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SPATIAL VARIATIONS IN LINEAR DUNE MORPHOLOGY AND SEDIMENTS IN THE NAMIB SAND SEA

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SUMMARY

Spatial variations in dune height and spacing and in the grain size and sorting parameters of dune crest sands suggest that the Namib sand sea has accumulated principally by the movement of sands from southern and western coastal source areas to central and northern areas of net sand accumulation. This model appears to be consistent with the available wind data and agrees with existing hypotheses of sand sea formation.

INTRODUCTION

Linear dunes are the most widespread of all dune types, and cover approximately 70 % of the area of the major sand seas in Africa, Arabia and Australia. Despite their sedimentary and environmental importance, linear dunes have been infrequently studied, and there are no previous detailed investigations of large complex dunes of the type which dominate the Namib sand sea. A knowledge of their composition and morphology is thus central to an understanding of the ways in which the sand sea accumulated.

Studies of linear dunes at 16 sites in the Namib sand sea (Figure 1) have provided a spatial view of the variability in their morphology and composition. This has pointed to important relationships between their morphometric characteristics and suggested a new model for the accumulation of the Namib sand sea. This paper presents a preliminary account of these investigations.

SPATIAL VARIABILITY IN LINEAR DUNE MORPHOLOGY

Morphometric characteristics of the linear dunes have been described in detail by Lancaster (1981a), and are summarised in Figure 2. Most dunes are 50-150 m high, 500-800 m wide at the base, and have a crest to crest spacing of 1 500-2 500 m. In addition small secondary barchanoid dunes with a spacing

