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SHORT COMMUNICATION

A TWENTY-ONE-YEAR RECORD OF SURFACE CHANGE ON A NAMIB LINEAR DUNE

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ABSTRACT

Repeated surveying of two sites on a Namib linear dune between 1980 and 2001 provides a 21-year record of dune surface change. The surveys confirm the view that the dunes are not inactive relics but are responding to the present-day wind regime. They also provide no evidence that the dunes are migrating laterally. Examination of wind data for the survey period provides some evidence that the form of the crest of the dunes is actively responding to the natural year-by-year climate variability, such that an increase in the frequency of easterly winds leads to the development of a double-crested form while fewer easterly winds lead to a single-crested form. Copyright © 2003 John Wiley & Sons, Ltd.

KEY WORDS: aeolian geomorphology; linear dune; Namib Desert; dune dynamics

INTRODUCTION

Considerable effort has rightly been expended in the past two or three decades on measuring the mechanisms responsible for sand transport on aeolian dunes (this work was recently reviewed by Wiggs (2001)). However, these process studies have necessarily often been short-term in nature and there are understandably rather fewer studies covering long-term dune movement. While studies of small-scale, short-term mechanisms are essential for understanding the processes by which geomorphological features change, these need to be allied to broader observations of landform development (cf. Harrison, 1999). There are a few reports of direct measurement of dune movement stretching over several years (these are summarized by Thomas (1992) and Cooke *et al.* (1993)). Those covering a decade or more have often involved surveys at the beginning and end of the study rather than a series of surveys throughout the period. Where long-term studies of dune movement do exist they are largely restricted to monitoring barchan dunes (e.g. Hastenrath, 1987; Haynes, 1989; Hesp and Hastings, 1998; Stokes *et al.*, 1999; Barnes, 2001).

This short communication reports survey data for the movement of a linear dune cross-profile in the Namib sand sea over the period from 1980 to 2001. Survey data from this site have already been reported (Livingstone, 1989, 1993): this paper is a progress report of a continuing long-term study. The site was initially surveyed in 1980 when a network of erosion pins was established. These were measured weekly for four years and some of the results of this work were reported by Livingstone (1989). Subsequent visits to the site provided a report of a decade of results (Livingstone, 1993). Since that report was published the site was visited again in 1993 and 2001 so that there is now a 21-year record of change on this dune.

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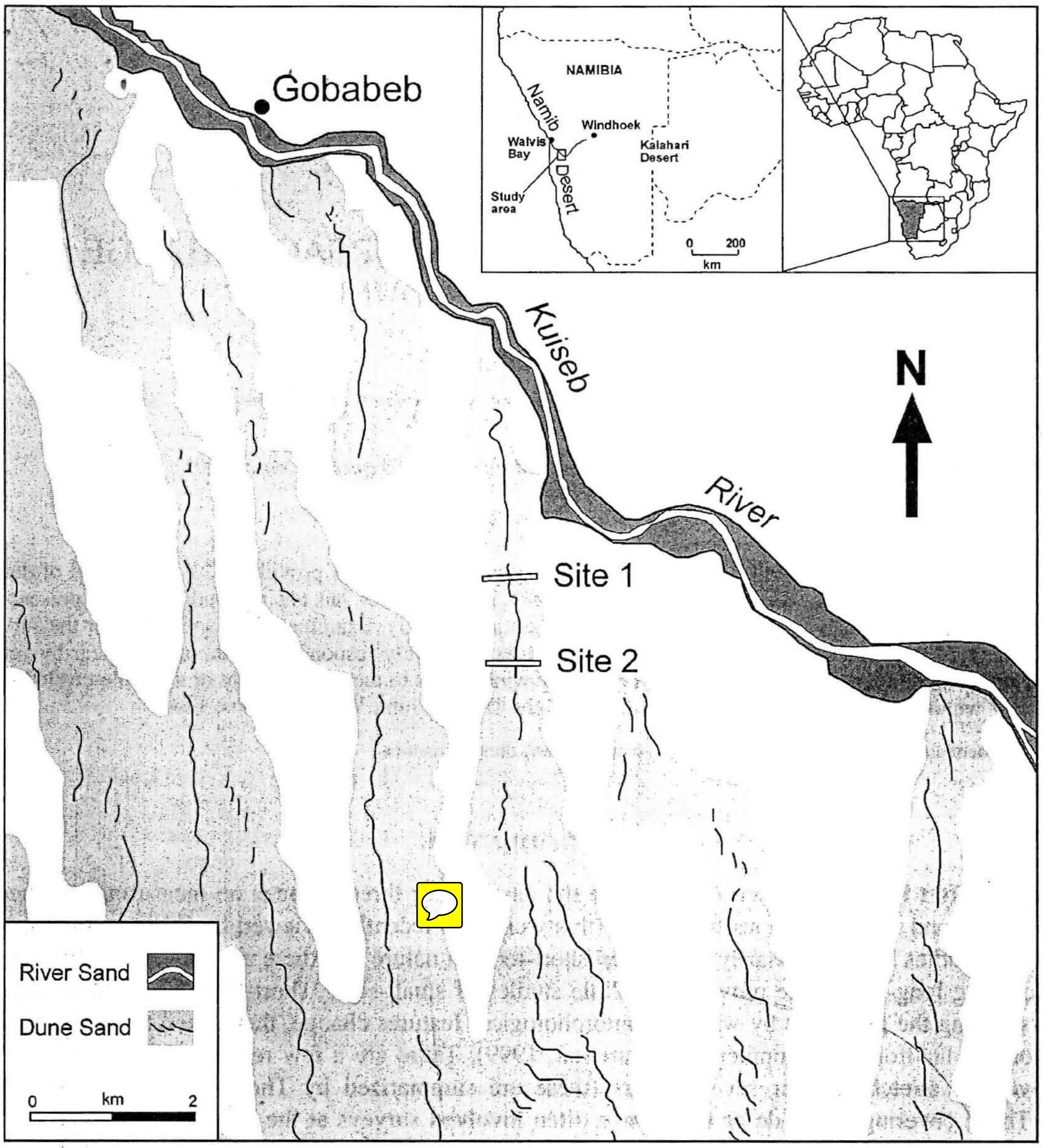

