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Sources of sand for the Namib sand sea

by

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with 3 figures and 1 table

Zusammenfassung: Verschiedene Herkunftsgebiete sind für die Sande der Namib angenommen worden. Dazu wird eine Analyse der Korngrößenverteilung und Kornmineralogie der Sande vorgestellt und der Schluß gezogen, daß die Sande aus metamorphen Gesteinen stammen, wahrscheinlich aus dem Gebiet südlich der Wüste, und daß sie die Namib über den Oranje-Fluß und im Meer entlang der Küste erreicht haben. Dieses einfache Modell deckt nicht alle Variationen ab. Der Sand hat wahrscheinlich eine kompliziertere Geschichte, einschließlich einiger Beimischung von Sand aus anderen Quellen.

Summary. Several sources have been postulated for the sand in the Namib sand sea. Analyses of particle size distribution and grain mineralogy of sands are presented, and it is concluded that the sand originated in metamorphic rock, probably to the south of the desert, and has reached the Namib via the Orange River and offshore sands. This simple model does not account for all the variation, and the sand probably has a more complicated history, including some admixture with sand from other sources.

Résumé. De nombreuses sources ont été proposées pour expliquer l'origine des sables dunaires du Namib. L'analyse granulométrique et minéralogique des sables sont présentées. Il apparaît que le sable a pour origine des roches métamorphiques, probablement au sud du désert, et qu'il était transporté au Namib par la rivière Orange et par les courants côtiers. Ce modèle simple n'explique pas toutes les variations, et peut-être l'histoire du sable est-elle plus compliquée, surtout par le mélange des sables provenant d'autres sources.

Introduction

The Namib sand sea has an area of 34 000 km^2 and extends for over 300 km along the Atlantic coast of south western Africa between Luderitz (26 °S) and the Kuiseb river (23 °S) and for 100–150 km inland to the base of the Great Escarpment at the 1000 m contour. The sand sea is dominated by large linear dunes, with areas of star and reversing dunes on its eastern margins and a belt of simple and compound transverse and barchanoid dunes along the coast.

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Sands from the Namib sand sea are generally medium to fine. Coarser sands occur in southern areas of the sand sea, and in interdune areas: finer sands in the crestal areas of linear and star dunes. The grain size character of the linear dunes is discussed by LANCASTER (1981 a). Colour of the dune sands varies from 10 YR 5/4 (yellowish brown) or 10 YR 6/4 (light yellowish brown) in coastal areas through 7.5 YR 5/4–6/6 (yellowish brown to reddish yellow) over wide areas of the central and southern parts of the sand sea to 5 YR 5/8 (yellowish red) in eastern areas.