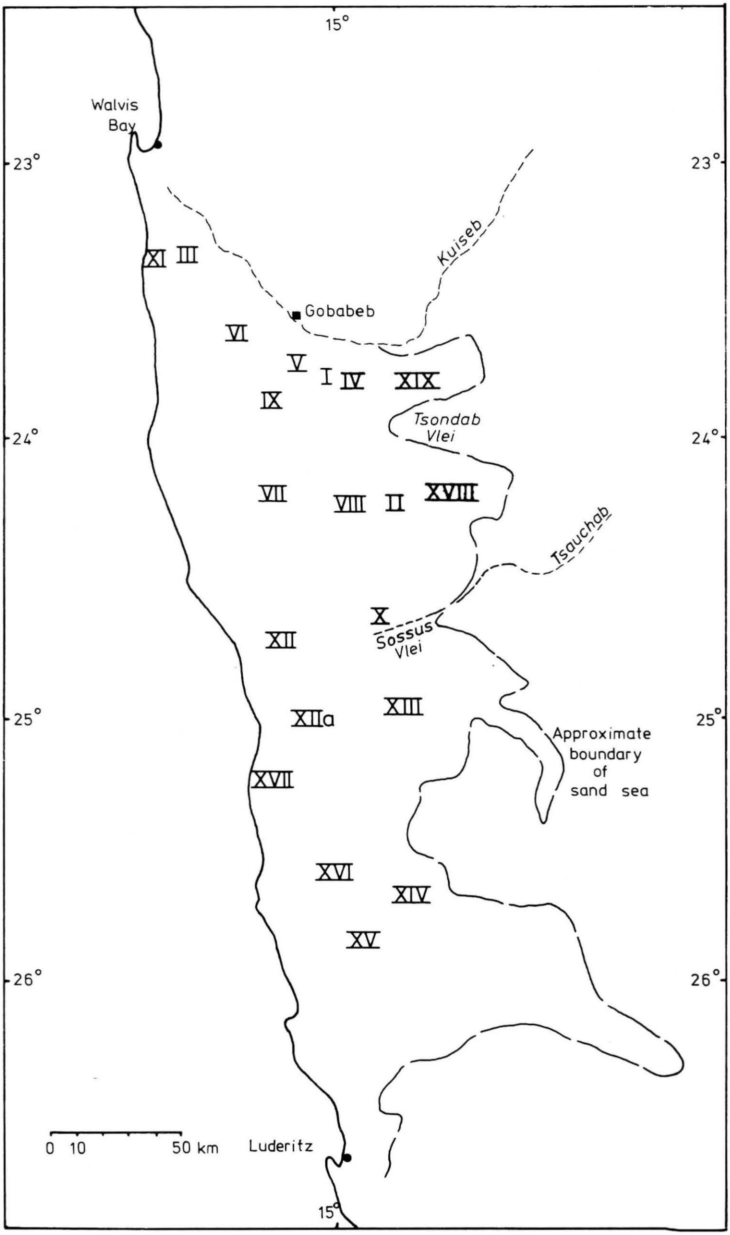

Figure 1. Location map of sites at which linear dunes were investegated.
N.B. No linear dunes at sites IX, XI and XVI.

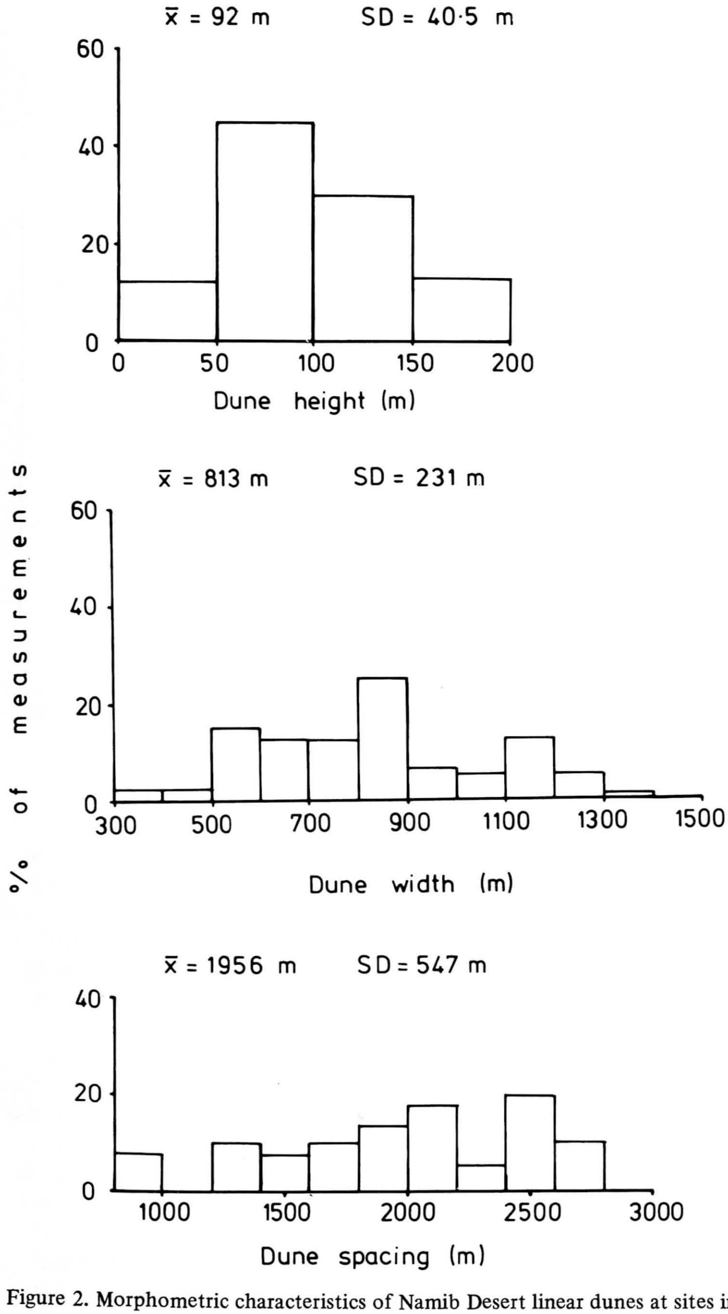

Figure 2. Morphometric characteristics of Namib Desert linear dunes at sites investigated.

