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# A Study of Global Sand Seas

Edwin D. McKee, *Editor*

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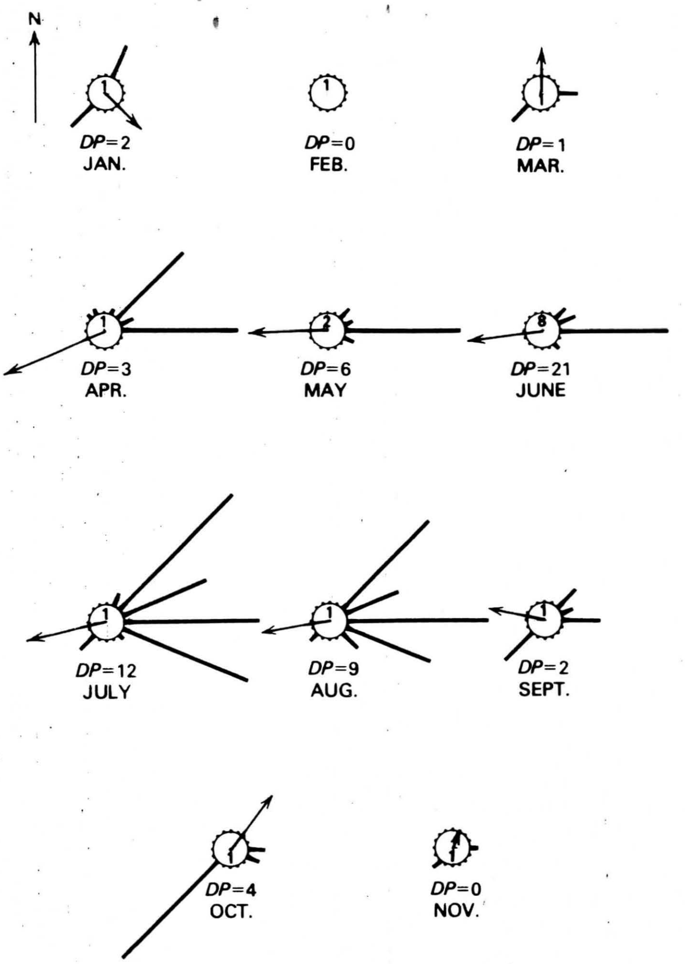



SAND ROSES FOR 11 MONTHS FOR GOBABEB, South-West Africa (location shown in figs. 222, 223). The southwest wind is strongest during October and is reflected in the long southwest arm of the sand rose. East ("Berg") wind is strongest in June, July, and August. December sand rose is unavailable. Drift potential is given for each month. (Fig. 229.)

ander Bay and Pelican Point experience a wide range in drift potential, with highest values occurring at Pelican Point (122 *VU*) during the spring (fig. 232). Maximum drift potentials at inland stations may occur in June or September (fig. 232).

# Kalahari Desert of South-West Africa, South Africa, and Botswana

## Summary of Conclusions

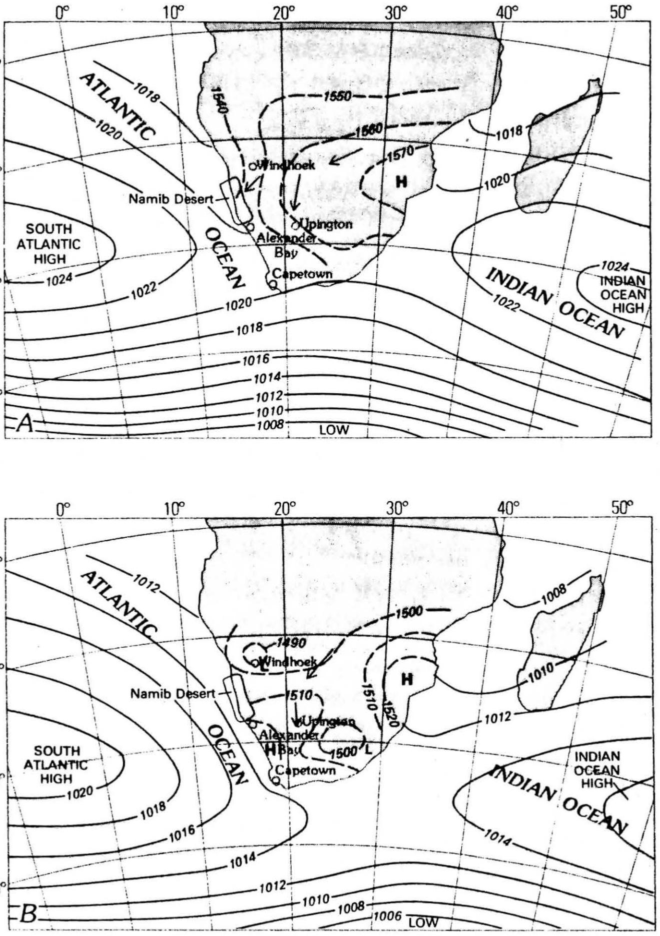
Linear dunes are the most common sand features of the western Kalahari Desert. Partially vegetated, mostly simple linear dunes trend northwest-southeast and cover about 100,000 km$^2$ (62,000 mi$^2$). These linear dunes average 0.3 km (0.2 mi) in width and 26.0 km (16 mi) in length, but many individual dunes are much longer. A second type of feature consists of long narrow sand bodies (which may be very large linear dunes or elongate sand sheets) that trend east-west in a region of about 15,000 km$^2$ (9,300 mi$^2$) between the Blydeverwachterplato and the Molopo River valley. These sand features have an average width of 2.3 km (1.5 mi), and some extend more than 100 km (62 mi) across hills and valleys. They swing southward at the Molopo River and merge with the sand sea of linear dunes to the east.

Annual rainfall in the southwestern Kalahari Desert is less than 200 mm (8 in.) in most places but increases northward and eastward — from regions of little vegetation into regions of much greater vegetation. At present, the Kalahari Desert as a whole has little wind energy available for sand movement, but drift potentials vary widely within the desert. High drift potentials occur in the less-vegetated, southernmost part of the study area. Low drift potentials occur in the northern parts of the study area in regions of partially vegetated simple linear dunes. The linear dunes and (or) sand sheets in the southwestern Kalahari Desert are alined with the resultant drift directions of present-day winds.

