahara and Arabia, in marked contrast to the Tertiary basin and range landscapes of the less arid western USA. The prevalence of American undergraduate textbooks does little to advance explanation of African arid geomorphology.

Endoreic drainage is usual. Exoreic drainage, reaching an oceanic base level, is restricted to rivers rising outside the arid region with sufficient discharge to survive high evaporation losses. Such rivers include the Nile, Colorado, Fish and Orange. Even such high discharge rivers as the Okavango and Botletle are endoreic. Endoreic drainage implies that each catchment or basin develops independently as a *closed system.* Salts brought down in solution are deposited in pans or *playas* (salinas) as the water dries up. The silted saline floor of Etosha Pan, lake Makarikari and Lake Ngami are all playa deposits. Little solid waste material leaves the system. As rivers carrying waste material end in playas, each in their own basin, waste accumulates to bury the base of the surrounding structurally controlled hills. The hills themselves shrink under normal slope recession processes and ultimately jut out as isolated residuals. The waste level in a desert interior basin accumulates until it can overflow through a *pediment pass* into an adjacent lower level basin. The lower basin then acts as a local base level until the surfaces equalise. Accumulation exceeds removal for little water is available for transport out of the system and the proportion of fine material removed by wind is minimal. Regional base levels are the exception in desert environments.

Wind action is restricted to surface scour on a small scale and to removal of fines by deflation. Dust size material may be lifted by storm turbulence and transported outside the desert to be deposited as loess. Many of the fine red soils of the Orange Free State and Cape Province are probably of this provenance. Wind transport on a considerable scale is restricted to within a metre of ground level. Heavier sand size grains travel by *saltation* in a series of hops or rolls and the lighter grains travel in suspension. The rate of transport is very largely governed by the rate of impact of falling grains to lift other grains, and the hardness of the surface across which they travel. Harder surfaces allow sand grains to bounce higher so that they are blown further before they fall back onto the ground. Sand therefore accumulates on sand, where the impact effect and rate of travel are diminished. Despite traditional impressions, even the major sand sheets occupy a relatively small proportion of desert areas (Table 2). Rocky and stony landscapes where fine material has been removed from waterlaid waste sheets by deflation to create reg are the chief components of desert landform assemblages.

TABLE 2

Sand desert extent.

COUNTRY	NAME	km^2
Arabia	Rub el Khali	600 000
Algeria	Great Eastern Erg	196 000
Australia	Simpson	113 000
S. Africa	Namib	34 000

Desert landform assemblages

Three components in arid landscapes can be distinguished: the *rocky* or mountain desert, the *stony* or gravel plain desert and the *sandy* desert with or without dunes. In reality the stony and mountain deserts are closely associated and cannot easily be discussed separately.

In the central Namib these three landform assemblages can be clearly distinguished. The escarpment margin and its residual outliers are components of mountain, rocky desert terrain. North of the Kuiseb river, gravel plains with low rocky residuals form the arid landscape. Localised oases exist where larger catchments such as that of the Tubas river or small streams end in playas. Between the Kuiseb river and Luderitz is the dune Namib, dominated by linear *(seif)* dunes in the centre, by complex tangled multi-age partially vegetated dunes in the east and by *transverse* and *barchan* dunes near the coast (Fig. 5).

Within these three types, individual landforms can be identified and explained. It is important to retain a sense of scale and to lay proper emphasis on macro-scale features rather than on micro-scale detail.

Rocky and Stony Deserts

In arid rocky environments, structure is paramount. Differential weathering and the absence of concealing vegetation or waste mantle cover enhances the impact. The gross form of residuals is the effect of geological control; tabular landscapes are seen on Nama sandstone, tors and bornhardts on Salem granite and distinctive jagged inselbergs wherever a combination of a schistose rocks outcrop. Residuals have been separated from the escarpment