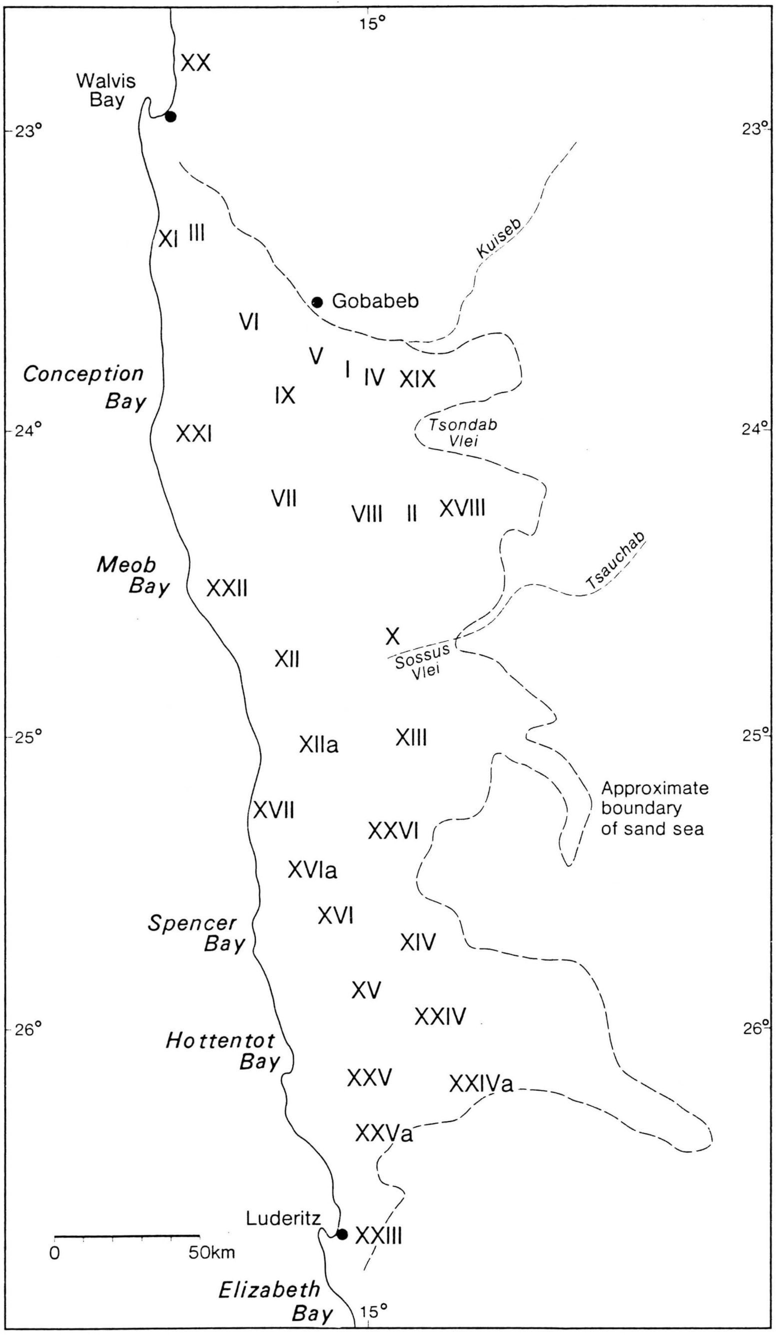
The volume of sand contained in the sand sea is uncertain. Preliminary estimates suggest that the spread-out thickness of sand contained in the dunes ranges from 5–7 m in southern areas where dunes are low (25–40 m) and closely spaced to 20–30 m in central areas where dunes are 100–150 m high and 2000–2500 m apart. Widespread outcrops of the sub-dune surface in interdune areas suggest that much of the sand in the sand sea is contained in the dunes themselves and that the amount of other sand blanketing the terrain is relatively small. On this basis an estimate of total sand volume of 3.73×10^{11} m^3 (derived by multiplying the area of the sand sea covered by dunes of different types by the estimated spread out thickness of sand contained in them) seems a reasonable approximation.

Two major and contrasting hypotheses have been put forward to explain the origin of the sand sea and the source of the sand contained in it. Extensive semi-consolidated red-brown sandstones up to 100 m thick apparently underlie much of the area of the present sand sea, as well as areas to its east and north. This formation was called Tsondab Sandstone by OLLIER (1977) and Namib Sandstone by BESLER & MARKER (1979) and is generally thought to be Tertiary in age. BESLER & MARKER (1979) stated categorically that it constituted the source for the dune sands.

BESLER (1980) has argued that fluvial processes have been responsible for the accumulation of the sands of the Namib sand sea. In her view, Namib sandstones at the base of the escarpment were extensively eroded during a period of the 'high Würm' and deposited as a series of alluvial fans to the west. These were reworked by strong southerly winds during the late Glacial period into the south-north linear dunes, a hypothesis supported in BESLER's view by the apparently fluvial character of the dune base sands and the weakness of modern winds. BESLER argued that the changes in grain size and patina of the sands from west to east reflected, not eolian transport of sand, but fluvial transport, bleaching and mixing. This model of the formation of the Namib sand sea corresponds closely to the fluvial hypothesis of sand sea formation advocated by many workers in the Sahara (e.g. ALIMEN et al. 1958, CAPOT REY 1970), on the basis that, because sand seas are found in low lying areas, they are essentially of fluvial origin, with the sand being contributed from surrounding upland areas.

