Temporal trends in grain-size measures on a linear sand dune

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ABSTRACT

Within aeolian dune systems spatial patterns of grain-size variation have been recognized, but little has been said about temporal changes. Increasingly it is becoming clear that linear dunes are associated with bi-directional wind regimes which are often seasonal. In the Namib Sand Sea, where linear dunes are aligned roughly north–south, winds blow from the west in summer and from the east in winter. In response to this regime, sand is eroded from the west slopes and deposited on the east slopes in summer, and eroded from the east slopes and deposited on the west slopes in winter. Preliminary evidence from a study of a single Namib linear dune reported here confirms that this seasonal aeolian regime induces seasonal responses in some grain-size measurements due to the dynamics of sand transport on the dune, the characteristics of the sand source immediately upwind of the sample point and the nature of the deposit. Thus, time of sampling is crucial to the results obtained.

INTRODUCTION

Considerable effort has been expended in investigating patterns of grain-size parameters related to variations of process, and in debating their significance particularly in discriminating the sediments of fluvial, marine and aeolian environments (e.g. Friedman, 1961, 1979; Greenwood, 1969). Within aeolian dune systems spatial patterns of grain-size have been recognized (e.g. Lancaster, 1981, 1986; Watson, 1986), but little has been said about temporal changes.

Elsewhere I have reported spatial variations in grain-size within a linear dune system, and commented on their process implications (Livingstone, 1987). This note reports temporal changes in grain-size characteristics on a linear sand dune. A linear dune is defined as one in which net sand transport is parallel to the crest, and in which the dune's long-axis length is many times greater than its width. The changes documented here are a response to a seasonally bi-directional wind regime. The implication is that time as well as place of sampling must be noted.

METHOD

The linear dune on which sampling for this study took place lies near the northern fringe of the Namib Sand

Sea in Namibia, southern Africa (23°34′S 15°03′E). At the study site the crest of the dune is aligned roughly N–S, and the dune is 350 m wide and 50 m high (Fig. 1).

Wind directions here are seasonally bi-modal (Lancaster, Lancaster & Seely, 1984). In summer, winds are predominantly of high frequency and low intensity from the west. In winter, stronger but less frequent winds blow from the east.

The dynamic response of the dune to this wind regime is for wind speeds on windward slopes to increase from the interdune corridor to the crest thereby causing erosion, and for wind speeds on lee slopes to decrease causing deposition. Sand is thus eroded from the west flank of the dune and deposited on the east side of the crest in summer, while the reverse—erosion on the east flank and deposition on the west—occurs in winter. Consequently, the dune's crest moves approximately 15 m laterally in one year, returning at the end of a year's cycle to its position at the beginning (Livingstone, 1986, 1989).