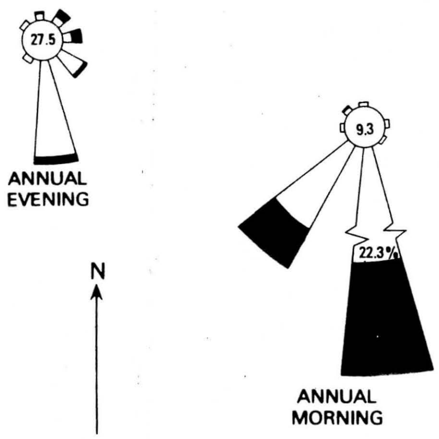
## Introduction

The Kalahari physiographic province (Wellington, 1955, p. 52) includes about 1,613,800 km$^2$ (1,002,800 mi$^2$) of lowland sandy desert, but only the southwestern part — in South Africa, Botswana, and South-West Africa — has dunes recognizable on Landsat imagery. The sand sea of the southwestern Kalahari Desert is in a basin of internal drainage centered at Abiekwasputs on the Molopo River (fig. 233). The lower parts of this river and its tributaries (the Auob, Nossob, and others) are abandoned drainages that have been choked with eolian sand for at least 1,000 years (Lewis, 1936, p. 30, fig. 6). They are thus cut off from the perennial Orange River, which marks the southern boundary of the Kalahari dune country and drains surrounding territories.

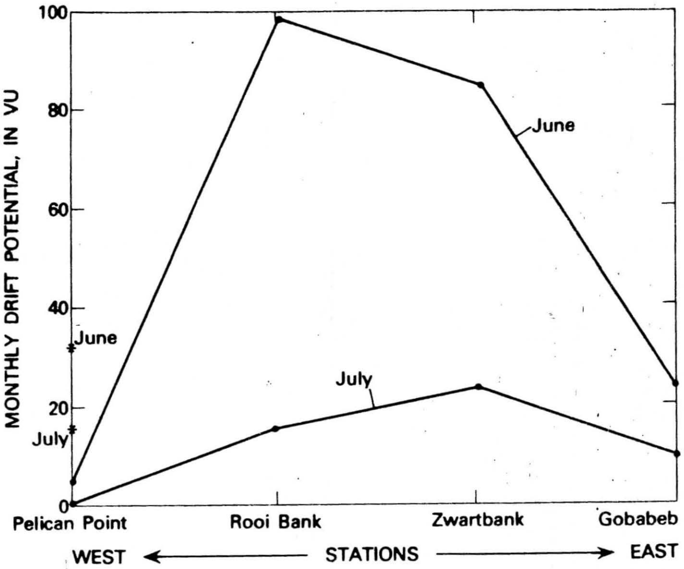
Published reports of the Kalahari region include reconnaissance work (A. W. Rogers, 1934, 1936), field observations of dunes (Lewis, 1936), a general geographic treatise (Wellington, 1955), accounts of geology and geomorphology in the southwestern




MEAN SEA LEVEL ISOBARS (solid lines) and isobars of the 850-millibar-pressure surface (dashed lines) at 1200 G.M.T. Arrows indicate general wind directions. *A*, June (winter in Southern Hemisphere); *B*, January (summer in Southern Hemisphere). Modified from Schulze (1972, p. 504). (Fig. 226.)




WIND ROSES SHOWING STRONG SOUTHERLY WIND REGIME at the south end of the sand sea in the central Namib Desert at Lüderitz. Number in centers of circles equal percent calm; white, 14–27 knots (25–50 km/hr); black, 28–40 knots (51–75 km/hr). (Fig. 227.)