An alternative model for the development of the Namib sand sea, first suggested by ROGERS (1977) and subsequently developed by LANCASTER (1981 b) views the sand sea as the product of an ongoing process of sediment accumulation. ROGERS (1977) drew attention to the high energy of winds in the southern Namib and their effectiveness in transporting sand from the beaches of Elizabeth and Chamais Bays south of Luderitz into the main sand sea. The beaches were supplied by vigorous longshore movement of sand derived from the Orange River mouth. LANCASTER (1981 b) compared patterns of dune

Fig. 1. Sample sites in the Namib sand sea.


15°
XX
Walvis Bay
23°
23°
XI
III
Kuiseb
Gobabeb
VI
V
I
IV
XIX
Conception Bay
IX
Tsondab Vlei
24°
24°
XXI
VII
VIII
II
XVIII
Meob Bay
Tsauchab
XXII
X
Sossus Vlei
XII
25°
25°
XIIa
XIII
Approximate boundary of sand sea
XVII
XXVI
XVIa
XVI
Spencer Bay
XIV
XV
XXIV
26°
26°
Hottentot Bay
XXV
XXIVa
XXVa
Luderitz
XXIII
0
50km
Elizabeth Bay
15°

size and spacing and grain size and sorting in the sand sea with data on wind regimes and sand transport and concluded that sand was being moved from southern and western coastal source areas with high energy, unimodal wind regimes to accumulate in central and northern areas of the sand sea, where complex low energy wind regimes occurred. Following ROGERS, he concluded that the ultimate source of the sand was the Orange River. This model follows WILSON (1971) and FRYBERGER & AHLBRANDT (1979) in suggesting that sand seas accumulate downwind of source zones in regions of low total or net wind energy.

During the course of a study of the controls of dune morphology in the Namib sand sea by N.L., sand was sampled systematically at 26 major sites throughout the sand sea (fig. 1). The availability of a wide range of samples provides the possibility of testing the above hypotheses using data from grain size and mineralogical analyses. This paper reports the results of these investigations and discusses their implications for the source of sand for the Namib sand sea.

Methods

Sand was sampled systematically from facets of the dune landscape at sites throughout the sand sea. Each sample consisted of approximately 500 gm of surface sand. For analysis each sample was split to 100 gm and sieved through a nest of 9 sieves at 0.5 phi intervals. Grain size and sorting parameters were calculated from graphical data following the formulae of FOLK & WARD (1957).

Heavy minerals were separated by conventional methods with bromoform, and both light and heavy fractions examined with a petrological microscope.

Grain size and sorting patterns in the Namib sand sea

The grain size and sorting vary at two scales in the sand sea. In any area, there is a progressive fining of sands, accompanied by an increase in sorting, from interdunes to dune crests. Overlain on this, is an overall change in grain size from area to area.

The pattern of grain size and sorting changes over the sand sea is shown in fig. 2. Data are for dune crest sands, as these are the most frequently sampled and show the regional changes most clearly. Average values of phi mean grain size for each site range between 1.98 and 2.67 phi (0.25–0.16 mm). Figure 2a shows that the finest sands (>2.50 phi, 0.18 mm) occur in the central and also the north eastern areas of the sand sea. Sands from the southern parts of the sand sea are coarser, with phi mean values between 2.05 and 2.24 phi (0.24–0.21 mm). The coarsest crest sands (<1.98 phi, 0.25 mm) occur in the large compound transverse dunes east of Conception Bay. Values for phi standard deviations (fig. 2b) show that most dune crest sands are well or very well sorted. Sands from the northern group of transverse dunes along the coast are significantly less well sorted and are classed as moderately or poorly sorted. Figure 2b shows that sorting tends to improve towards the east of the sand sea, where most sands are very well sorted. Phi

Fig. 2. Spatial variations in grain size and sorting parameters of dune crest sands (phi units)