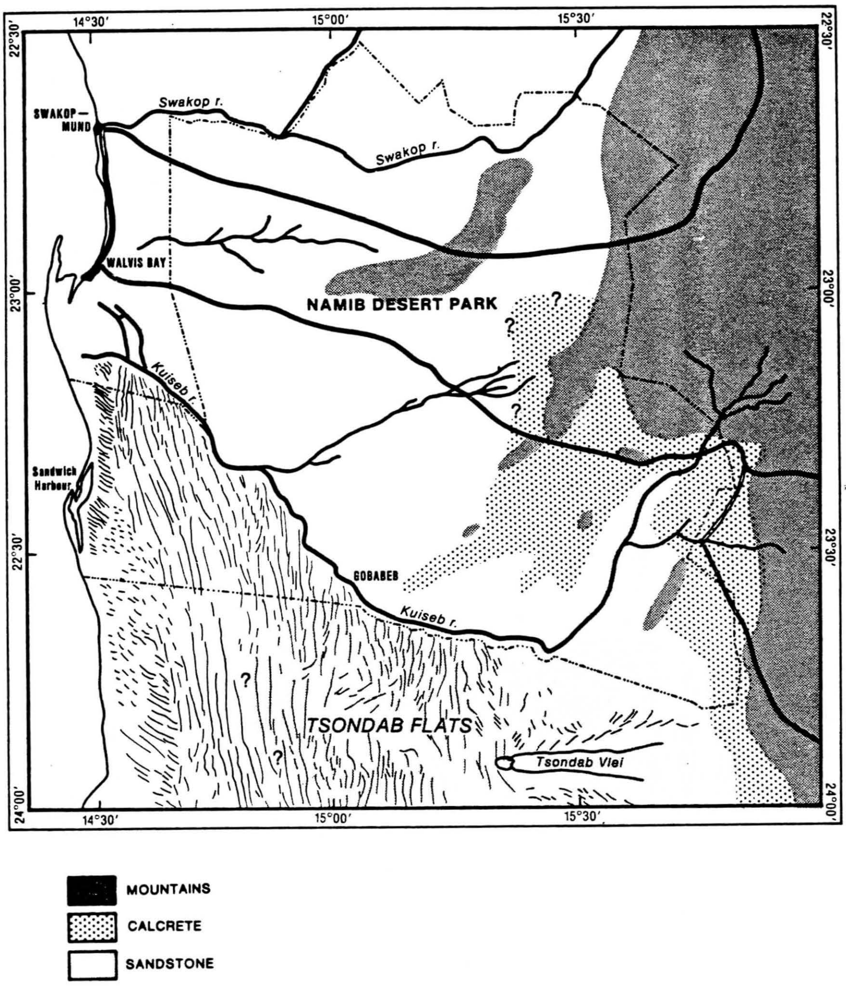

Figure 5. Namib desert showing rocky or mountain desert (dark shading), gravel desert (unshaded) with calcrete sheets (stippled), and dune Namib south of Kuiseb river

massif and these diminish in size by normal slope recession, albeit slowly. Rectilinear, transport slopes, whose angle is governed by the size of the detached blocks that move down by gravity, are common. On close examination such apparent talus slopes are seen to be rock cut and rectilinear (Fig. 6a). In detail chemical weathering is frequent. The shaded sides of most rock outcrops reveal tafoni, sheeting and honeycomb weathering where the rock type is suitable (Fig. 6b).

The mountain residuals are dissected by systems of integrated dry channels. The valley sides are steep, for slope processes of wash and creep are minimised by aridity. Flat floors result from sedimentation. Such wadi valleys are water scoured and discharge whenever there is sufficient runoff from the bare rock catchment. For short periods water energy is high and unsorted debris is transported (Fig. 6c)