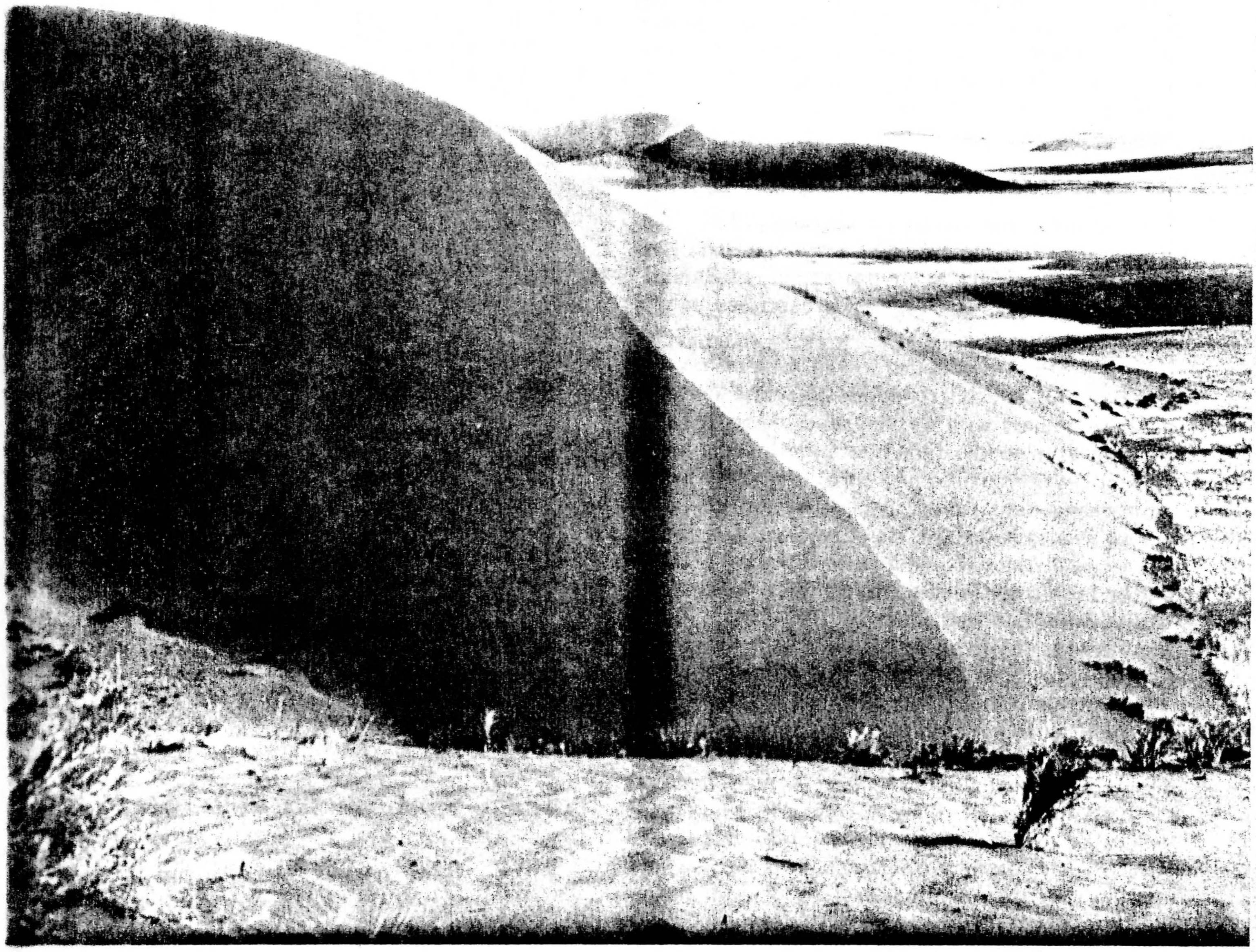



MONTHLY DRIFT POTENTIAL, in vector units, of winds from the northeast quadrant ("Berg Winds") during June and July at four stations from west to east across the northern part of the Namib Desert. During June, the "Berg Wind" increases in strength between Gobabeb and Rooi Bank, then decreases rapidly between Rooi Bank and Pelican Point (fig. 222). Southwest resultant drift directions at Rooi Bank and Zwartbank during June (fig. 222) aline with sand streaks north of the Kuiseb River, partly shown in figure 223. Asterisks indicate drift potential of southwest wind at Pelican Point during June and July, for comparison. (Fig. 228.)

some degree be sheltered from effective winds by high dunes nearby. All wind regimes, however, reflect both the southwest and east winds to some degree and suggest that in the central part of the desert, wind regimes may be roughly bimodal, with the two modes approximately equal in effectiveness. A bimodal wind regime is compatible with linear dunes (chapter F).

A comparison of the low drift potentials at most inland stations with those at stations on the coast suggests that the dunes in the center and along the interior margins of the sand sea are much less active than those near the coast. Wind data from Aus (fig. 231) suggests that some areas along the eastern margin of the Namib Desert may have complex wind regimes. Aus is about 80 km (48 mi) from fields of star dunes, which are generally in areas that have variable wind directions (chapter F, fig. 116).

The average drift potential of the Namib Desert is 237 *VU*, which places it in a moderate-energy range when compared to other deserts of the world (chapter F, table 15). The coastal stations of Alex-



RED SAND DUNES AND TAN PLAYA SEDIMENTS along the interior margin of the Namib Desert. Ground photograph; view at the Sossus Vlei. Photograph by M. K. Seely. (Fig. 225.)

Two lines of evidence suggest that at inland stations the potential sand-moving effect of the east winds is greater than that of southwest winds. First, during June and July, which is the season of east winds, the drift potential of winds from the northeast quadrant (encompasses the "Berg Winds") is highest at inland stations (fig. 228). Second, the high energy of the sea breeze, or southwest wind, seems to diminish rapidly inland, as shown by the decrease in drift potentials from Pelican Point eastward to Gobabeb (fig. 222). At Gobabeb, the southwest wind is an important sand-moving wind only during October (fig. 229). At Rooi Bank, only 30 km (19 mi) from the coast, the "Berg Wind" is also a very important sand-moving wind (fig. 230).

Available data from stations along the Kuiseb River suggest that the resultant drift direction along the northern interior margin of the sand sea is roughly southwestward but wind data from Narabeb, a station within the sand sea, suggest a northeastward resultant drift direction (fig. 222). All the stations except those at the coast may to

Landsat imagery shows dune-free surfaces on pediments around outliers of the Great Escarpment and in valleys of intermittent streams (fig. 224). Such dune-free areas around topographic barriers may result from sheetwash by occasional torrential rains along the escarpment. The escarpment is generally parallel to the 100-mm precipitation isohyet on the map (fig. 222). The eastern margin of the sand sea is marked by a high rampartlike ridge of sand (fig. 224), described by Logan (1960, p. 136) and similar in aspect on Landsat imagery to boundaries of sand seas in Tunisia, as described earlier (fig. 210).

Figure 225 shows dunes in the interior zone at the Sossus Vlei. Interbedding of white and tan playa sediments with the red sand of the dunes is common at the ends of the intermittent streams (M. K. Seely, written commun., 1975). Reddish hues of eolian sand translate on Landsat false-color imagery as shades of yellow (fig. 224), and the deeper the red of the sand, the more intense its yellow tone on the false-color imagery. In general, observations made from Landsat imagery (fig. 224), Skylab photographs (McKee and Breed, 1977), and ground photographs (fig. 225) confirm Logan's (1960, p. 136) statement that dunes farthest inland are also the reddest. In general, also, large linear dunes in the central zone of the Namib sand sea are redder than are crescentic dunes both to the west and east of them. Reddest of all are the star dunes and other eolian sand features, mainly complex dunes and sand sheets, around inselbergs near the eastern margin (fig. 224). Relative degrees of redness cannot be attributed simply to age differences, or to different lengths of time in a subaerial environment because numerous factors other than time can also control the degree of redness (Walker, chapter D).