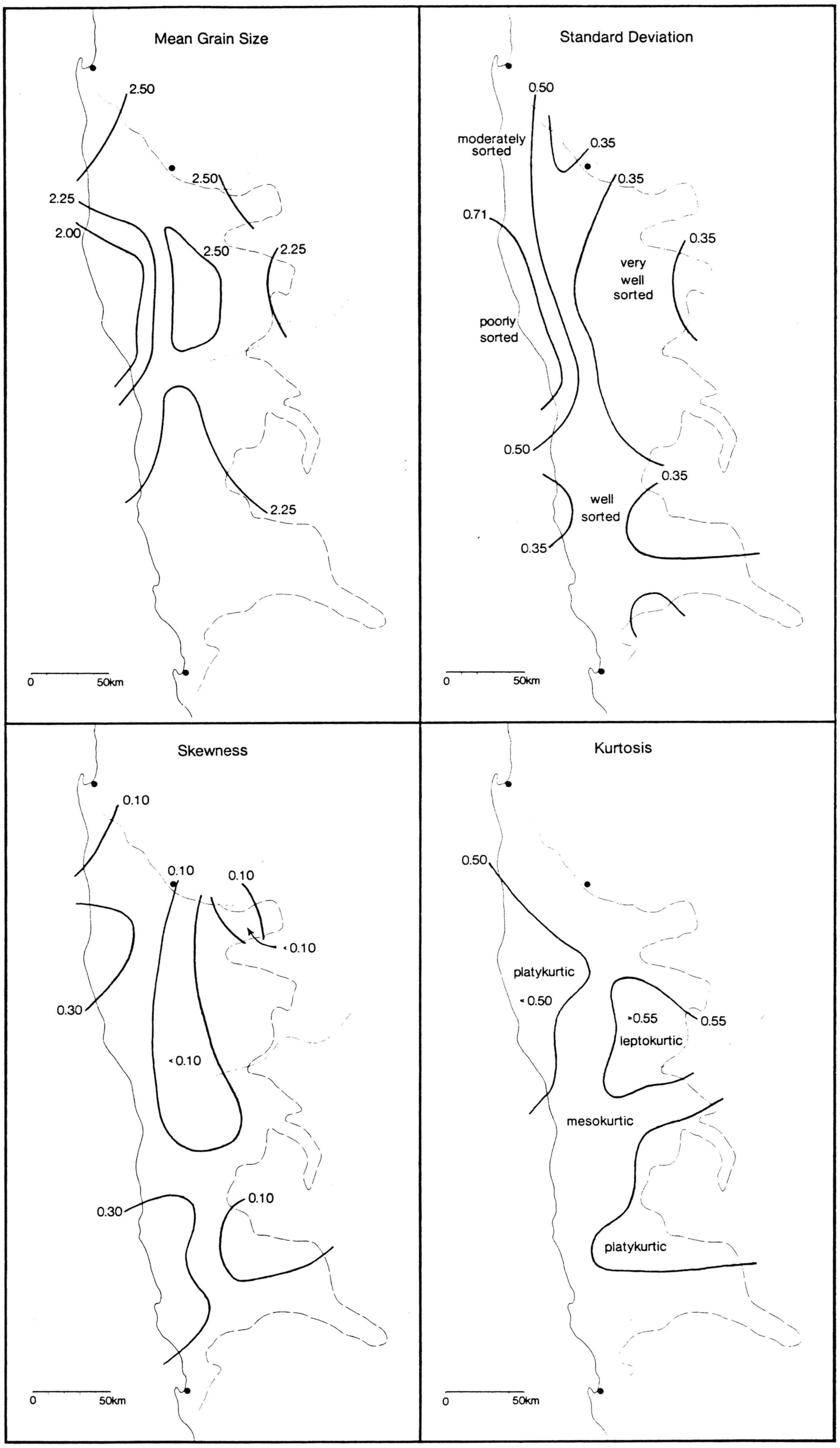

Mean Grain Size
2.50
2.50
2.25
2.00
2.50
2.25
2.25
0
50km
Standard Deviation
0.50
moderately sorted
0.35
0.35
0.71
0.35
very well sorted
poorly sorted
0.50
0.35
well sorted
0.35
0
50km
Skewness
0.10
0.10
0.10
< 0.10
0.30
< 0.10
0.30
0.10
0
50km
Kurtosis
0.50
platykurtic
< 0.50
> 0.55
0.55
leptokurtic
mesokurtic
platykurtic
0
50km