The working hypothesis for a study such as this can be formulated along the following lines: (i) grain-size is controlled, at least in part, by process; (ii) the pattern of process (aeolian erosion and deposition) on the dunes of the Namib Sand Sea is seasonal; and, therefore, (iii) we might reasonably expect some
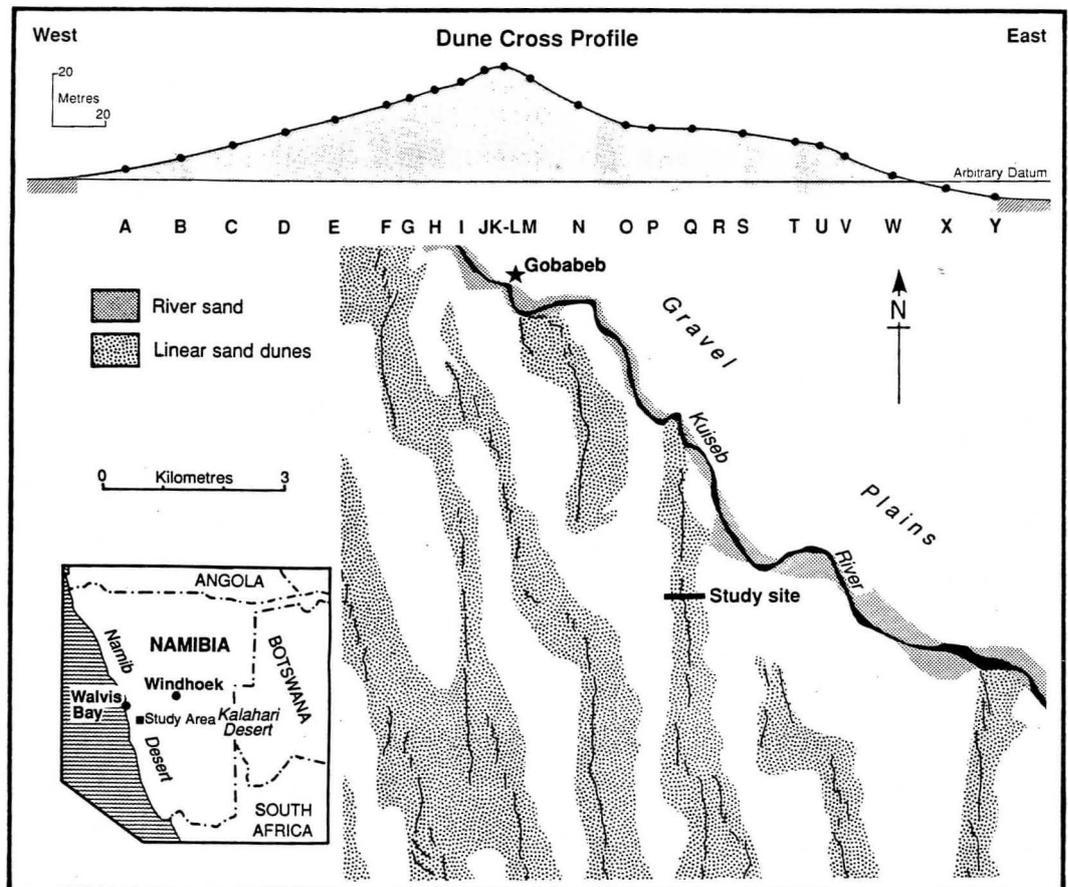
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Fig. 1. Map showing the location of the study site, and cross profile of the study dune showing the sample points A to Y. The survey was made in November 1981 showing the crest position at the end of winter. At the end of summer in April the crest is around 15 m east of the position shown here, close to post M.

response of grain-size parameters to temporal (seasonal) process variations.

To test this, samples were collected by scraping sand from the surface at 25 points across the dune's cross-profile at monthly intervals between April 1981 and April 1982. The sample points, which were marked by steel posts lettered A to Y, were spaced every 20 m on the lower slopes and every 10 m around the dune crest (Fig. 1). The samples were split, and part of the sample sieved at half-phi size intervals in the range +4·0 − +0·5 phi (63–707 μm). Particles finer than +4·0 phi were collected in a pan. The sand retained in each sieve was weighed, and this information plotted as a cumulative frequency curve on arithmetic probability paper. From these graphical

representations of the data percentile values were extracted, and grain-size parameters (mean, standard deviation, skewness and kurtosis) calculated using the formulae of Folk & Ward (1957). The results of this and a wider grain-size study are reported in full in Livingstone (1985).

The pattern of grain-size variations over linear dune cross-profiles in this part of the Namib Sand Sea is reported in studies by Besler (1980), Lancaster (1983), Livingstone (1987) and Watson (1986). Progressively finer, better sorted and less skewed sands are found towards the crests of Namib dunes, although these patterns are not invariably repeated on linear dunes in other sand seas (Livingstone, 1987). The wind appears preferentially to carry grains of diameter

+2·5 − +2·0 phi (177–250 µm). Coarser grains, predominantly moved by creep, cannot ascend dune slopes. Elsewhere, Binda & Hildred (1973) have interpreted bimodal sands lacking the +2·5 − +2·0 phi size range as a lag left after the aeolian removal of the intermediate sizes. In the Namib Sand Sea ranges of mean grain-sizes are very limited, and standard deviation values from this study of between 0·15 and 0·61 indicate that the sands are very well sorted. This may well be related to the antiquity of the sand sea, and the great distance that the sand has been transported by aeolian processes from its source which is to the south and west (Lancaster, 1985; Lancaster & Ollier, 1983). As Bagnold (1941), McArthur (1987) and others have noted, slip face (encroachment) sand populations tend to have moderate negative (fine) skewness as coarser grains are removed and rolled to the base of the slip face by avalanching.

INDICATIONS OF TEMPORAL TRENDS

Without making any assumptions about the nature of the changes, it is possible to use a statistical test to show that grain-size parameters do indeed vary with time. Table 1 presents the results of month-by-month comparison of mean grain-size using the Wilcoxon Paired Sample Test. In this non-parametric statistical test the samples for each point for one month (a total of 25 points A–Y) are compared with their counterparts taken at the same points in another month by ranking the differences between pairs of data. The test has been carried out 78 times to give the matrix of results presented as Table 1.