## Climatic Regime [14]

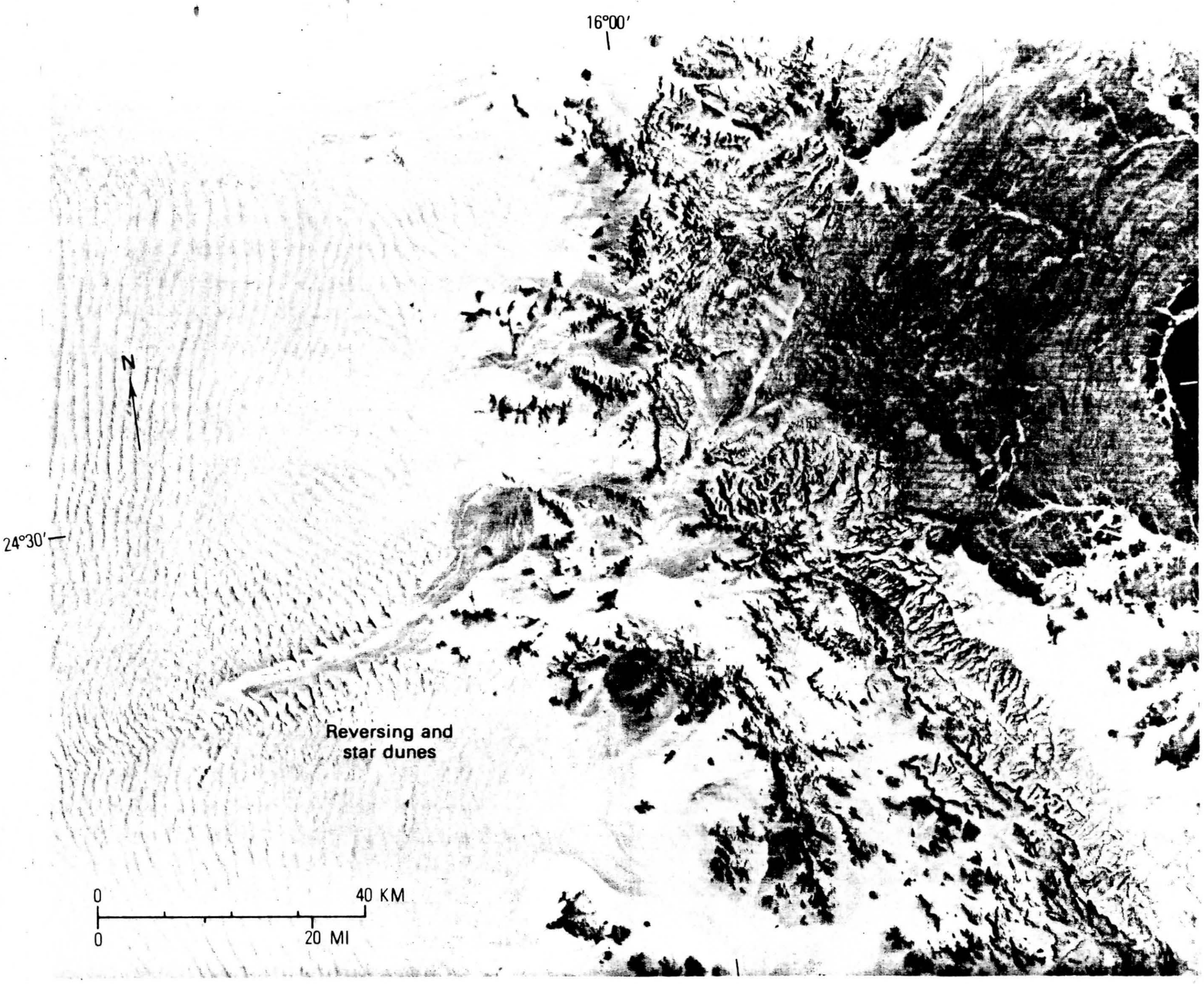
Southern Africa lies within a belt of high atmospheric pressure centered at approximately lat 30° S. (Schulze, 1972, p. 503). Surface wind circulation over the Namib Desert during the winter is controlled by the South Atlantic high, the Indian Ocean high, and high pressure over the interior plateau (fig. 226). Counterclockwise circulation around the South Atlantic high during the winter season results in southerly winds along the Atlantic coast. These winds may be deflected inland by the heating of the desert sands and thus become southwesterly winds, particularly near the coast (Harry Van Loon, oral commun., 1974). Strong easterly winds also occur in the Namib Desert during the winter and are locally referred to as the "Berg Winds." They may be initiated when coastal lows appear on the west coast during the summer or winter and move around to the south coast (Schulze, 1972, p. 506), promoting winds across the adjacent desert. During the summer, a thermal low develops in the interior plateau and promotes landward circulation throughout southern Africa (fig. 226). Onshore (southwest) winds in the Namib Desert are strongest during spring and summer.

The Namib Desert receives less than 100 mm (4 in.) of rain per year, as shown by the isohyets in figure 222, and the variability of this rainfall may be as much as 80 percent from year to year (Schulze, 1972, p. 512, 514). An important source of moisture along the coast is the heavy dew associated with frequent fogs. This moisture may amount to as much as 2.5 cm (1 in.) of equivalent rainfall in a year (Royal Navy and South African Air Force, 1944, p. 37).

## Direction and Amount of Sand Drift

Annual resultant drift directions along the Namib coast, and as far as 50 km (31 mi) inland, are toward the north or northeast as shown by annual sand rose and wind roses from Alexander Bay (south of the mapped area), Lüderitz (fig. 227), and Pelican Point, South Africa (fig. 222). This northward and northeastward direction of sand drift along the coast is steady throughout the year, with the exception of May–June, when the east winds ("Berg Winds") increase in strength. (See monthly sand roses for Pelican Point, chapter F, fig. 97*A*). Resultant drift directions at stations farther inland along the Kuiseb River, at the north end of the sand sea (fig. 222) seem to be toward the southwest. This apparent change in direction of potential sand movement may result from a decrease in the strength of the southwest wind from the coast inland, and a corresponding increase in the strength of the easterly winds ("Berg Winds") in the same direction.

[14] Principal sources of meteorological data are National Climatic Center, Asheville, North Carolina, U.S.A., and Desert Ecological Research Unit, Walvisbaai, South-West Africa.

