Palaeont. afr., **23**, 185–189 (1980)

DUNE SYSTEMS AND PALAEOENVIRONMENTS IN SOUTHERN AFRICA

by

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ABSTRACT

Extensive systems of fixed linear dunes occur throughout the Kalahari. Together the dunes form a semicircular arc with a radius of 1 000 km which corresponds approximately with the pattern of outblowing winds around the South African anticyclone. The dunes were formed by a wind regime broadly similar to that existing today. However, differences between dune alignments and present-day potential resultant sand flows in the northern part of the system suggest that shifts in the position and strength of the South African anticyclone may have taken place since these dunes were formed.

Comparison of the extent of fixed dunes with that of the presently active dunes indicates that the extent of the arid zone in southern Africa has altered substantially in the past. Evidence exists for at least two periods of much greater aridity in the subcontinent, but their dating remains uncertain.

INTRODUCTION

At the regional scale the pattern of dune trends in desert sand seas reflects the regional pattern of sand moving winds. Such systems of dunes have been described from the Sahara and Australia (Jennings 1968) and their relationship to present-day winds analysed by Brookfield (1970) and Mainguet and Canon (1976). However, relatively little is known about dune patterns and winds in the Kalahari and Namib apart from the preliminary work of Besler (1977), Goudie (1971) and Grove (1969).

Today active dunes are restricted to areas where mean annual rainfall is less than 150–200 mm. Comparison of the extent of vegetated, inactive dunes with the present position of active dunes may indicate the former distribution of arid climates as Grove and Warren (1968) have demonstrated for the southern Sahara and Goudie *et al.* (1973) for India. Similarly, comparisons of dune alignments and present-day winds can also provide information on past wind regimes and circulation patterns.

This paper presents the initial results of a systematic study of dunes in southern Africa and their relationships to present and past wind regimes.

THE PATTERN OF DUNES

Fixed dunes exist throughout the Kalahari between the Orange River and 16°30′S in Angola and western Zambia. Mapping of the dunes from LANDSAT imagery shows that they form an approximately semicircular arc with a radius of 1 000 km (fig. 1). Within this arc two distinct subsystems, called the northern and southern dunes, can be recognised. They are separated by an area corresponding to the main Kalahari watershed where there is little dune development save for the crescentic dunes associated with the pans in this area (Lancaster 1978). The presently active dunes of the Namib form a further, entirely separate, subsystem.

The northern dunes

The northern part of the dune system consists of dunes on E–W to NE–SW alignments that run from western Zimbabwe to the Etosha pan. In western Zimbabwe the dunes have a ENE–WSW alignment, and, according to Flint and Bond (1968), consist of subparallel ridges as much as 150 km long with a maximum present-day relief of 4 to 5 m and a spacing of 0,8 to 1 km.

The northern dunes are best developed between the Okavango Delta and the Etosha pan. In this area they consist of parallel broad sand ridges up to 25 m high and 1,5 to 2 km apart. Some of the ridges are continuous for up to 200 km with a general ESE—WNW alignment curving round westwards to ENE–WSW. The dunes are much degraded with a cover of open savanna woodland and are locally cut by stream valleys. In terms of their spacing and the volume of sand contained in them these dunes can be compared with some of the massive linear dunes of the Namib sand sea.

The southern dunes

The southern dunes are best developed in a 100–150 km wide belt which extends from 100 km south-east of Windhoek to the Orange River at Upington. They are bounded to the south-west by the Kalk Plateau. To the east and north-east they become progressively less distinct and more vegetated. North of 26°S the dunes consist of parallel or subparallel linear ridges 8–10 m high and 0,5–1,5 km apart with a NW–SE alignment. Gen-

Figure 1. Preliminary map of dune systems in southern Africa, compiled from LANDSAT 1 imagery.

erally the ridges are steeper on their southern sides and on aerial photographs can be seen to join with Y junctions open to the north-west similar to those described by Mabbutt and Sullivan (1968) from the Simpson Desert, Australia.

In the vicinity of the Nosop–Molop confluence the dunes are more complex with compound linear ridges and reticulate patterns. This is an area of converging dune trends and local sediment sources in the many pans which occur in this area. Frequently the pans have crescentic dunes on their lee sides from which small linear dunes extend. Dune alignments here are WNW–ESE, but south-east of the Molopo valley they revert to a NW–SE alignment curving round to NNW–SSE near Upington.

In general the southern dunes are comparable with those in the Simpson Desert described by Folk (1971). They occur in an area which is today marginally arid and have active crests where overgrazing has disturbed the vegetation.

In the central Kalahari there are few well marked dunes except for highly degraded linear dunes on a NE–SW trend curving round to N–S and NW–SE in the southern parts of the region, where they join with the trend of the southern linear dunes. The crescentic dunes on the pan margins show a similar pattern (Lancaster 1978).