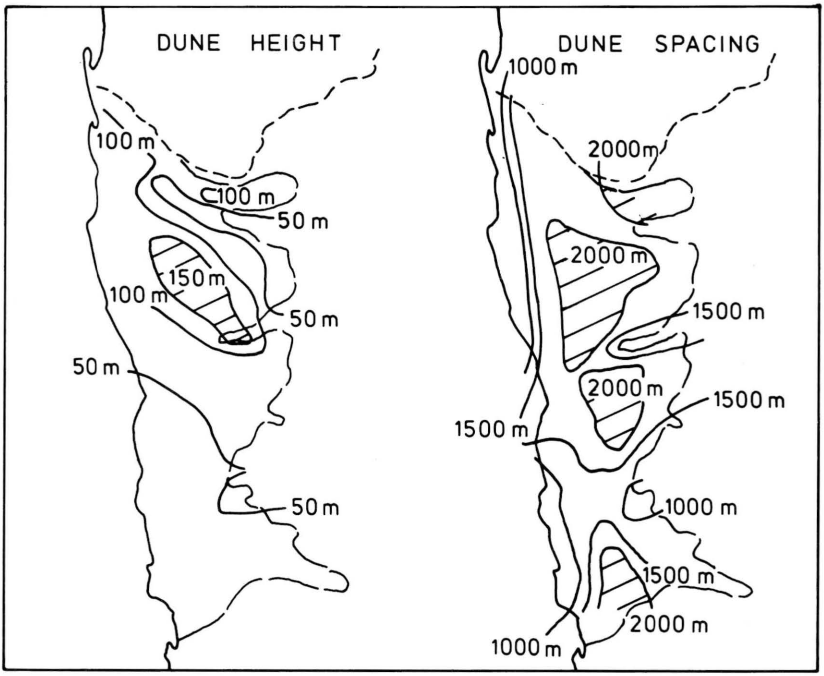

Figure 3. Spatial variations in dune height and spacing in the Namib sand sea. Dune height distribution extrapolated from measurements at sites shown in Figure 1. Dune spacings measured from aerial photographs.

of 60-150 m frequently occur on the east flanks of the main linear dunes, forming a hierarchy of dune spacings. Figure 3 shows that linear dune height and spacing vary systematically through the sand sea. Dunes are most widely spaced (>2 000 m apart) in central areas, and locally in the extreme northeast and south of the sand sea. A similar pattern of dune heights is evident, with dunes over 150 m high being concentrated in central areas, and progressively lower dunes occurring towards the margins of the sand sea. Over wide areas of the southern parts of the sand sea, dunes are less than 50 m high.

The apparent relationship between dune height and spacing is borne out by Figure 4, which demonstrates that they are statistically significantly correlated ($r = 0{,}59$ significant at the 95 % level). Similar relationships between the height and spacing of linear dunes have been observed by Twidale (1972) in the Simpson Desert, Australia, and by Grove (1969) in the Kalahari. Breed & Grow (1979) found a good correlation between dune width and spacing on a world wide sample of linear dunes. As dune width and height are correlated (Lancaster 1981a), one would expect a similarly good relationship between dune height and spacing. This suggests that it is a universal property of linear