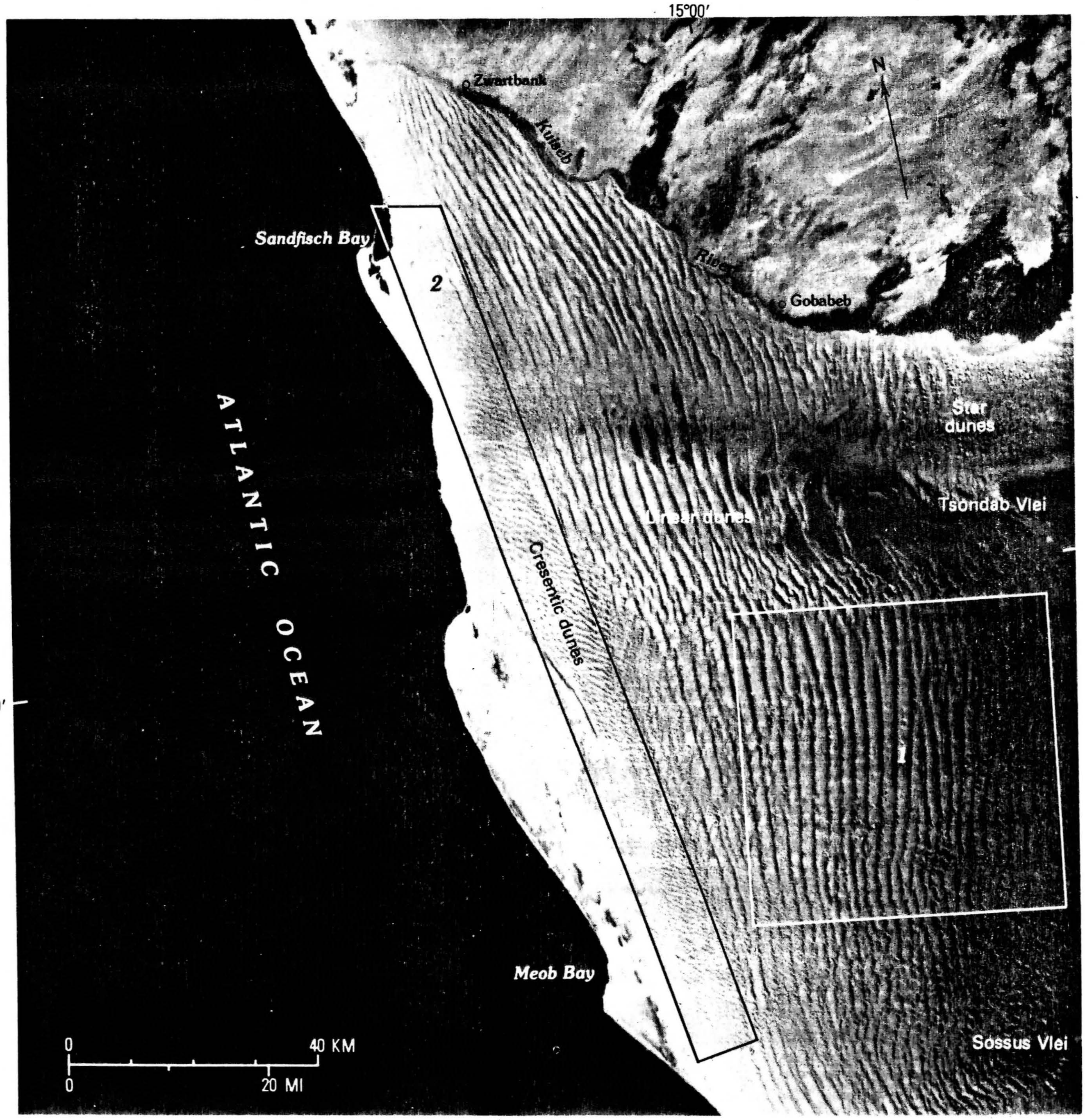



NORTHEAST MARGIN OF THE MAIN SAND SEA near inselbergs of the Great Escarpment (to the east) in the Namib Desert. Landsat false-color imagery E1202 – 08222. Disruption of the dune pattern around the Sossus Vlei (playa) is shown. (Fig. 224.)

values: dune width, 0.83 km (0.51 mi); dune length, 27 km (16 mi); dune wavelength 2.20 km (1.36 mi). The Namib dunes are compared with other dunes of linear type in chapter J (tables 36, 37).

Fields of star dunes, reversing dunes, and dunes of indeterminate (complex?) type occur along the eastern margin of the sand sea, near pediplains and inselbergs of the Great Escarpment (fig. 224). The sharply delineated boundaries of dune fields (fig. 224) coincide approximately with the 1,200-m (4,000-ft) contour line shown on a map of the area (U.S. Department of Commerce, U.S. Air Force Operational Navigation Chart Q–4). Varieties of dunes in the interior marginal area contrast greatly with the simple crescentic dunes of the coastal belt but merge into the linear dunes of the middle zone (figs. 222, 223, 224).

Star dunes north of Aus (fig. 222) range in diameter from 0.4 km (0.2 mi) to 1 km (0.6 mi), mean diameter, 0.7 km (0.4 mi), and are spaced an average 2.2 km (1.4 mi) apart. The Namib star dunes are of medium size, compared with those of other deserts (chapter J, tables 40, 41). They have a preferred east-west orientation (large arms oriented N. 48° W.).




WESTERN PARTS OF THE MAIN SAND SEA in the central Namib Desert. Landsat imagery E1383–08264; E1383–08270. Outlined areas are samples of imagery on which (1) complex linear dunes with superimposed star dunes were measured and (2) crescentic dune ridges were measured. (Fig. 223.)

The linear dunes of the central zone occur in distinct parallel straight patterns (figs. 222, 223, 224). Disruptions of individual dune crests and interdune troughs seem to the authors to create a complexity of dune forms but not a "chaos" as described by Logan (1960, p. 136). Variations from the generally straight pattern of dunes alined N. 9° E. (fig. 223) are most pronounced near valleys of the Tsondab River and Tschaubrivier (figs. 223, 224).

Measurement of the linear dunes in a 2,500 $km^2$ (1,550 $mi^2$) sample area in the center of the sand sea (fig. 223, sample area 1) yields the following mean

DISTRIBUTION AND MORPHOLOGY OF EOLIAN SAND in the central Namib Desert of South-West Africa. Map based on Landsat imagery. Sand roses for Zwartbank, Rooi Bank, and Gobabeb are each for the month during which highest drift potential occurs and are not directly comparable to annual sand roses (annual sand roses for these stations are not available). Drift potentials, resultant drift potentials, and resultant drift directions for Zwartbank and Rooi Bank were estimated from December-to-August, and December-to-July data, respectively. An annual sand rose is shown for Pelican Point. Isohyets are from Grove (1969). (Fig. 222.)

Dune ridges of the central Namib are described by Logan (1960, p. 136) as having a chaotic and disorderly pattern, the result of disruption of their crests by "blowouts," and partial closure of their interdune troughs by "transverse" dunes. A threefold division of dunes is recognized by Barnard (1973, p. 2) in the sand sea of the central Namib. It consists of (1) "a littoral belt of closely packed transverse dunes," (2) an interior zone of "longitudinal" dunes which he believed to have formed by deflation, and (3) an eastern zone of "multicyclic" complex dunes.

Some reported dune heights are as follows: 65 m (210 ft) for dunes in the coastal belt between Sandfisch Bay and Zwartbank (Stapff, 1887, in Goudie, 1970, p. 94); 80–100 m (260–380 ft) for "basically linear dunes" at Gobabeb (Goudie, 1970, p. 94; 1972, p. 24) and 300 m (nearly 1,000 ft) for "high, sharply crested dunes" near the Sossus Vlei along the interior margin of the sand sea (Barnard, 1973, p. 2,5).