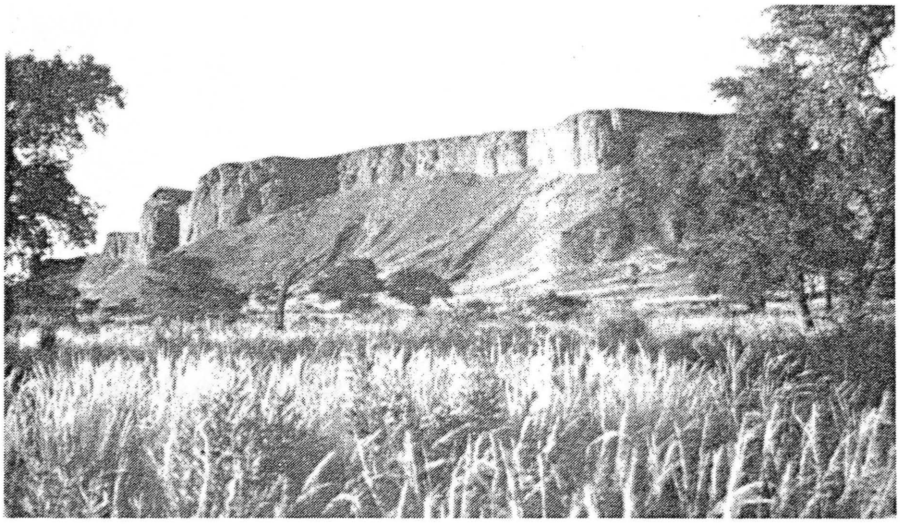

Figure 6a. Rectilinear slope developed on sandstone at Diep Rivier.

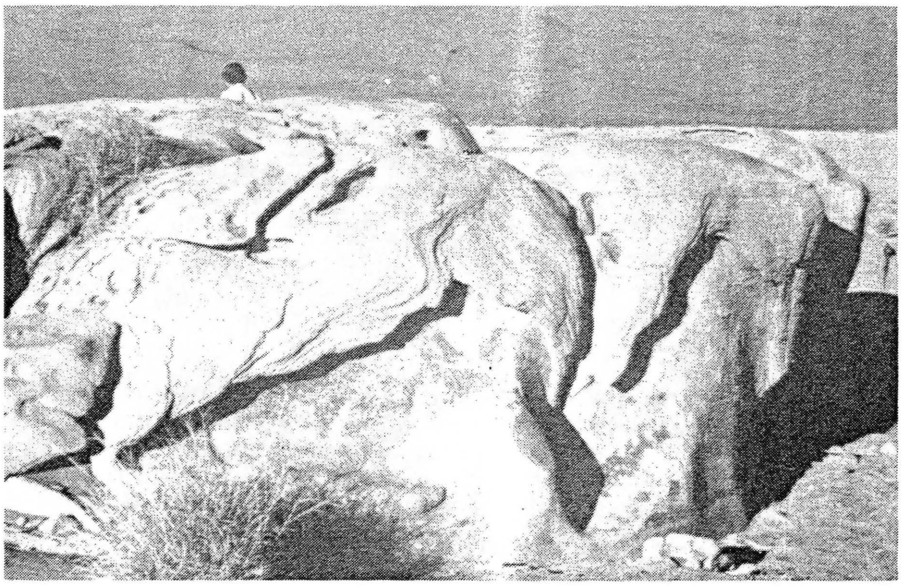

Figure 6b. Chemical weathering in granite at Gobabeb: Sheeting and tafoni.

Around the mouths of these wadis, *bahadas* (fans) form. Where the rivers debouch from the constriction of the wadis, the flow spreads, energy is lost and waste material is dropped. Evaporation also reduces flow and infiltration into the fan itself further promotes sedimentation. The size of the fans may be such that the bahadas coalesce as steep 5°-15° scalloped-edged, aprons surrounding the mountain front. Such bahadas ultimately create *reg* or gravel plains. Wind removes the fine material further into the desert leaving a lag of close packed pebbles protecting the underlying mixture of sand, gravel and pebbles.