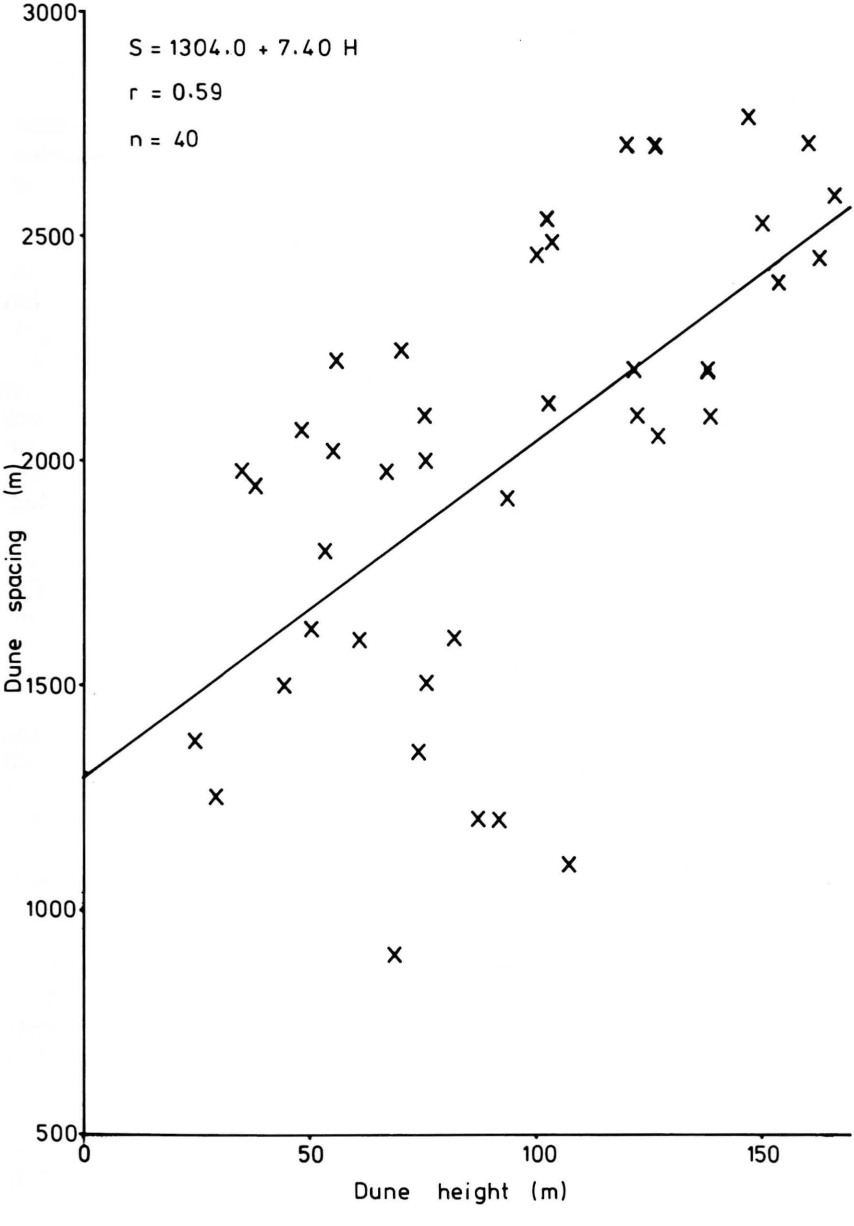

Figure 4. Relationship between dune height and spacing at sites investigated (mean values for each site).

dunes, and probably also of transverse dunes, and implies some overall control of dune morphology.

Studies of internal structures (McKee & Tibbitts 1964), wind regimes (Fryberger & Dean 1979), and winds and sand movements on individual dunes (Tsoar 1978) all support the view that a bidirectional wind regime, with sand moving winds from directions less than 180° apart, is necessary for the formation of linear dunes. Such conditions appear to be satisfied in the Namib sand sea.

The spacing of linear dunes is therefore probably related to the scale of turbulence created in winds as they cross the dunes at an acute angle. It is not a true separation distance, as suggested by Tsoar (1978). The downwind effect of artificial obstacles is limited to a distance which is 12-15 times their height (Oke 1978) but the dune height/spacing ratio in the Namib sand sea is 1:20. Further, as winds frequently cross the dunes at an angle of 30-45°, the effective height/spacing ratio along the wind direction is in the order of 1:40. However, it is possible that wide obstructions may have a greater downwind effect than narrow ones which have mostly been studied. Until more is known about the movements of winds over groups of dunes, this question will remain unsolved.

