Grain-Size Characteristics of Wind Ripples on a Desert Seif Dune

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The grain-size distribution of sand from ripples and megaripples, formed on a desert seif dune in the northern Sinai desert, was analyzed by using a unique method of sampling the surface layer. The dune, on the surface of which the ripples under investigation were formed, is composed of unimodal fine sand. The plinth of the dune is composed of bimodal, fine and medium-grained, sand on which the megaripples form. In both ripples and megaripples, the sand, several centimeters below the surface, is coarser than that of the dune body. The sand of the crest of the ripples and megaripples is coarser than that of the trough. Megaripples are characterized by an armored layer of coarse sand covering the windward slope, which thus makes up the trimodal distribution of megaripple sand. Ripples, however, are composed of unimodal sand and lack an armored surface. It seems that, more than anything else, it is the process of sand grain sorting that affects the wavelength of the ripples and megaripples.

Wind ripples are ubiquitous on the surface of active aeolian sand dunes. Sorting plays an important role in the formation of wind ripples whose height and wavelength increase as the range of grain-size becomes greater (Bagnold, 1941; Sharp, 1963; Ellwood *et al.*, 1975).

In spite of the resemblance of wind ripples to sand dunes, their formation is different, since different proportions of transportation, by saltation and creep modes, are the cause of the ripple formation. This contrasts with the configurations of sand dunes which are due to local variations in surface shear stress rather than to saltation impact (Bagnold, 1941; Greeley and Iversen, 1985; Tsoar, 1985). One result of these two differing processes of formation is the distinct grading of grains over dunes as compared with ripples. On the former, fine sand is found around the crest because the increase in surface shear stress on the windward slope is not strong enough to entrain the coarse grains, whereas, understandably, the plinth of the dune is composed of coarser grains and, in some cases, of a bimodal mixture of fine sand with coarse sand to form a moderator slope there (Fig. 1; Vincent, 1984). On the latter, the coarse sand is concentrated around the crest through the impact of saltating grains, whilst the trough is made up of finer sand grains (Sharp, 1963).

Two types of wind ripples are distinguishable in the field. One is composed of well-sorted unimodal fine sand and has wavelengths in the range of 1-20 cm. The other type

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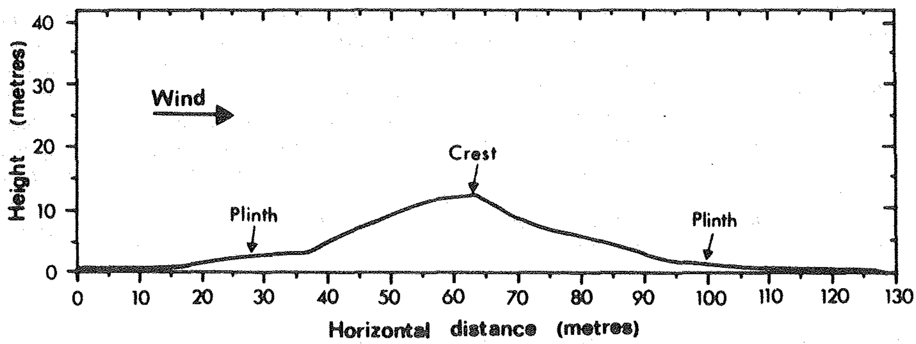
is known as "ridge" (Bagnold, 1941) or "megaripple" (Greeley and Peterfreund, 1981), with wavelengths of 25 cm and longer. Megaripples are formed by sand with a wide range of grain-sizes, usually a bimodal mixture, and these are often found on the plinth of a dune (Fig. 1; Vincent 1984). The object of the field work was to study differences in surface grain-size characteristics in ripples and megaripples, and between the crests and troughs of ripples and megaripples, over several different sections of a desert seif dune in the northern Sinai desert 35 km. south of El Arish. The samples were taken in summer after a long period in which the wind was unidirectional (Fig. 1).

Figure 1: The profile of the dune and the location of sampling points.