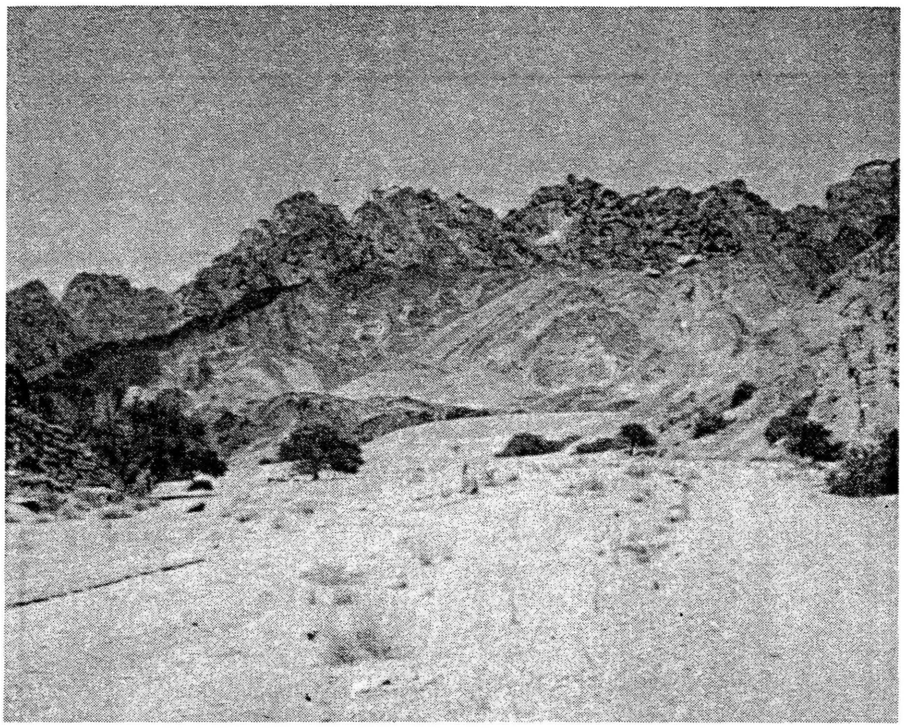

Figure 6c. Khan river wadi.

In some cases where discharge is particularly high in solutes (dissolved solids), the bahada may be sealed by *caliche* of calcium-dominant (calcrete) or saline dominant crusts. Usually such crusts form just below the surface at the wetting depth and are exposed only after deflation. Calcrete fans are common throughout the Namib for the Naukluft Mountains are rich in limestone. The Chilean nitrate enterprises work caliche crust along the foot of the Andes.

The pebbles that compose the reg surface may become wind polished to a high gloss or wind facetted to form *ventifacts.* In other cases, where more water is available, *desert varnish,* a dark chemical precipitate, of pyrolusite, and ferric oxides may coat the stones.

Yardang, zeugen and *gours* (mushroom or pedestal rock), so beloved of the textbook authors, are sometimes found associated with arid rocky areas. They never exceed 1-2 m in overall dimensions and, though making traverses difficult, are merely micro features. They result from differential weathering followed by removal of loosened waste by wind. Yardangs result from wind fretting of near vertical thin bedded strata and zeugen from a similar process in horizontal strata. Gours are pedestal rocks where maximum removal has occurred at the base. Chemical weathering enhanced by damp in contact with the rock beneath the waste mantle, causes rock rotting and weathering material is later stripped. Wind abrasion tends to act preferentially in one or two directions. It can polish and may etch micro grooves some metres long and 1-2 mm wide but it rarely works on a larger scale. The perfect preservation of carved Egyptian monuments from 5000 BC, indicate the relative ineffectuality of wind as an erosive force.

Sandy deserts

For most non-specialist geomorphologists, the study of sand sheets, dunes and associated playas should be limited in view of their restricted extênt. Rippled sand sheets, undulating, sand covered plains, are *erg* and monotonously cover the greatest extent of the sandy area (Table 2).

In the central Namib most of the basic dune types can be identified (Fig. 7, Table 3).