Sand of the Namib Desert is generally described as brown (Goudie, 1970, p. 94) or red (Logan, 1960, p. 136). Inland dunes were said by Logan (1960, p. 136) to be "brick red," whereas dunes near the coast are recorded as "yellow-white." He stated that "This difference in coloration [between coastal and inland dunes] is believed to be the result of the greater age of the inland dunes which has allowed greater oxidation of the iron components within the sand" (Logan, 1960, p. 136).

The Namib Desert sand is reported to be 90 percent quartz and of uniform size, except that deviations in median diameter and sorting occur near the coast (Barnard, 1973, p. 2). Textures of Namib sand from dunes near Gobabeb and from "sand glaciers" (sand sheets, including climbing dunes) near Rossing Mountain, east of Swakopmund and north of the Swakop River, have been reported by Goudie (1970, p. 96; 1972, p. 24–25, fig. 16).

The main vegetation among the dunes near Gobabeb consists of sparse clumps of *Stipagrostis sabulicola* (Goudie, 1970, p. 94). Interdune areas support periodic growth of grass following infrequent precipitation (M. K. Seely, oral commun., 1975).

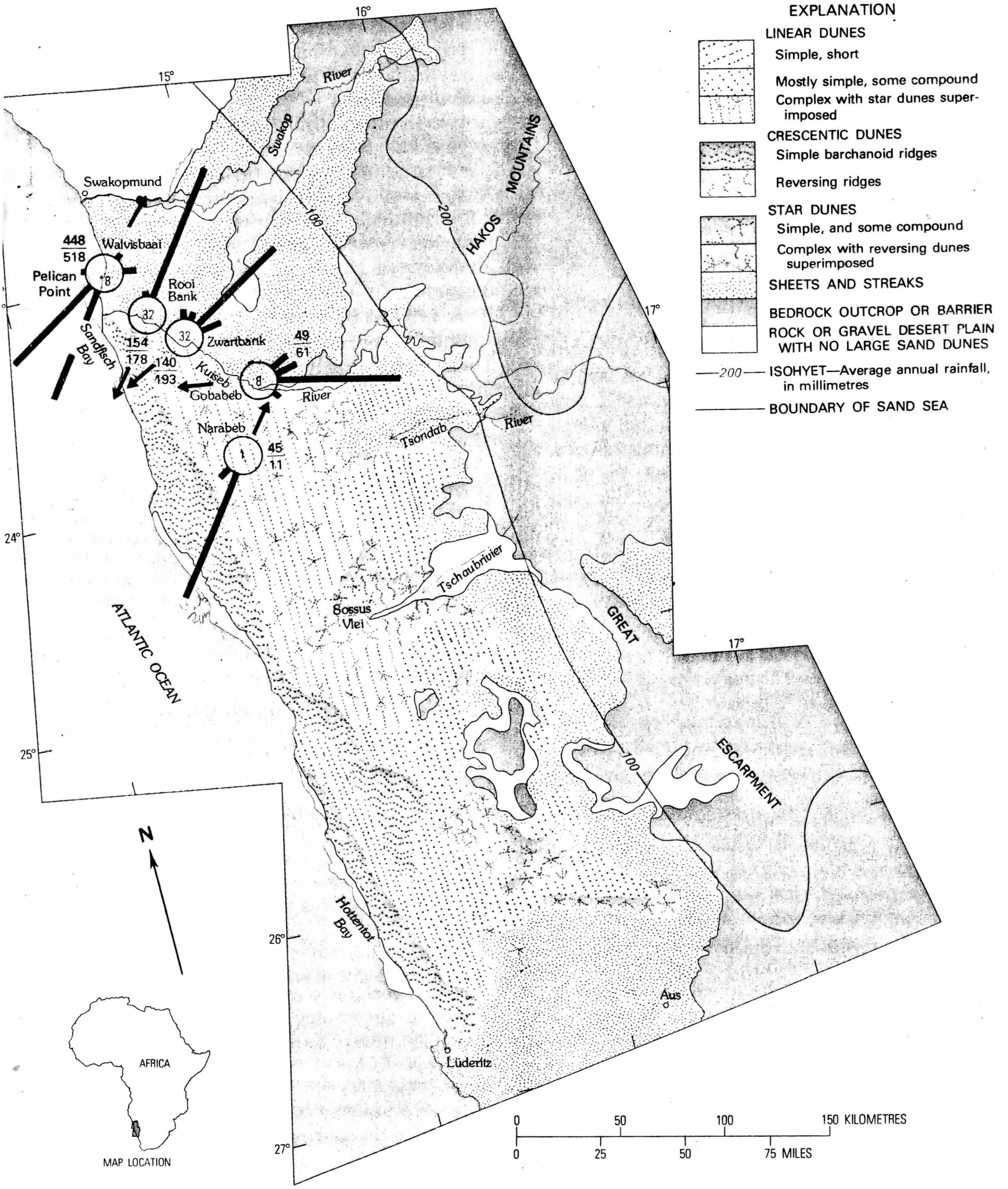
Fresh or brackish water that occurs beneath dunes near the coast, about 85 km (50 mi) west of the playa at the end of the Tsondab River (figs. 222, 223), is interpreted as evidence that the Tsondab River, the Tschaubrivier (fig. 224), and probably other intermittent streams that flow from the Great Escarpment at one time reached the Atlantic but that their courses have been truncated by the northward movement of dunes (Seely and Sandelowsky, 1974). A late Pleistocene age for the earliest occupation by man of the area near Narabeb, west of the Tsondab Vlei (figs. 222, 223), is based on the occurence of Early Stone Age tools, estimated to be 40,000–60,000 years old, in an interdune valley (Seely and Sandelowsky, 1974, p. 64).