Figure 1. Location of the study sites in the northern Namib sand sea, Namibia

THE SURVEYS

The study site is on a linear dune in the Namib sand sea, Namibia, southern Africa (Figure 1). Large linear dunes dominate this part of the central Namib sand sea. At its northern fringe they are between 30 and 100 m high but further south they are often over 150 m high. In this paper data from two cross-profiles (sites 1 and 2), roughly 0·8 km apart, are reported. At site 1 the dune is approximately 50 m high and 350 m wide; at site 2 it is approximately 70 m high and 550 m wide. The dune was described in some detail in the previous reports (Livingstone, 1989, 1993).

Previous surveys have variously used theodolite, level-and-staff and clinometer-and-tape techniques. The survey in 2001 used a total station (theodolite plus electronic distance measurement linked to a data logger). As reported in 1993, a number of the erosion pins from the initial work in the early 1980s remain in place and provide fixed points so that each survey can be related to the others.

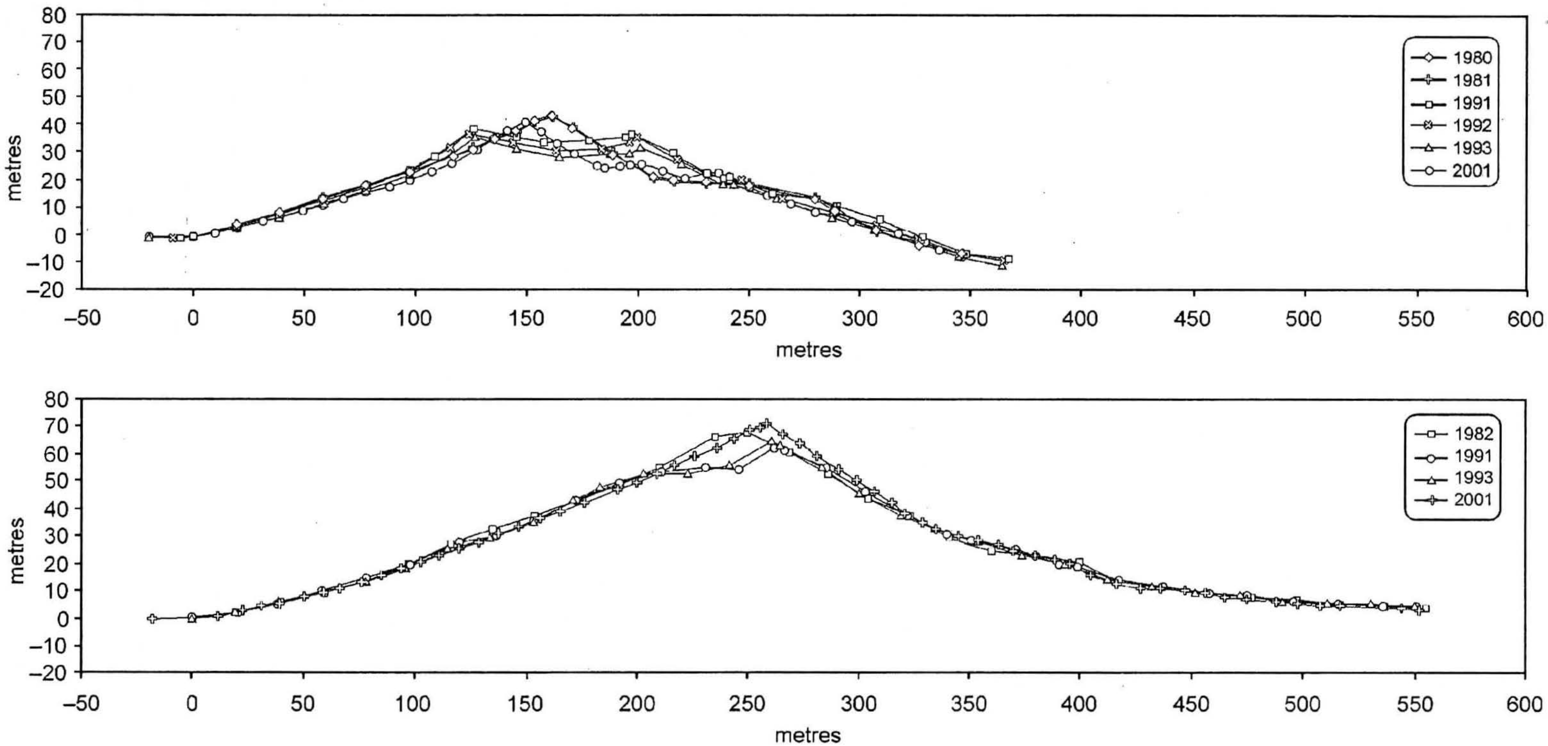

Figure 2. Cross-profiles for the two transect sites (top, site 1; bottom, site 2). Transects are aligned roughly west (left) to east (right); the dune long-profile runs roughly north–south

The survey data for the two transects are presented in Figure 2. Note that although measurements started at site 1 in October 1980, measurements at site 2 only commenced in August 1982. For both sites, the most recent survey was undertaken in October 2001.

In 1993 it was clear that at both sites during the previous decade the dune cross-profile had changed from single- to double-crested and the overall height of the dune had reduced. Since then both sites have continued to undergo considerable change. At both sites the dune has returned to a single-crested form and regained much of the early-1980s height. At site 1 the crest in 2001 was to the west of its position in 1980 while at site 2 it was to the east. For both sites it is very clear that the lower slopes of the dunes