From the table it is clear that samples taken in the summer months from January to April are statistically significantly different from those taken in the winter months from June to September. The time of sampling affects the results obtained. Skewness values give statistically significant differences between September and December, January, February and April. Standard deviation (sorting) values do not give statistically significant time-based changes when using this test.

Having ascertained that there is a seasonal variation in at least two of the grain-size parameters, it would clearly be of value to elucidate the nature of that change. By plotting mean grain-sizes for two end-of-season months (April at the end of summer and September at the end of winter) on one dune flank, it is possible to show that sands become significantly finer, particularly on the lower slopes during winter

Table 1. Month-by-month comparison of mean grain-sizes using Wilcoxon Paired Samples Test ($n = 25$). (Note that there are two Aprils, 1981 and 1982.)

| Months	A	M	J	J	A	S	O	N	D	J	F	M	A
April 1981	–												
May	O	–											
June	×	O	–										
July	O	O	O	–									
August	×	O	O	O	–								
September	×	O	O	O	O	–							
October	O	O	O	O	O	O	–						
November	O	O	O	O	O	O	O	–					
December	O	O	O	O	O	O	O	O	–				
January 1982	O	O	×	×	×	×	×	O	O	–			
February	O	O	×	×	×	×	×	O	O	O	–		
March	O	O	×	×	×	×	×	O	O	O	O	–	
April 1982	O	O	×	×	×	×	O	O	O	O	O	O	–

× Statistically significant difference at 0·01 level of probability; O No statistically significant difference

(Fig. 2). This trend can also be illustrated by following changes through the year at one point on the dune (Fig. 3). At 'F' at the mid-point on the west slope a seasonal response of mean grain-size and skewness is clear. Finer sands, which are also less positively skewed, are found here at the end of a winter season (September), while coarser, more positively skewed sand is found at 'F' during summer (December–April). The pattern of standard deviation (sorting) is less clear, although it is possible that the trend in Fig. 3 suggests that sorting is poorest in periods of transition of the other two parameters, and best when mean and skewness have reached maximum or minimum values.

The trends illustrated in Figs 2 and 3 are not, however, universally repeated. Patterns on the east flank of the dune do not show such clear, unequivocal seasonal responses, and at none of the other 24 sample points is the trend as clear as that at 'F'. Nevertheless, negative (fine) skewness is associated with slip faces, and apart from a single value of −0·08 recorded at point 'H' in January, all the other 10 negative skews recorded on the west slope of the study dune occurred in the winter months, five of these in September 1981 after predominantly strong easterly winds.

DISCUSSION

There is evidence from these and other data that several controls of size and sorting are responsible for the patterns of grain-size variation on linear dunes. There seems to be the overall control of the size of
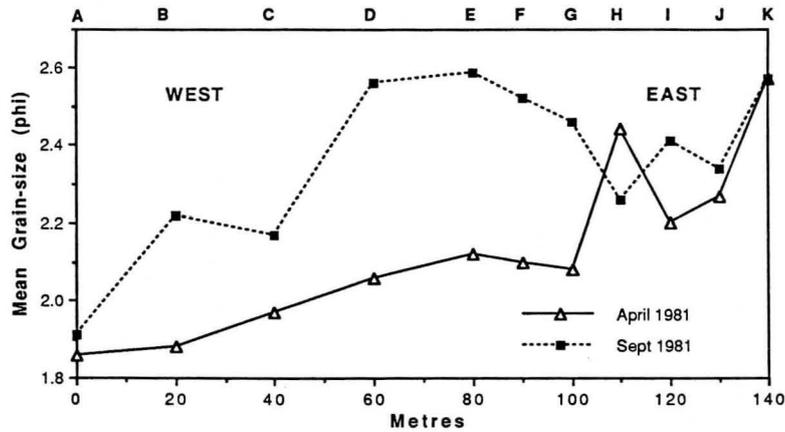
Fig. 2. Mean grain-size on the west slope of the study dune. April 1981 represents the end of a summer season of predominantly westerly winds blowing sand upslope from interdune to crest. September 1981 represents the end of a winter season of predominantly easterly winds blowing sand downslope from crest to interdune. Point 'A' is at the base of the dune and point 'K' at its crest.
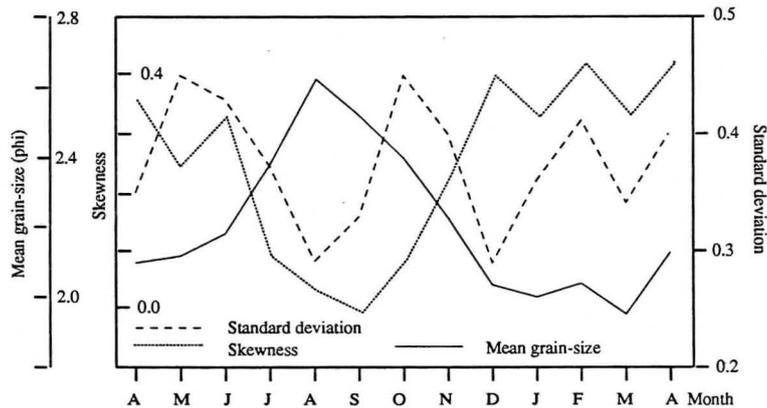
Fig. 3. Temporal variation of mean grain-size, standard deviation (sorting) and skewness at point 'F' (located on the cross profile in Fig. 1).