PRESENT-DAY WINDS AND POTENTIAL SAND MOVEMENTS

Present-day wind directions in the Kalahari correspond to the anticlockwise pattern of outblowing winds around the southern African anticyclone situated over the Transvaal in winter and moving south-east to the Natal coast in summer. Thus winds are easterly at 19–21°S swinging round to northerly and north-westerly in the south-western Kalahari. In this area wind regimes are also influenced by the South Atlantic anticyclone which gives rise to a south-westerly air flow, particularly in summer.

Monthly and annual potential sand flows were computed following the method of Bagnold (1953) from the autographic records of wind speed and direction contained in the South African Weather Bureau (1960 and 1975) and the Rhodesia Meteorological Services (1974). Resultant sand flows were calculated using Lambert's formula.

The pattern of potential sand movements is shown by the sand flow roses in Figure 1. Most stations show some seasonal changes, but potential sand movements are usually from one dominant sector except stations affected by both anticyclonic circulations (table 1).

TABLE 1
Patterns of Potential Sand Movement in the Kalahari

Station	*Dominant sector*	*Mean from dominant sector*	*Minimum from dominant sector*	*Maximum from dominant sector*	*Resultant*
Victoria Falls	E-SE	86 %			93°
Bulawayo	E-SE	98 %			123°
Maun	NE-ESE	69 %	43,5 % (March)	84 % (January)	77°
Windhoek	NNE-NNW	44 %	7 % (January)	62 % (July)	357°
Keetmanshoop	NNE-NNW	40 %	10 % (Dec/Jan)	78 % (July)	
	SSW-SW	31 %	3 % (July)	63 % (Dec/Jan)	297°
Upington	NNE-NNW	73 %	50 % (January)	89 % (July)	348°
Tsabong	N-NE	64 %			26°

Potential sand movement is greatest at Kalahari stations during the period July to October with a maximum in August or September. Stations such as Keetmanshoop and Windhoek that are influenced by both circulations show a double maximum of sand flow: August, and December–January.

The pattern of winter sand flow maximum in the Kalahari parallels the Sahara situation as described by Mainguet and Canon (1976) but is the opposite of that observed by Brookfield (1970) from Australia where maximum potential sand movements occur in summer.

PALEOENVIRONMENTAL SIGNIFICANCE

The former extent of aridity in southern Africa

The present-day limit of active sand dunes in southern Africa corresponds approximately to the 150 mm isohyet which extends along the eastern margin of the Namib Desert. Fixed dunes are found in the northern Kalahari in areas where annual rainfall is 500–700 mm. In the southern Kalahari the dunes occur in areas where rainfall is 250–300 mm.

The distribution of the dunes clearly demonstrates that in the past there have been substantial changes in the area of southern Africa affected by arid climates. At the time of the formation of the northern linear dunes the 150 mm isohyet must have been 1 200 km north-east of its present position. This compares with shifts of 500 km calculated for the southern Sahara (Grove and Warren 1968), 350 km for the Thar Desert (Goudie *et al.*, 1973), and 900 km for Australia (Mabbutt 1971). To reactivate the southern dunes, more modest changes involving a 250–400 km movement of the 150 km isohyet are necessary.

Former wind regimes and circulation patterns

As Figure 1 indicates, there is a general correspondence between modern resultant potential sand movements and dune alignments, allowing for the separation of wind recorders and areas of dunes. This suggests that the dunes were formed by a wind regime like that existing today. Similar conclusions were reached by Brookfield (1970) for Australia and Mainguet and Canon (1976) for the Sahara.

However, there are important differences between dune alignments and modern potential sand flows, particularly in the northern system of dunes (fig. 2). These suggest that a change in the size and possibly position of the South African anticyclone may have taken place at the time of their formation to produce a greater radius of the anticyclonic circulation pattern. Contemporary parallels suggest that, when the anticyclone over the eastern Transvaal intensifies and expands, airflow on its northern margins becomes dominantly easterly and even brings strong north-easterly winds to the Namib. "Berg wind" conditions prevail in this and other western and southern coastal areas.

Age and chronology of periods of dune formation

A major question is whether the dune systems of the Kalahari were formed synchronously or diachronously. A variety of evidence suggests the latter. For example, the dunes on the southern margins of the pans indicate two periods of late Quaternary wind action separated by a period of high lake