SAMPLING METHOD

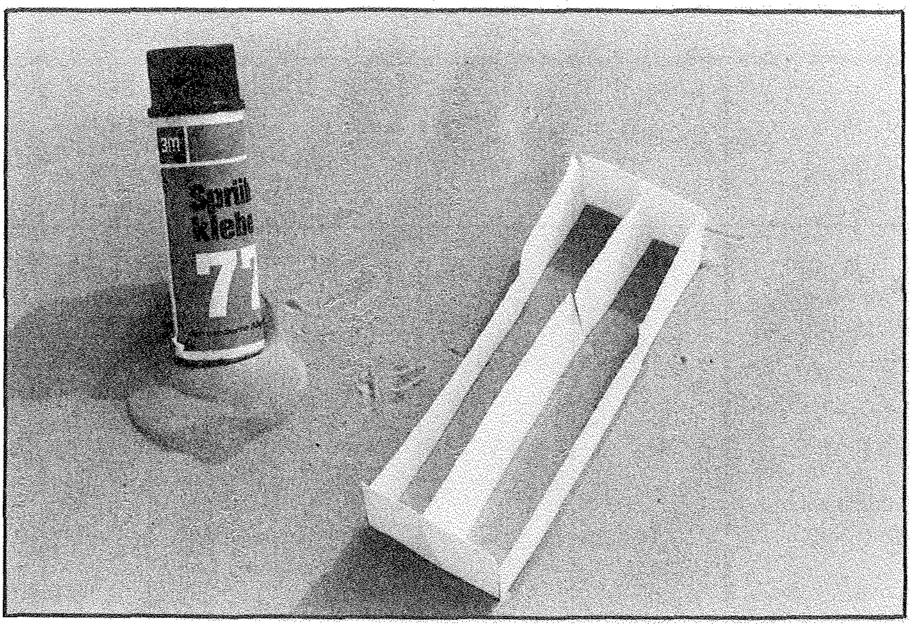
In most analyses of grain-size, little attention has been paid to the technique of sampling. The study of microfeatures on sand dunes is met with difficulties in sampling because of rapid vertical lamination and lateral variation of sand on ripples. Several investigators (Apfel, 1938; Otto, 1938; Ehrlich, 1964) have stressed the importance of drawing samples from a single bed deposited under uniform environmental conditions. Apfel (1938) termed it "phase sample," and Otto (1938) "sedimentation unit." White and Williams (1967) suggested that the ideal sampling unit was a single-grain layer.

The usual sampling method of dune sand consists of taking a volume of sand from the body of the dune after removing the surface ripples that are regarded as lag sediments (e.g., Folk, 1971; Warren, 1972; Vincent, 1984; Watson, 1986). However, when sampling a certain volume from several centimeters below the immediate surface layer, or scooping up dry sand in any other way, a mixing of material from several laminae and environments will result.

The sampling technique used in this study is based on spraying the surface of the ripple crest and trough separately with spray adhesive. The crest is defined according to

Allen (1968) as that part of the ripple of greater elevation than half the ripple height. The trough is thereby the lower part having an elevation of less than half the ripple height. These boundaries were delimited by cardboard papers (Fig. 2). Spraying must be done carefully; the first spraying should be at short intervals from a height of 60 cm, and then from a height of about 30 cm, in order to prevent the sand from being scattered by the impact of the spray. Spraying continues until the first layer of the sand is saturated with glue. After one minute the sample can be peeled off.

Figure 2: The ripple crest and trough as outlined with cardboard.
Spraying can in the background.



Such samples proved not to include more than two layers of grains ranging in thickness from 0.5 mm to 2.5 mm, depending on the grain-size. In the laboratory the glue is dissolved with chloroform ($CHCl_3$) or carbontetrachloride (CCl_4), both solvents being soluble in water. After dispersion with a high-intensity sonic processor, washing and drying, the samples are loose and ready for grain-size analysis.

Grain-size analysis was undertaken by means of standard sieves (7.62 cm in diameter) suspended on a shaker. The scale of the sieves was the usual geometrical grain-size phi-scale. Their orifices were between 0.062 and 2.000 mm in 1/2 phi class interval. The four moment statistics, mean ($\bar{X}_\varphi$), standard deviation (s_φ), skewness (Sk_φ) and kurtosis (Kg_φ), were calculated arithmetically.