are remarkably stable while the upper slopes are far more active. It is now commonplace to suggest that the norm for linear dunes is for an active crest to rest on a more stable 'plinth' and these surveys confirm that normative model (e.g. Lancaster, 1995; Livingstone and Warren, 1996). This is clearly related to the speed-up of the wind that occurs as a result of compression of streamlines.

The question of whether these large Namib linear dunes are relics of either a windier or a drier Pleistocene was tackled by Livingstone (1993). Of course, 21 years is not long in the life of a large sand dune. The 'reconstitution period' for large dunes – the time taken for the dune to be built and therefore to respond to changes of wind regime – has been estimated as being of the order of 1–10 ka (Warren and Allison, 1998). None the less, the evidence presented here continues to support the view that substantial amounts of sand are moved on these dunes in current conditions year after year.

There has also been considerable debate about lateral movement of linear dunes (e.g. Hesp *et al.*, 1989; Nanson *et al.*, 1992; Rubin, 1990), fuelled most recently by the report of Bristow *et al.* (2000) of the internal structure of a linear dune immediately neighbouring the one used in the present study to the east. Bristow *et al.* (2000) provided ground-penetrating radar (GPR) images that showed evidence of lateral migration of the dunes. However, while some of their six cross-profiles showed predominant dips to the east (profiles 2, 3 and 6), from which they inferred west-to-east migration, profiles 4 and 5 showed dips to the west indicative of east-to-west migration. As all these profiles were from the extending tip of the dune and were never more than 20 m high, they are most readily inferred as the product of the migration of sinuous elements of an extending dune rather than progressive lateral migration. The data from the present study provide no evidence to support the sort of progressive lateral migration that might be inferred from steeply dipping beds.