Table 1. Summary table of heavy minerals. (Major = over 20% approx.; minor = less than 20% approx.; rare = few grains. Each column is in approximate order of abundance. Bimodal refers to size distribution of heavy minerals)

Sample	Major	Minor	Rare	Comment
I	garnet (large)	opaques clinopyroxene		
II	garnet (large) clinopyroxene opaques		epidote	
III	clinopyroxene opaques	garnet	hornblende zircon biotite	
IV	clinopyroxene opaques	garnet hornblende	tourmaline zircon rutile	
V	clinopyroxene opaques garnet (large)	hornblende	zircon	
VI	clinopyroxene opaques	garnet hornblende	zircon	
VII	clinopyroxene opaques	garnet	apatite	
VIII	opaques (large) garnet (large)	clinopyroxene (small) opaques (small)	epidote hornblende chlorite zircon	bimodal
IX	clinopyroxene opaques	garnet	zircon hornblende epidote	
X (north)	clinopyroxene opaques	garnet	rutile hornblende	
X (south)	garnet (large) opaques clinopyroxene		epidote	
XI	clinopyroxene opaques	garnet	epidote staurolite hornblende tourmaline apatite	
XII	clinopyroxene opaques	garnet (large)	hornblende epidote zircon	
XII a	garnet (large)	opaques (large)	clinopyroxene hornblende staurolite	bimodal

Sample	Major	Minor	Rare	Comment
XIII	clinopyroxene opaques	garnet	apatite hornblende epidote	
XIV	garnet (large)	opaques clinopyroxene	hornblende zircon	bimodal
XV	clinopyroxene	garnet opaques	hornblende rutile	
XVI	garnet (large)	clinopyroxene (very small) opaques (very small) hornblende	hypersthene	bimodal
XVII	clinopyroxene opaques	garnet staurolite	hornblende epidote tourmaline	
XVIII	clinopyroxene garnet opaques	staurolite	tourmaline epidote zircon	no hornblende
XIX	garnet (large) opaques clinopyroxene	hornblende	epidote biotite rutile staurolite chlorite zircon tourmaline	bimodal
XX	sample missing			
XXI	clinopyroxene garnet (large) opaques	hornblende	biotite epidote staurolite rutile	bimodal
XXII	clinopyroxene garnet opaques		zircon staurolite hornblende epidote	
XXIII	clinopyroxene opaques hornblende	garnet (large)	biotite staurolite tourmaline	bimodal
XXIV	clinopyroxene garnet opaques	hornblende	biotite epidote rutile	
XXV	clinopyroxene garnet opaques	hornblende staurolite	tourmaline	
XXVI	clinopyroxene garnet opaques	hornblende	epidote hypersthene tourmaline	

skewness values (fig. 2 c) show large areas in the centre of the sand sea where dune crest sands are near symmetrical. There are two areas, in southern and western coastal localities, where the sand is strongly positively skewed, denoting an abundance of coarse grains.

Phi transformed kurtosis values (fig. 2 d) show that most sands are mesokurtic but coarse, poorly sorted sands in the west are platykurtic and finer, very well sorted sands in some eastern areas are leptokurtic.

The pattern to emerge is that of fine, well sorted, nearly symmetrical sands in central and northern areas of the sand sea, and coarser, less well sorted sands in southern areas. The sands of the coastal transverse dunes appear to be much less well sorted, and often coarser than those from adjacent areas of linear dunes. There is also some suggestion for coarser, but very well sorted sand in the area of Sossus Vlei and along the eastern margin of the sand sea.

Grain mineralogy of the dunes

Quartz is the dominant light mineral. In some specimens a few large, well-rounded grains are present as well as the main group of smaller grains. In general roundness decreases with size of grain, as is expected.

Feldspar is common, and is about 10% or more of the light minerals in most specimens. Orthoclase, plagioclase and microcline are all present, but not all in all samples. The grains are as well rounded as the quartz grains. No regular variation in the composition of the light mineral fraction could be determined.