RESULTS AND DISCUSSION

A total of 92 samples were collected for troughs and crests at five different points across and along the dune. Two points were at the plinth of the dune where megaripples are located (Fig. 1), two others at the middle of both slopes (windward and leeward), and one on the crest. The lee slope is generally a slip-face which has no ripples; however, in many cases there is sand transport on some parts of the lee slope, parallel to the crest-line, which is manifested by ripples (Tsoar, 1983). Table 1 presents the average moments of the five sampling points and their size range.

Table 1: The average moments at the five sampling points on the dune and the size range including 90% of the sample.

Sampling point	Moment				Size range (in φ) including 90% of the sample
	($\bar{X}_\varphi$)	σ_φ	Sk_φ	Kg_φ	
Lee plinth	1.18	0.75	0.52	4.00	0.06-2.42
Windward plinth	1.41	0.70	0.68	3.79	0.25-2.57
Middle lee slope	2.05	0.47	0.32	3.24	1.27-2.83
Middle windward slope	1.70	0.47	0.31	7.32	0.92-2.40
Crest	1.87	0.42	0.80	5.28	1.18-2.50

The mean values of the various samples appear in a wide range from 0.41 φ (0.75 mm) to 2.22 φ (0.21 mm), the mean being 1.62 φ (0.33 mm). The separate samples from the crest and the trough give more extreme values, whereas, in all cases (except one), the crest has coarser sand than the trough. This spread is more obvious with the megaripples (Table 2).

The modal grain-size of aeolian dune sand taken from five continents is generally in the range of 2-3 φ (0.125-0.250 mm) (Ahlbrandt, 1979) which is also the modal grain-size taken several centimeters below the immediate ripple surface of the dune under investigation. The average grain-size of the ripples is coarser than that of the dune. The coarse sand of the ripples travels mostly by surface creep (Sharp, 1963). The driving force behind the creep is the finer saltating grains which are about 75% of the total sand flow (Bagnold, 1941). These fine saltating grains move quickly across the dune and settle down on the lee slope where they form the laminae of which the dune body is composed. The source of the fine saltating sand is the process of erosion on the ripple troughs on dune slopes which gradually exposes the underlying laminae.

Table 2: Mean grain-size values of the trough of ripples and megaripples, crest and dune body.

Location	Mean $\bar{X}_\varphi$
Ripple trough	1.87
Ripple crest	1.71
Megaripple trough	1.16
Megaripple crest	0.46
Whole ripple	1.77
Whole megaripple	0.74
Dune body below the crestline	2.21
Dune body below the plinth	1.99

Except for Folk (1971), who found that sand grains at the crest of the dune were larger than those on the slopes, most other authorities found that the finest sand is at the crest and the coarsest concentrates at the plinth. Bagnold (1941) believed that coarse sand collected at the base of a dune due to its inability to move up onto the slope. Sharp (1966) found fewer coarse sand grains at the crest than at the plinth, whereas the finest grains were more common on the slopes than on the crest. In the present research, the finest grains were found on the ripples of the lee slope, then on the crest of the dune and finally on the windward slope. The coarsest were found on the megaripples at the plinth of the dune (Table 1).

Statistical tests show that there are significant differences (at 1% level) between grain-sizes at various points on the dune, with the exception of those found on the windward plinth and the middle windward slope, and the windward plinth and the lee plinth. The lee plinth and the windward slope, and the crest and the lee slope show significant differences between the two means at the 5% level. It may be that the grain-size of the sand decreases from the plinth toward the crest because of a decrease in the wind's competence. The finest grains were found and sampled on the middle lee slope, apparently because coarse sand does not reach there. The fine saltating grains are found to concentrate there, while they are depleted on the windward slope. Despite this, the grain-size on the surface of the middle lee slope is still coarser than that of the samples of the underlying sand below the crestline (Table 2).