sand preferentially moved by the wind which is between +2·5 and +2·0 phi (177–250 μm). Consequently, dune crest sands in the northern Namib Sand Sea are always finer, better sorted, and less positively (coarse) skewed than sands from the interdune corridors and dune bases (Besler, 1980; Lancaster, 1983; Livingstone, 1987; Watson, 1986).

Superimposed on this general pattern are other subsidiary controls of grain-size. McLaren & Bowles (1985) argued recently that any sediment being transported is always finer and more negatively skewed than its source, and therefore that the resulting

lag deposit must be coarser and more positively skewed than the original source sediment. Sorting depends on the initial sediment distribution, but eventually both the lag and the transported sand must be better sorted than the source sediment. The results presented here provide some support for the model of McLaren & Bowles. In summer, when the winds are from the west, the dune's west slope becomes the windward slope and is subject to erosion. Sand being transported from W to E is entrained here to be deposited on the east slope. Conversely, in the easterly winds of winter, sand transport is E to W, and sand is

deposited on the west slope. Thus at the end of winter (September), sands on the west slope in a zone of net deposition are much finer than sands which are lags at the same points at the end of summer (April) (Fig. 2). The data from point 'F' (Fig. 3) also suggest that in the period when the sands are changing from deposit to lag or *vice versa*, represented by samples from May and October, sand populations are more poorly sorted than towards the end of seasons. The evidence suggests that lag sands are indeed coarser and more positively (coarse) skewed than the sands deposited downwind.

The nature of the source sand upwind of sample points also influences grain-size patterns. In summer, sand is moving from W to E, and the source of sand on the west slope of the dune is always the coarser sand from further down the slope. In winter, sand moves from E to W and therefore the source for the west slope is the finer sands of the crest. This may well compound the pattern described by McLaren & Bowles (1985).

Furthermore, slip-face sands have their own distinct grain-size distributions (McArthur, 1987), and in some cases the decreasing coarse skewness will be a consequence of sorting by the avalanching of slip faces.

CONCLUSION

Several different factors seem to be controlling the variability of sand grain populations on Namib linear dunes. There is an overall pattern, which has been widely reported, of finer, better-sorted, less skewed sand populations at the crest. Other factors are related to a seasonal switch of dominant wind direction. This switch changes the effective source of sand within the dune system, so that, for instance, on the west flank of the study dune, summer, westerly winds bring sand upslope from the coarser interdune deposits, while in winter, easterly winds bring finer sand from the crest. In addition, in summer, sand is being entrained from the west slope, while in winter, sand is deposited here. Thus samples from the west slope in summer represent a residual lag following erosion, but winter samples represent net deposition. Finally, the slip face also switches seasonally from one side of the crest to the other, and the negative (fine) skewness associated with slip-face deposits consequently demonstrates a seasonal pattern.

The evidence for temporal change in grain-size parameters is far from clear-cut, but there is sufficient preliminary evidence in this study to confirm that a seasonal, aeolian regime induces seasonal responses of grain-size characteristics. Until other studies provide more data on temporal change, the conclusion can be no more certain than that, on this particular dune, seasonal changes do occur in grain-size parameters in response to a seasonal wind regime. However, there is sufficient evidence that time of sampling will affect the result to justify further research.

ACKNOWLEDGMENTS

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