A RESPONSE TO WIND REGIME VARIABILITY

The changes of form apparent in the series of surveys from 1980 to 2001 – the switch from a single crest to a double crest and back to single crest – could be attributed to two types of mechanism. One explanation would be that the single- and double-crested forms co-exist at different points on a linear dune crest. The surveys are therefore merely reporting the migration of these features along the dune. While it is indeed the case that both forms do occur at different points along the dune at the same time, it would be extremely coincidental if both transect sites underwent the same pattern of change at the same time, as is suggested by Figure 2.

A second possibility is that the dune is responding to the natural variability of the wind climate. Linear dunes exist in wind regimes where winds blow from different directions at different times: most simply, these regimes are either seasonally or diurnally bimodal. In the northern Namib sand sea, winds blow from a number of directions during the course of a year (e.g. Lancaster, 1989; Livingstone, 1989). The major sand-moving winds blow from the southwest in summer (particularly October to December) and from the east in winter (peaking in July). The easterly winds tend to be high magnitude/low frequency events while the southwesterly winds are more moderate but more persistent. The dunes respond to this regime by extending slowly northwards towards the Kuiseb River while the crests migrate seasonally west-to-east in summer and east-to-west in winter (Livingstone, 1989).

It is possible, therefore, that the change in crestal form found from the surveys is a response to variability in wind regime. Wind data for the survey period (1980–2001) are available from the meteorological station at Gobabeb which is approximately 8 km northwest of the survey sites (Figure 1). Unfortunately, the dataset suffers from numerous gaps so that it is not possible to calculate sand drift potentials year-by-year. However, on the assumption that gaps in the dataset occur randomly (i.e. they do not occur preferentially during episodes of wind