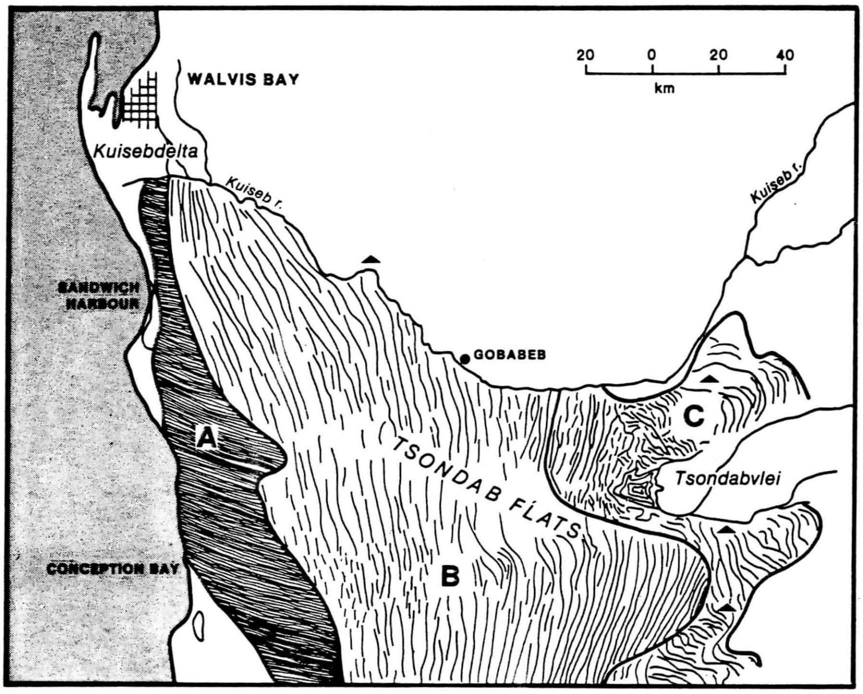

Figure 7. The dune Namib zones: A, coastal and barchan dunes; B. linear seif dunes; C. complex eastern dunes *(after Barnard, 1972).*

TABLE 3

Namib dune morphology *(after Barnard,* 1972).

	Coastal Dunes	Longitudinal Dunes	Inland multicyclic dunes
E-W Width of Belt (km)	10-15	< 60	< 40
Trend	NW-SE	N-S	NNW-SSE dominant also curved
Spacing (m)	100-400	1000-1500	100-200
Height (m)	< 100	60-100	20-30
Steep face	NE	W (E)	Convex to west
Activity	Extends measurably	(Stationary extending (N only tops move	W and WSW slowly
Secondary dunes	Barchans where free sand	(NE cross dunes (E side dunes	Localised dunes round inselbergs

Linear, 50 km long, *seif* dunes rise to heights of about 100 m above gravel plains. They have a wave length of 1,5 to 2 km and are approximately 0,5 km wide at the base. Their crests are often knife-edged when active; debased seif dunes, such as those of the Kalahari, are lower and exhibit few active crests. The Namib dunes advance slowly northwards and spill into the Kuiseb valley whence the sand is washed away. For this reason the dunes stop abruptly along the Kuiseb river (Fig. 8). The present wind regimes at Gobabeb suggest that these self dunes are no longer forming. They can still be modified by the present winds but appear to be relict from a past period of stronger wind regimes (Besler, 1976).

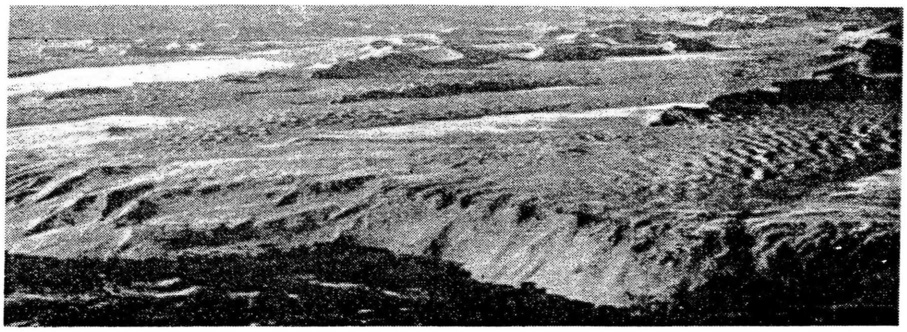

Figure 8. Seif dunes terminating at the Kuiseb river near Homeb. Note the riverine woodland in the valley floor.