If dune height appears to control dune spacing, then what may control dune height? The availability of sand is clearly a limiting factor of dune size. More important is the ratio between sand availability and wind energy, or the degree to which sand flow is saturated. Models of sand sea formation (Wilson 1971, Fryberger & Ahlbrandt 1979) show that sand tends to move from areas of higher wind energy and constant direction to areas of lower wind energy and contrary directions. It will tend to accumulate in the latter areas, and dunes grow to a size controlled by the erosion-deposition balance on the dune itself. Once dunes have grown to this dynamic equilibrium size, then they will pass on more sand to the growing dunes downwind. So wind size may be a function of position in a sand sea, relative to the relationship between sand availability and wind energy, as has been hinted at by Mainguet and Callot (1974). As dunes take some time to reach an equilibrium, height, dune size may be also partly a function of age.

In the Namib sand sea, there is a clear decrease in available wind energy from south to north, accompanied by a progressive increase in directional variability of the winds (Table 1). Similar changes also occur from west to east. Thus sand in the Namib appears to move from southern and south western areas to accumulate in the northern and central parts of the sand sea. Low

Table 1. Wind regime changes in the Namib.

Locality	% of time wind able to move sand	% of winds from opposing directions
Kolmanskop (Lüderitz)	65	12
Narabeb	30	72
Gobabeb	25	75

dunes in southern areas result from a high energy wind regime but low sand availability. The high dunes in the centre are at, or close to, equilibrium size in a low energy wind regime. Dunes in eastern and northern areas are lower because they are probably still growing.

SPATIAL VARIATIONS IN GRAIN SIZE AND SORTING

The grain size characteristics of linear dunes in the northern parts of the sand sea have been analysed by Lancaster (1981b). Extension of the sampling programme to cover the whole sand sea has established that all linear dunes have a similar composition with two populations of sand: a well sorted, fine crest, slip face and upper west slope group; and a moderately sorted, to poorly sorted dune base or plinth group.

In addition the grain size and sotting character of the crest sands varies systematically through the sand sea (Figure 5). Rather finer sands (mean grain size >2,50 phi, 0,18 mm) are found in western areas; whilst coarser sands (mean grain size <2,30 phi, 0,20 mm) occur in eastern and southern areas. The pattern of sorting values, as measured by phi standard deviations, shows that sands tend to be very well sorted in the east ($\sigma_1 < 0{,}30$) and moderately well sorted in the west ($\sigma_1 > 0{,}40$). Patterns in skewness values are less clear, but show an area of strongly positive, or fine, skewed sands in the east. Transformed kurtosis values (the ratio of sorting between the centre and tail of the distribution) show areas of lower kurtosis to the west and south.

Examination of these patterns suggests that there are three main groups of sand in the Namib sand sea: a finer, moderately to well sorted, low kurtosis group to the west; a coarse moderately well sorted group to the south; and a coarser, but very well sorted and locally strongly fine skewed group to the east. They may be related to different sources for the sand. The first group is probably derived from the Conception-Meob area; the second from the Elizabeth-Chamais Bay areas south of Luderitz; and the third may be derived from the consolidated sands in the east (the Namib sandstone of Besler & Marker 1979).

Currently the Elizabeth-Chamais Bay area is an important source for sand transported into the sand sea (Rogers 1973). But much of the sand deflated from the beaches appears to be very fine (average mean grain size 2,55-3,00 phi, 0,17-0,13 mm). Thus the occurrence of coarser sands in the southern parts of the sand sea may reflect a macro scale operation of the grain size and sorting processes on individual dunes, and the sands may be coarser because the more mobile fine fractions have moved on towards the north.

Today, the Conception-Meob area is one where sand transport from beaches to dunes takes place. Formerly, in periods of lower sea levels, it was probably more important. Bathymetric data (Rogers & Bremner 1973) indicate that with sea levels 20-40 m below those of the present, beaches would have been at right angles to onshore southwesterly winds, favouring large scale deflation and movement of sand inland.