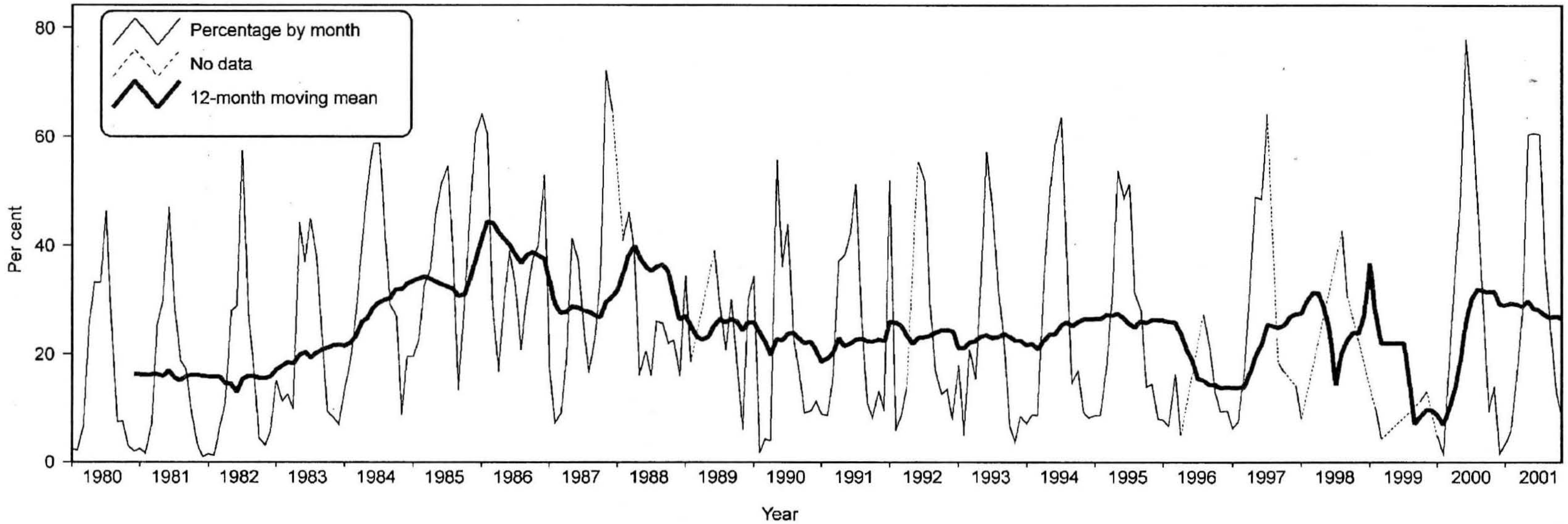

Figure 3. Percentage of winds recorded blowing from the east (i.e. between north-northeast and south-southeast, inclusive). Wind data are recorded hourly at the meteorological station at Gobabeb. Data are plotted as monthly values and as 12-month moving means

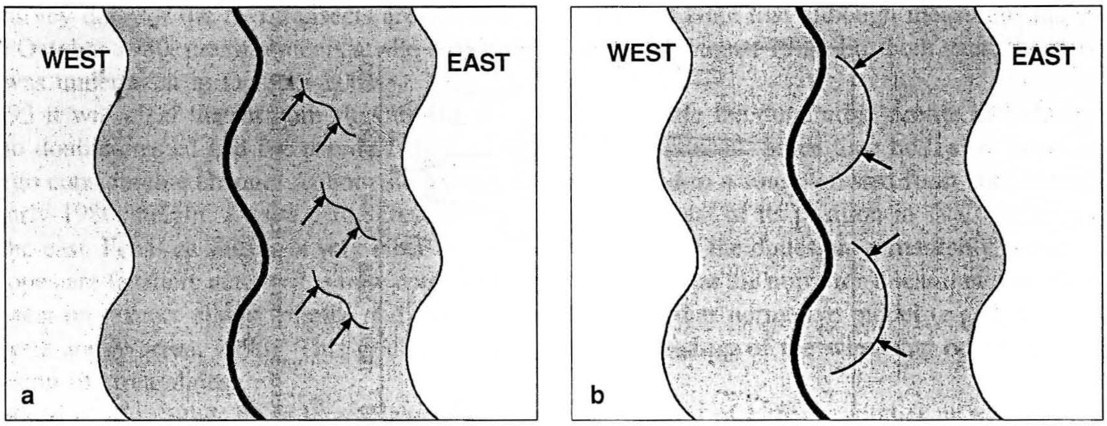

Figure 4. Idealized diagram of dune-crest form in different wind regimes: (a) a regime with a relatively low percentage of easterly winds; (b) a regime with a relatively high percentage of easterly winds

from one direction), it is possible to calculate the variability of winds from different directions. (Between 1996 and 1999 considerable amounts of data were lost so that during this period even the averages are rather unreliable.) Figure 3 shows the percentage of winds blowing from the east side of the dune, that is all winds between north-northeast and south-southeast, inclusive. No allowance is made for the wind speed: the record is simply the number of hours recorded as blowing from those directions.

Figure 3 records the actual percentage of winds blowing from the east for each month between 1980 and 2001. These data show a clear seasonal pattern of the occurrence of easterly winds peaking during the winter and diminishing during the summer. In addition, however, 12-month moving means have been plotted which smooth the seasonal effect. The data show clearly that easterly winds increased in frequency in the mid-1980s, more than doubling from an annual value of 15·9 per cent in 1982 to 37·6 per cent in 1986, and then dropped back almost to their early 1980s levels during the 1990s (e.g. 20·7 per cent in 1990). The moving mean values peaked early in 1986 at over 44 per cent easterly winds compared with typical values of between 15 and 17 per cent in the early 1980s. The data further suggest that the increase in easterly winds does not represent an overall increase in the number of 'windy' hours: the percentage of 'calm' hours (those with speeds recorded as below 1·67 $m\ s^{-1}$) has remained more or less constant throughout the 21-year period, and indeed shows little month-by-month variation. The increase in the proportion of easterly winds has therefore been at the expense of winds blowing from the west. However, the increased easterly winds are not the high magnitude/low frequency winter winds which in fact decreased during the mid-1980s. The greater proportion of easterly winds can be attributed to moderate northeasterly winds which blow in late summer (December–February).