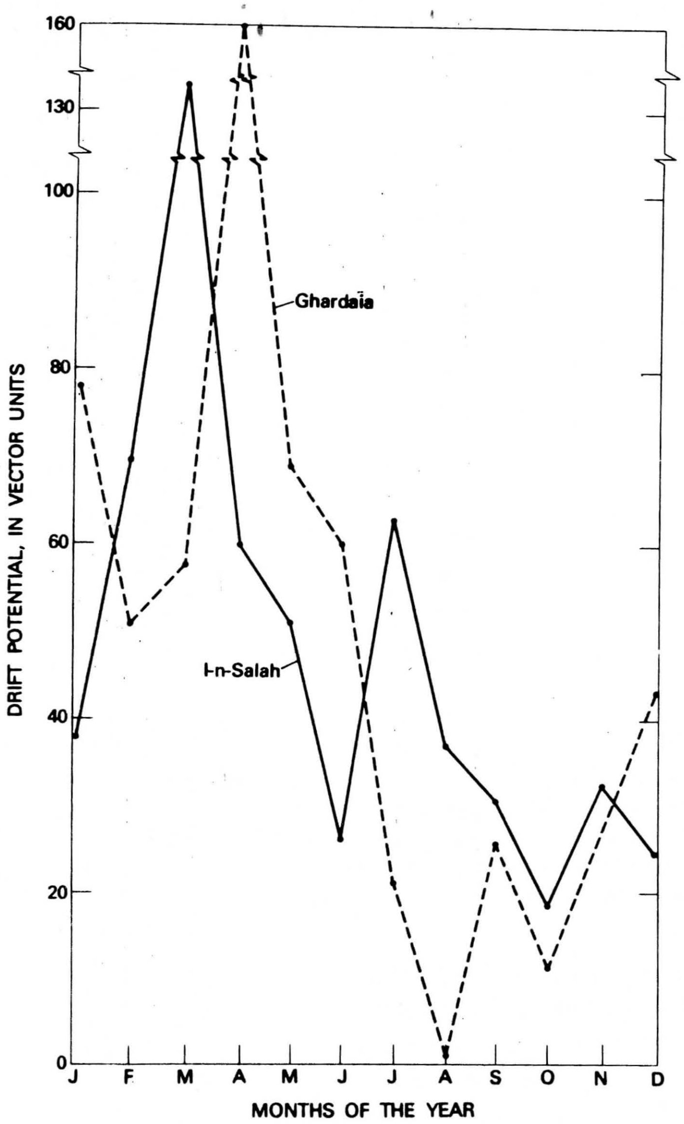
## Interpretation of Landsat Imagery

Dune types are distributed in three distinct zones across the sand sea — a coastal zone of crescentic dunes, a central zone of compound linear dunes, and an interior zone of star dunes and reversing dunes. Local variations of dune patterns within the zones occur especially near inselbergs and valleys of intermittent streams.

Closely spaced crescentic dune ridges occupy a belt 5–30 km (3–18 mi) wide along the Atlantic coast between Swakopmund and Lüderitz (figs. 222, 223). Measurements of dune width (horn to horn), length, and wavelength (spacing) were made on Landsat imagery (fig. 223, sample area 2) at 10-km (6-mi) intervals between Sandfisch Bay and Meob Bay. Mean dune width is 1.12 km (0.69 mi), mean length is 0.68 km (0.42 mi) and mean dune wavelength, 0.87 km (0.54 mi). These dunes are comparable to crescentic dunes in other areas observed on Landsat imagery (chapter J, table 38).

Compound linear dunes and complex dunes, mainly linear dune ridges with small star dunes and reversing dunes developed along their crests (chapter J, fig. 168), extend from the middle of the desert east of Lüderitz to an abrupt boundary at the south bank of the Kuiseb River (figs. 222, 223).


EXPLANATION
LINEAR DUNES
Simple, short
Mostly simple, some compound
Complex with star dunes superimposed
CRESCENTIC DUNES
Simple barchanoid ridges
Reversing ridges
STAR DUNES
Simple, and some compound
Complex with reversing dunes superimposed
SHEETS AND STREAKS
BEDROCK OUTCROP OR BARRIER
ROCK OR GRAVEL DESERT PLAIN WITH NO LARGE SAND DUNES
—200— ISOHYET—Average annual rainfall, in millimetres
BOUNDARY OF SAND SEA
16°
15°
17°
24°
25°
26°
27°
Swakopmund
Swakop
River
HAKOS MOUNTAINS
200
100
Walvisbaai
448
518
Pelican Point
Rooi Bank
Sandfisch Bay
154
178
140
193
Zwartbank
49
61
Kuiseb
Gobabeb
River
Narabeb
45
11
Tsondab
River
Tschaubrivier
Sossus Vlei
ATLANTIC OCEAN
GREAT ESCARPMENT
Hottentot Bay
Aus
Lüderitz
N
AFRICA
MAP LOCATION
0 50 100 150 KILOMETRES
0 25 50 75 MILES




VARIATION IN DRIFT POTENTIAL during the year at Ghardaïa and I-n-Salah, Algeria, illustrating the extreme variation in drift potential which may occur at some stations. Hassi Messaoud, Algeria, and Ghudāmis, Libya, also exhibit this variable pattern. I-n-Salah is far enough south to reflect the summer high in drift potentials which occurs at southern stations. (Fig. 221.)

15); it ends at the south in sandy plains north of Luderitz and Aus. The sand sea area is about 34,000 km² (21,000 mi²) (Barnard, 1973, p. 2). It rests upon the Namib platform, a Tertiary erosional surface cut on schists, quartzites, and granite intrusives. Regional slope of the Namib platform is about 2.3 m/km (65 ft/mi) from the base of the escarpment to the Atlantic Ocean. Numerous intermittent streams flow from the escarpment into playas among the dunes, and rock outliers protrude through the sand as inselbergs.

Landsat imagery has been used to map eolian sand distribution and morphology in the main sand sea of the central Namib Desert (fig. 222). Interpretations were made with the aid of Skylab photographs.

Principal published reports (in German) about the Namib sand sea are by Range (1927) and Besler (1972). A major work (in Afrikaans) on dunes of the central Namib is by Barnard (1973). Reports (in English) include a descriptive geomorphic paper by Gevers (1936), general geographic treatises by Wellington (1955) and by Logan (1960), and two papers by Goudie (1970, 1972) that give descriptions of the dunes near Gobabeb. Relationship of dunes to the Tsondab River and Tschaubrivier is described by Seely and Sandelowsky (1974).

Comprehensive aerial photography of the Namib Desert is unavailable and maps of the sand sea, U.S. Department of Commerce, U.S. Air Force, Operational Navigation Charts P–3, P–4, and Q–4, state that "relief data are unavailable."

## Review of Previous Work

Sand of the Namib Desert is thought by most workers (J. Rogers, in Seely and Sandelowsky, 1974, p. 61) to be derived mainly from fluvial sediments transported to the Namib platform by the perennial Orange River, in an area off the map (fig. 222) at about lat 28° S., long 17° E. Some sand is also brought in by intermittent streams from the Great Escarpment (fig. 222). Some of the sand near the coast may be of marine origin (Gevers, 1936, p. 71). The sand sea may be as old as Miocene according to Barnard (1973, p. 2). Recent active sands in the Namib are believed to be derived mostly from reworking of Tertiary dunes (Martin, in Seely and Sandelowsky, 1974, p. 61).