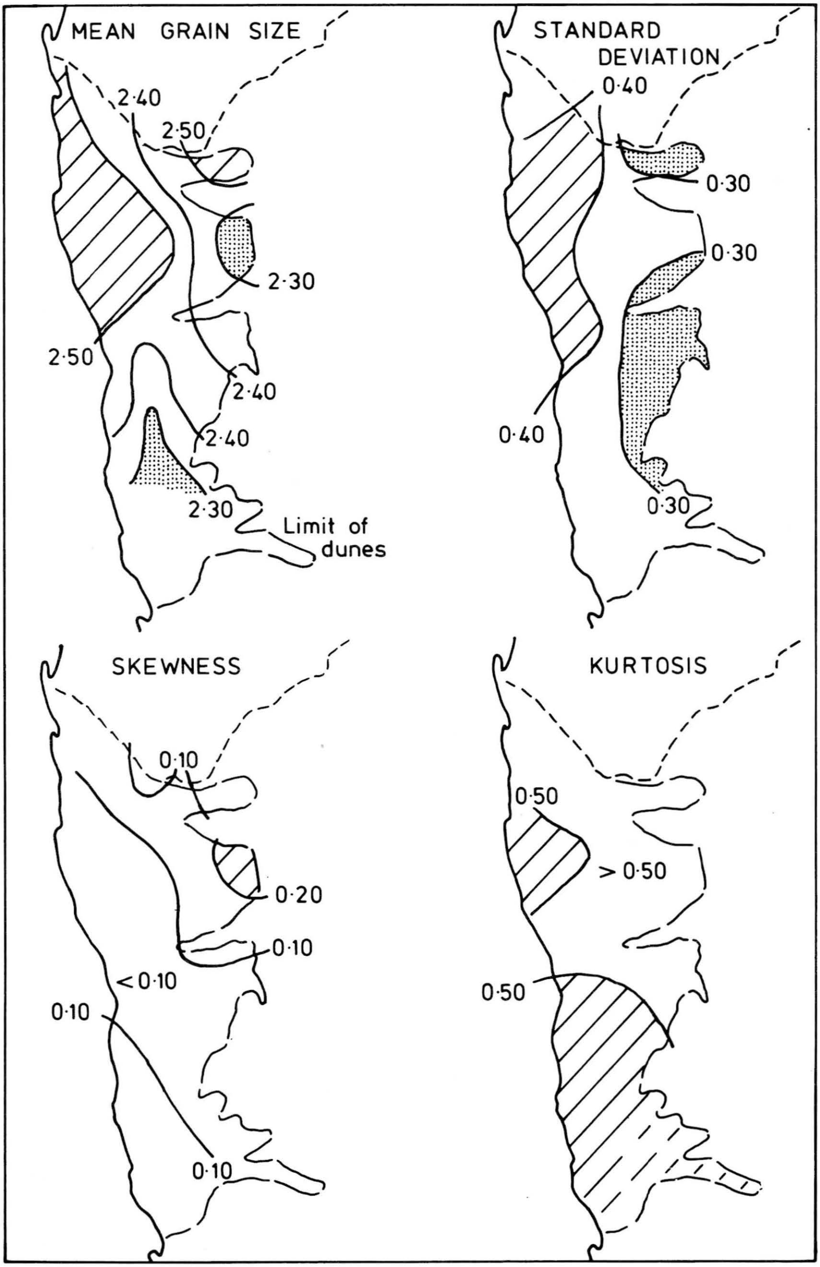

Figure 5. Spatial variations in grain size and sorting parameters of linear dune crest sands. Phi units are used.

DISCUSSION

Besler (1976, 1977) argued that the linear dunes of the Namib sand sea were formed from underlying sands by paired helical vortices in a period of stronger winds during the last Glacial maximum. The major source of the sand was fluvial and only the coastal transverse dunes were derived from a coastal source. Analyses of spatial variations in linear dune morphology and sediments suggest that such a model is not appropiate. Patterns of dune size and grain size and sorting parameters indicate that the Namib sand sea has formed by the movement of sands from southern and western sources towards areas of accumulation in central and northern parts of the sand sea. This model is also consistent with the available wind data. Thus the areas of finest sand are also those with the largest dunes and the least net wind energy. Away from these centres of net accumulation of sand, particularly along the direction of sand transport, the sand becomes coarser and less well sorted and dunes become lower.