Heavy minerals

The heavy mineral assemblage of the dune sands is dominated by clinopyroxene, garnet, and opaque minerals. Other minerals are present only as accessory or rare minerals (table 1).

Clinopyroxene: The commonest transparent mineral. Usually in well-rounded torpedo-shaped grains. Cleavage visible, slightly etched, sometimes stained brown. Colour is variable, from colourless, yellow, pale green or pale brown.

Garnet: Equant but irregular grains. Variable in colour: mostly pink, but some tawny, colourless, or yellowish. Some grains clear, others with many inclusions. Often present as grains two or more times as big as other heavy minerals, in which case pink is commonest.

Opaques: Rounded grains. Magnetite (some black, others with limonitic coatings). Ilmenite.

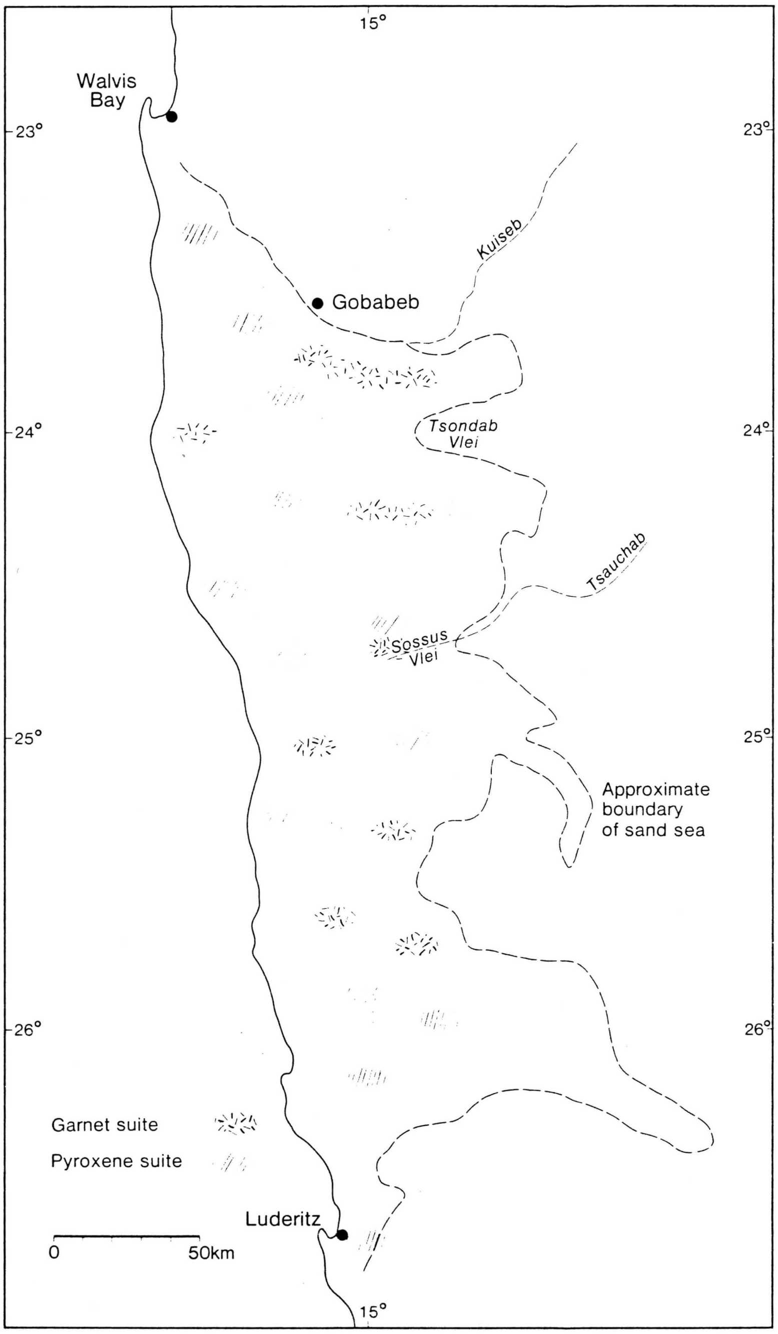
Hornblende: Rounded tabular grains, generally green and pleochroic.