Field data from the Namib sand sea consist mainly of descriptions of dune areas near the coast or accessible from Gobabeb (fig. 222). Sand forms near Gobabeb are at the downwind end of the sand sea near topographic barriers and thus, may not be representative of those to the south in the main part of the sand sea. Linear ridges near Gobabeb are described by Goudie (1970, p. 94–95) as "composite forms made up of as many as five subparallel and sinuous segments which sometimes isolate deep hollows within the dune." Interdune valleys near Gobabeb are largely sand free corridors containing a few small barchans (Goudie, 1970, p. 95).

Carol S. Breed, S.C. Fryberger
S. Andrews, C. McCauley, F. Lennartz, D. Gebel,
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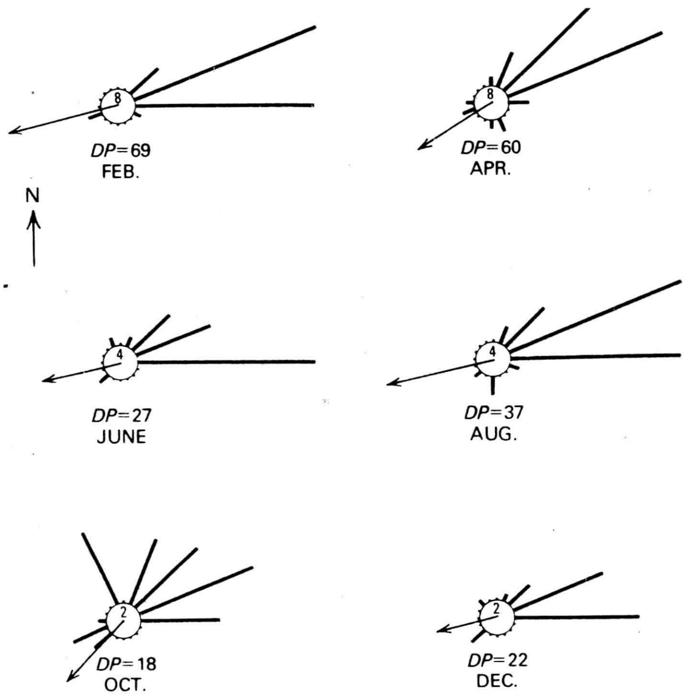
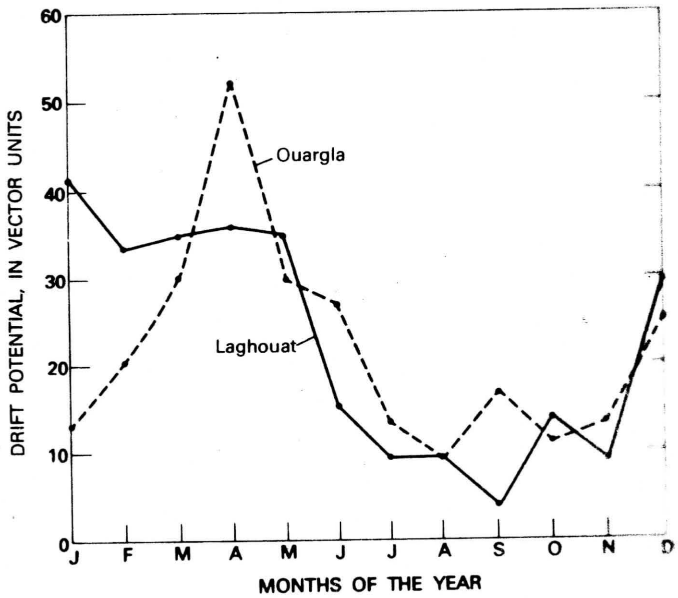



SAND ROSES FOR 6 MONTHS FOR I-N-SALAH, Algeria, south of the Grand Erg Occidental and east of the 'Erg Chech, illustrating the steadiness of easterly to northeasterly effective winds and resultant drift direction toward the west-southwest and to the southwest. This wind regime, in a region of sand sheets, contrasts markedly with some more complex wind regimes farther north in Algeria in a region of star and complex dunes. (See figs. 216–218.) (Fig. 219.)




VARIATION IN DRIFT POTENTIAL during the year at Laghouat (solid line) and Ouargla (dashed line), Algeria. These stations typify much of the northern Sahara, including southern Tunisia and northwestern Libya. Laghouat experiences high drift potentials in the winter and spring. Ouargla, which is closer to the interior, experiences highest drift potentials in the spring but is too far south to have equally high drift potentials in the winter (Fig. 220.)

# Namib Desert of South-West Africa

## Summary of Conclusions

CRESCENTIC, LINEAR, AND STAR DUNES occur in the Namib Desert in three elongate zones parallel to the Atlantic coast. Crescentic dunes with an average wavelength of 0.9 km (0.6 mi) occupy a belt 5–30 km (3.1–18.6 mi) wide along the Atlantic coast between Swakopmund and Lüderitz. Compound linear dunes occupy much of the central portion of the desert, from Lüderitz northward to the Kuiseb River. These linear dunes average 2.2 km (1.4 mi) in wavelength and 27 km (16.8 mi) in length. Isolated fields of star dunes, reversing dunes, and complex dunes of indeterminate type occur along the east margin of the Namib Desert. The star dunes have a mean diameter of 0.7 km (0.4 mi) and are spaced an average of 2.2 km (1.4 mi) apart. In general, redness of the dune sands seems to increase inland from the coast.

Average annual rainfall is less than 100 mm (3.9 in.) throughout the Namib Desert, except in some of its extreme eastern parts. Heavy dew along the coast may be the equivalent of as much as 25 mm (1 in.) of annual rainfall. High-energy unimodal winds from the southwest or south occur along the Atlantic coast in a zone which corresponds roughly to the region of crescentic dunes. An intermediate- to low-energy bimodal wind regime may occur in the central zone of linear dunes; a complex low-energy wind regime prevails near the star dunes of the eastern Namib Desert. The observed present-day wind regimes of the Namib Desert are roughly compatible with the observed dune types in the several zones. The rapid decrease in wind energy inland from the coast, however, suggests that linear and star dunes in the interior are considerably less active than are crescentic dunes along the coast.

## Introduction

The main sand sea of the central Namib Desert, South-West Africa, is bounded on the north by the Kuiseb River, on the west by the Atlantic Ocean, on the east by the Great Escarpment (Goudie, 1972, p.