Relating this variability in wind regime to the dune form reported by the 'snap-shot' surveys can only be speculative (Figure 4). During periods of decreased easterly winds (typically around 20–25 per cent of recorded hours) the dune develops a single main crest with a series of secondary, transverse ridges developed on the east slope which migrate northeastwards under the influence of the summer southwesterly winds. This situation was described in some detail by Livingstone (1989) based on the surveys from the early 1980s. During periods of increased easterly winds, and particularly northeasterly winds, those secondary forms migrate towards the main crest. If these conditions persist for long enough, as they did in the mid-1980s, these secondary ridges become a second main crest, while the original main crest shifts westward and diminishes in height.

The forms that show double crests in two dimensions on the sections for 1991, 1992 and 1993 (Figure 2) are in fact more 'bowl' shaped in three dimensions (Besler, 1976/77; Livingstone, 1993) and these 'closed depressions' are common in the complex dune landscape of the northern Namib. It may be that wherever these features are found they represent a relic of a period of wind climate variation from the 'norm'. However, we should also assume that the double-crested forms are transitional, so that if the increased level of easterly winds persisted a single-crested form related to that wind regime would eventually develop.

CONCLUSION

The continued surveying of these sites confirms the view that the dunes are not inactive relics but are actively responding to the present-day wind regime. It also continues to fail to provide any evidence that these dunes have migrated laterally over the past two decades. In addition, examination of the wind data for the survey period provides some evidence that the form of the crest of the dunes is actively responding to the natural year-by-year climate variability.

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REFERENCES

Barnes J. 2001. Barchan dunes on the Kuiseb River delta. *South African Geographical Journal* **83**: 283–292.

Besler H. 1976/77. Untersuchungen in der Dünen-Namib (Südwestafrika). *Journal of the South West Africa Scientific Society* **31**: 33–64.

Bristow CS, Bailey SD, Lancaster N. 2000. The sedimentary structure of linear sand dunes. *Nature* **406**: 56–59.

Cooke RU, Warren A, Goudie AS. 1993. *Desert Geomorphology*. UCL Press: London.

Harrison S. 1999. The problem with landscape: some philosophical and practical questions. *Geography* **84**: 355–363.

Hastenrath S. 1987. The barchan dunes of Peru. *Zeitschrift für Geomorphologie* **31**: 167–178.

Haynes CV. 1989. Bagnold's barchan: a 57-yr record of dune movement in the eastern Sahara and implications for dune origin and paleoclimate since Neolithic times. *Quaternary Research* **32**: 153–167.

Hesp PA, Hastings K. 1998. Width, height and slope relationships and aerodynamic maintenance of barchans. *Geomorphology* **22**: 193–204.

Hesp P, Hyde R, Hesp V, Zhengyu Q. 1989. Longitudinal dunes can move sideways. *Earth Surface Processes and Landforms* **14**: 447–451.

Lancaster N. 1989. *The Namib Sand Sea: Dune Forms, Processes and Sediments*. Balkema: Rotterdam.

Lancaster N. 1995. *Geomorphology of Desert Dunes*. Routledge: London.

Livingstone I. 1989. Monitoring surface change on a Namib linear dune. *Earth Surface Processes and Landforms* **14**: 317–332.

Livingstone I. 1993. A decade of surface change on a Namib linear dune. *Earth Surface Processes and Landforms* **18**: 661–664.

Livingstone I, Warren A. 1996. *Aeolian Geomorphology: An Introduction*. Longman: London.

Nanson GC, Chen XY, Price DM. 1992. Lateral migration, thermoluminescence chronology and colour variation of longitudinal dunes near Birdsville in the Simpson Desert, central Australia. *Earth Surface Processes and Landforms* **17**: 807–819.

Rubin DM. 1990. Lateral migration of linear dunes in the Strzelecki Desert, Australia. *Earth Surface Processes and Landforms* **15**: 1–14.

Stokes S, Goudie AS, Ballard J, Gifford C, Samieh S, Embabi N, El-Rashidi OA. 1999. Accurate dune displacement and morphometric data using kinematic GPS. *Zeitschrift für Geomorphologie Supplementband* **116**: 195–214.

Thomas DSG. 1992. Desert dune activity: concepts and significance. *Journal of Arid Environments* **22**: 31–38.

Warren A, Allison D. 1998. The palaeoenvironmental significance of dune size hierarchies. *Palaeogeography, Palaeoclimatology, Palaeoecology* **137**: 289–303.

Wiggs GFS. 2001. Desert dune processes and dynamics. *Progress in Physical Geography* **25**: 53–79.