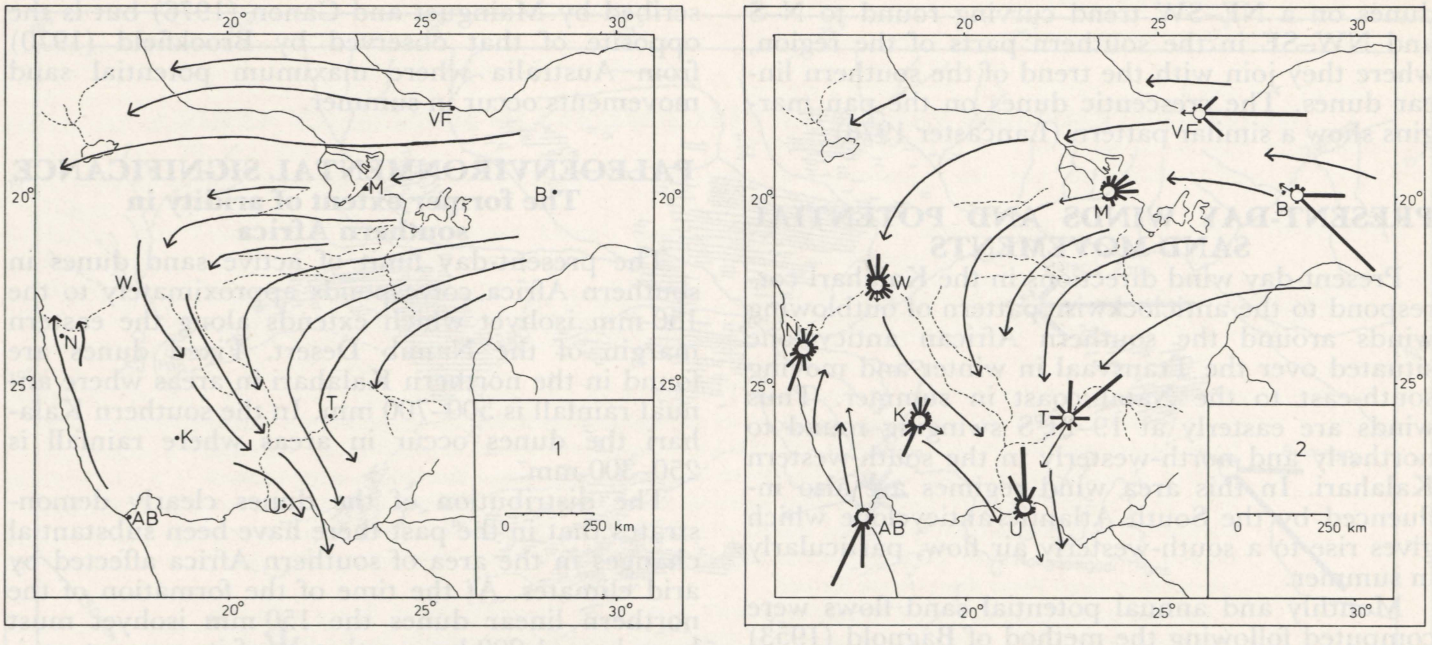

Figure 2. Comparison of potential resultant sand flows as indicated by:
1. Dune alignments.
2. Present-day computed resultant sand movements.
For names of stations see Figure 1.

levels (Lancaster 1978). A similar sequence was proposed by Flint and Bond (1968) and Grove (1969). In the lower Molopo area Heine (1978) describes evidence for four periods of sand movement.

Parallels from the Sahara and Australia (Rognon and Williams 1977) tend to support the idea of latitudinal shift of the margins of the area of aridity rather than a simple expansion of the whole zone of aridity. Dune formation on the margins is thus diachronous with probable equatorwards expansion of aridity during Glacial maxima.

In southern Africa modern drought periods are associated with increased persistence and strength of the main anticyclonic systems. During Glacial maxima, lower temperatures would have tended to promote arid conditions through increased anticyclonicity and decreased evaporation and moisture transport from the oceans. At the same time equatorward movement of pressure and wind systems would have brought the southern Kalahari within the present winter rainfall belt (Van Zinderen Bakker 1976).

Geomorphic evidence from the Kwihabe Hills (Cooke 1975) and from the pans (Lancaster 1978) points to a period of aridity and sand movement immediately preceding the widespread humid phase which prevailed in the Kalahari 14–17 000 B.P. This period may correspond to that when the northern dunes were formed or last reworked.

The dating of the southern dunes is equally problematical. However, they may date from the period of widespread dry climates which occurred in the southern part of the subcontinent during the Climatic Optimum some 6 000 B.P. Aridity at this time was probably more the result of higher temperatures than of much decreased rainfall.

CONCLUSIONS

The former extent of active dune systems provides convincing evidence for the widespread existence of arid climates in southern Africa at intervals during the Quaternary. Although climatic reconstructions are still tentative, it may be concluded that at least two periods of aridity and dune formation have occurred in the late Quaternary. In common with interpretations of other major desert areas it is suggested that no drastic changes in circulation patterns occurred during periods of dune formation.

Dating of the periods of increased aridity is difficult, but it is probable that the northern dunes were formed during a Glacial maximum. The last reworking of the southern dunes may relate to the period of mid-Holocene aridity proposed by some workers.

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