Barchan dunes are crescent shaped. They form in areas of lesser sand volume as individual entities under a constant wind regime. They are much smaller than seif dunes, some 30 m from plain to crest and 40 m from horn to horn. Barchan-like forms may be associated with the flanks of linear seif dunes, with occasional cross valley dunes or form on coastal flats. The respective sizes of these two basic dune types and the volume of sand involved, suggest that the textbook hypothesis that seif dunes form from the coalescence of barchans, is unlikely.

Nearer the coast, dunes transverse to the dominant southwesterly winds develop from beach sand blown inland. Such transverse dunes are also linear but are aligned at right angles to the wind direction, and advance rapidly along their extended front.

Complex and tangled dune systems, often only with active crests, are found along the inner Namib margin. It seems probable that multicyclic development, is sufficient to explain the lack of clear dune pattern in this area. The configuration suggests the influence of periods of stabilisation with partial vegetation cover and the occurrence of blow outs.

Complications to arid processes

Although the Namib is probably the oldest desert in the world (Seely, 1976) even it was affected to some degree by Quaternary climatic fluctuations when wetter periods alternated with periods perhaps more arid than now. The integrated wadi system of the Kalahari and the formerly more extensive courses of the Tsondab and Tsauchab rivers marked now only by disturbed dune patterns and outlying silt beds are relict from such wetter periods (Seely and Sandelowsky, 1974) (Fig. 9).

Most of the valleys of the Namib preserve calcretised terrace deposits. These were formed during past periods of greater discharge resultant from

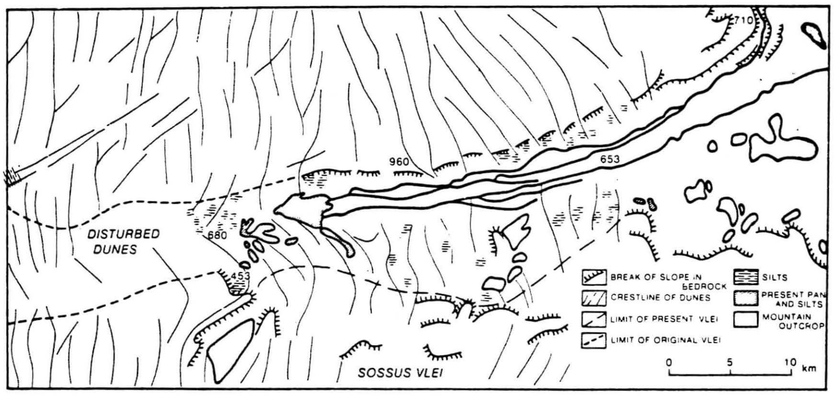

Figure 9: Disturbed dune pattern west of Sossus Vlei, indicating the former continuation of the Tsauchab river whose valley is incised into sandstone concealed by dunes.

higher rainfall on the inland plateaux. They are not characteristic of arid processes although now found within a desert environment.

Other manifestations of fluvial process may however be an essential component of arid landform process. Long-return rainfall events which have occurrence probabilities (return periods) of 50,100 or even 200 years, bring torrential rain. Runoff ensues and wadis flow with unaccustomed energy. Incision and deposition occur. Heavy rains totalling 75 mm over a three day period caused the Gobabeb side wadi to discharge in January 1976. Incision to depths of over 1 m occurred during a mere 13 hour discharge period (Marker, 1977). Such long return events may be of much greater significance for landform evolution in arid areas than has previously been considered. They cannot therefore be ignored.

Summary

Arid landscapes are of prime significance in southern African geomorphology. Their landforms have developed on stable shield areas over an extremely long period of aridity. Chemical weathering and water action are significant. Rocky and stony landform assemblages predominate, with structural control as the key for their explanation. The role of wind has been placed in perspective to emphasise the limited extent of dune areas and deliberate emphasis has been placed on macro-scale landforms and their characteristics.

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