Staurolite: Rounded tabular grains with brown/yellow pleochroism.

Biotite: Irregular flakes, quite fresh.

Rutile: Rare grains, yellowish brown.

Fig. 3. Location of samples of the garnet and pyroxene heavy mineral suites.


15°
Walvis Bay
23°
23°
Kuiseb
Gobabeb
Tsondab Vlei
24°
24°
Tsauchab
Sossus Vlei
25°
25°
Approximate boundary of sand sea
26°
26°
Garnet suite
Pyroxene suite
Luderitz
0
50km
15°

Zircon: Generally clear and slightly yellowish. Worn, but with crystal form still recognizable.

Minor minerals: Occasional grains of sillimanite, epidote, green tourmaline.

The same mineral suite is found throughout the sands, and suggests derivation from metamorphic rocks rich in quartz, feldspar, garnet, and clinopyroxene, together with a relatively small number of other minerals. Compared with many mineral suites, these are notably poor in zircon, rutile and tourmaline. The sands appear to be immature, in the sense that many weatherable minerals are still present, and that many are not very well rounded. There is no indication of local contamination by distinctive minerals.

The only general distinction that might be drawn from the heavy minerals is a tendency for the samples to fall into two suites: a pyroxene suite and a garnet suite. One has a heavy mineral content dominated by clinopyroxene. Garnet is minor, and of about the same size as the pyroxene grains. The second is distinguished by having common to abundant large grains of pink garnet, more common than the pyroxene.

Transported grains are generally sorted by size and specific gravity, and so minerals of "hydraulic" equivalence are found together. There seems to be no good mechanism for deriving a population of larger garnets by simple wind transport, and a mixture of minerals from some secondary source may be sought. Perhaps these samples with large garnets are from places that happen to have some nearby rock outcrops to provide suitable large garnets.

The two suites are not clear cut, and a few specimens fall between the two. No corresponding variation has been detected in the light minerals, and the two suites do not seem to correspond in any way with any of the patterns detected by grain size analysis. The distribution of the two suites is shown in fig. 3.

Biotite flakes are present in several samples. Biotite is common in river sediments, including those of the Kuiseb River, but it is not usual in dune sands. It is very susceptible to abrasion weathering, and disappears rapidly in the dune environment. The biotite flakes are not common, but sufficiently widespread to discount any special case explanation of contamination, and they do not appear to have suffered any noticeable attrition. The grains are generally small. Perhaps they are transported by occasional dust-storms that carry a few grains directly from river-bed sources to the dunes, which might be done without significant abrasion. Certainly they could not survive traction or saltation movements in a dune environment for very long. Alternatively they may be derived from occasional outcrops of rock, in the manner suggested for the large garnets.

It is perhaps worth noting that the pyroxene suite dominates to the south, and certainly the most southerly specimen appears to be so dominated by pyroxene that it could not be the source for the specimens further north. Similarly, many of the specimens near the coast seem to be pyroxene dominated, and are not a likely source for the garnet-bearing specimens further inland.

Possible sand sources

Mineralogical information has been determined or compiled on river sand, shelf sediments, Namib Sandstone and older metamorphic rocks to see how these rate as possible sources of the sand in the Namib sand sea.

River sand

Sand of the Kuiseb River was sampled 20, 40 and 70 km east of Gobabeb. In all samples the mineralogy was similar, and considerably different from that of the dune sands, even though dune sand is continually added to the stream load.

The light fraction consists of over 90% quartz, and the rest is feldspar. Microcline is present, but rare. The heavy mineral assemblage is dominated by opaque minerals, then biotite (20 to 40%), hornblende (about 20%) and smaller amounts of garnet, zircon, monazite, tourmaline, staurolite, and others. Biotite increases downstream and is presumably derived from local rocks.