It is probable that coastal areas have always been major sources of sand for dunes in the Namib, certainly since the development of the present climatic patterns in the late Tertiary. Potentially favourable conditions for dune formation are created by the existence of a major river with a high sediment load, the Orange, to the south and dominantly onshore south and south southwesterly winds which have promoted vigorous transport of sand along the coast and inland into dunes (Rogers 1977). The exact location and degree of development of dunes has probably varied considerably over time, in response to changes in the position and strength of circulation patterns and the configuration of the coastline as sea levels have changed.

The development of the Namib sand sea as we know it today probably dates from the period following the last major incision of the Kuiseb and Tsondab rivers, but it is difficult to make an accurate assessment of the age of the present dune patterns. Preliminary estimates based on the amount of sand now entering the Namib sand sea near Luderitz suggest a minimum age of 50 000 years, and a more probable age of the order of 100 000 years.

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REFERENCES

Besler, H. 1976. Wasserüberformte Dünen als Glied in der Landschaftgenese der Namib. *Baseler Afrika Bibliogr.* 15:83-106.

Besler, H. 1977. Untersuchungen in der Dünen Namib (Südwestafrika). *J. S. W. Africa Sci. Soc.* 31:33-64.

Besler, H. & M.E.Marker 1979. Namib sandstone: a distinct lithological unit. *Transact., Geolog. Soc. S.Africa* 82:155-160.
Breed, C.S. & T.Grow 1979. Morphology and distribution of dunes in sand seas observed by remote sensing. In: E.D.McKee (ed.), *A Study of Global Sand Seas.* US Geol. Survey Prof. Paper 1952:253-304.
Fryberger, S.G. & T.S.Ahlbrandt 1979. Mechanisms for the formation of eolian sand seas. *Zeitschr. für Geomorph.* NF23:440-460.
Fryberger, S.G. & G.Dean 1979. Dune forms and wind regime. In: E.D.McKee (ed.), *A Study of Global Sand Seas.* US Geol. Survey Prof. Paper 1052:137-170.
Grove, A.T. 1969. Landforms and climatic change in the Kalahari and Ngamiland. *Geograph. J.* 135:191-212.
Lancaster, N. 1981a. Aspects of the morphometry of Namib Desert linear dunes. *S.Afr. J. Science* (in press).
Lancaster, N. 1981b. Grain size characteristics of Namib Desert linear dunes. *Sedimentology* 28:115-122.
McKee, E.D. & G.C.Tibbitts 1964. Primary structures of a seif dune and associated deposits in Libya. *J. Sedim. Petrology* 34:5-17.
Mainguet, M. & Y.Callot 1974. Airphoto study of typology and interrelations between the texture and structure of dune patterns in the Fachi-Bilma erg, Sahara. *Zeitsch. für Geomorph.* Suppl. Bd.20:62-68.
Oke, T.R. 1978. *Boundary Layer Climates,* Methuen, London. 372pp.
Rogers, J. 1977. *Sedimentation on the continental margins off the Orange river and the Namib Desert.* Joint Geol. Survey/Univ. Cape Town Marine Geosci. Group, Bull. 7: 162pp.
Rogers, J. & J.M.Bremner 1973. *Bathymetry of the Lüderitz-Walvis Continental margin.* Joint Geol. Survey/Univ. Cape Town Marine Geol. Progr., Techn. Report 5:7-9.
Tsoar, H. 1978. *The Dynamics of Longitudinal Dunes.* Final Techn. Rept. European Res. Off., US Army. 171pp.
Twidale, C.R. 1972. Evolution of sand dunes in the Simpson Desert, Central Australia. *Transact., Inst. Brit. Geographers* 56:77-110.
Wilson, I.G. 1971. Desert sandflow basins and a model for the development of ergs. *Geogr. J.* 137:180-197.