Shelf sediments

JOHN ROGERS (pers. comm.) has kindly supplied the following unpublished information. AHMED (1968) examined samples from the inner shelf between the Olifants River and the Orange River and reported pyroxenes, amphiboles, magnetite, garnet, and zircon, with minor amounts of rutile, epidote, tourmaline, sillimanite, staurolite and kyanite. O'SHEA (1971) examined very fine sand of the inner shelf north of the Orange River and reported garnet, ilmenite, rutile, tourmaline, staurolite, pyroxenes and amphiboles.

Adding these together we can get something like the sand sea assemblage, with dominant clinopyroxene, garnet and opaques (both magnetite and ilmenite), minor amphibole, and traces of other minerals.

Older bedrock

ROY MILLER (pers. comm.) informs us that garnet, biotite, opaques, zircon, hornblende, rutile, sillimanite, epidote, and tourmaline are common north of the Kuiseb, at Conception/Meob, and in the rocks of the Namaqualand Metamorphic Complex which extends along the Orange and up to Spencer Bay. Clinopyroxene is commonest in the Namaqualand rocks, though present in other areas, which suggests that the Namaqualand Metamorphic Complex may be the ultimate source of the sands of the Namib sand sea.

Namib sandstone

Three samples of sandstone, from Gobabeb, Homeb and a few kilometres south of Gobabeb were crushed, treated with acid to remove the carbonate cement, and then examined like the dune sands.

The light fraction is very similar to that of the dune sand, with about 90% quartz and the rest feldspar including relatively fresh microcline, even in larger grain sizes.

The heavy minerals are dominated by opaques (up to 80%) with garnet, clinopyroxene, amphibole, epidote, and rarer grains of zircon, tourmaline, rutile and others.

There was considerable variation between samples of sandstone, but the overall impression is that the sandstone does not seem to be a likely source for the overlying dune sands. More specimens must be examined before a firm conclusion can be drawn.

Discussion

The limited samples of Namib Sandstone examined have a mineral assemblage fairly different from the dune sands. The dune sand is less red than the sandstone, but later bleaching (by attrition of iron oxide coatings) could possibly account for this. Much of the sandstone is still in place under cappings of calcreted conglomerate.

If other rivers draining the Great Escarpment were like the Kuiseb, their sands would not be suitable as a source for most of the dunes. The abundant biotite could be lost during attrition in wind transport, but differential weathering or attrition could not turn a dominant hornblende assemblage into one with clinopyroxene and garnet.

Grain size and sorting patterns suggest a coastal source for the dunes, with fining and better sorting inland and to the north. Perhaps the best available source is the coastal strip between the Orange River and Luderitz. There is a considerable similarity between the sands of the inner shelf, beaches and dunes of the Elizabeth Bay area. A clear and definite sand stream up to 10 km wide with rapidly moving barchans and barchanoid ridges links these beaches with the sand sea north of Luderitz. Potential (and probably actual) sand movement through this corridor is about 300,000 m^3 per year. The sand from near Luderitz appears to be considerably different mineralogically from all the other Namib sands examined. Other possible coastal source areas are the Meob-Conception Bay area, and Hottentot Bay north of Luderitz. These areas may have been more important when sea levels were lower.

It seems probable that the shelf sands have been derived from sediment brought down the Orange River, derived in turn from Namaqualand Metamorphic Complex. These seem to be the most promising source of abundant clinopyroxene.

Sands derived from an offshore or coastal source appear to be modified inland, with addition of other sand which still has a dominantly metamorphic mineral assemblage but with more garnet than the sand from the shelf. The other sand would have been derived ultimately from old metamorphic rocks, but may have reached its present position via fluvial deposits, or possibly earlier cemented sandstones.

In conclusion, of the two hypotheses for sand sources mentioned at the beginning of this paper that of ROGERS (1977), LANCASTER (1981 a) is more consistent with our findings than that of BESLER & MARKER (1979). It is perhaps naive to expect a single simple source of the dune sands, for the Namib has a very long history as a desert, and we might expect sands to be recycled several times through dune, river, coastal deposit, and indurated sandstone. This paper records a broad view of the problem and some of the data, but we are probably using too broad a brush in our attempt to delineate what now appears to be a complex problem of geomorphology and sedimentology.

Acknowledgements

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