The large range of mean values (Table 1) results from the fact that the sampling was done in five different sections of the dune, including ripples and megaripples. It is therefore desirable to classify the results in agreement with ripple wavelength (Table 3).

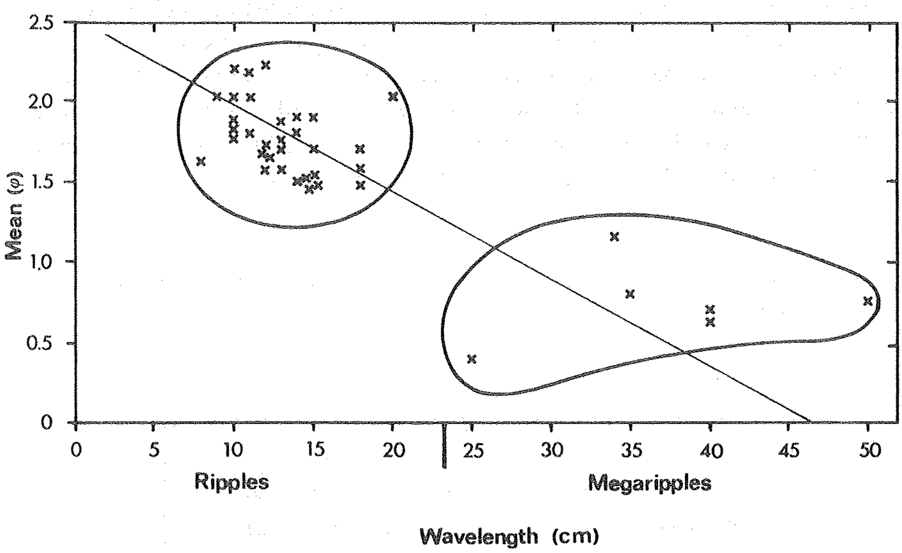
Table 3: Distribution of ripple wavelengths at various sampling points and their average moments.

	Number of Ripples Sampled According to Various Wavelengths (cm)						
	Ripples			Megaripples			
Sampling Points	0-10 cm	11-15 cm	16-20 cm	21-25 cm	31-35 cm	36-40 cm	46-50 cm
Lee plinth		3	1	1	1	1	1
Windward plinth		4	2		1	1	
Middle lee slope	5	2	1				
Middle windward slope	1	7					
Crest	1	7					
$\bar{X}_{\varphi}$	1.91	1.75	1.69	0.41	0.97	0.66	0.76
σ_{φ}	0.44	0.47	0.71	1.17	0.94	1.16	0.94
Sk_{φ}	0.36	0.59	0.48	0.98	0.39	0.56	0.52
Kg_{φ}	5.16	5.26	3.55	2.85	2.58	2.20	3.84

As shown in Table 3, the megaripples appear only on the plinth of the dune where mean grain-size is the highest. The smallest wavelengths are on the center of the lee slope. The wavelengths of the megaripples have no significant correlation (5% level) with mean surface grain-size of the megaripple crest, trough or the entire megaripple, but wavelengths of the ripples have a significant correlation with mean surface grain-size at the 5% level only. When ripples and megaripples are taken together in this respect, the wavelength has a significant correlation (1% level) with mean grain-size (Fig. 3). It seems that grain-size is not the only factor that determines the wavelength of ripples.

Values of the standard deviation (sorting) are related to the range of the grains and, hence, to the type of ripples (Tables 1 & 3). Sand on the megaripples has a high standard deviation (above 0.9 φ), demonstrating poor sorting. Sand on the ripples is better sorted, with a standard deviation averaging between 0.44 φ and 0.71 φ (well to moderately-well sorted). For ripples alone, and for megaripples taken with the ripples, there is a significant correlation (1% level) between standard deviation of grain-size and wavelength. The megaripples themselves do not exhibit any such significant correlation. These results support Walker's (1981) conclusion that ripple wavelength also depends on sorting and can extend as sorting becomes poorer. The standard deviation and mean grain-size values also intercorrelate significantly (1% level) when ripples and megaripples are taken together, whereas, separately, their significance of correlation stays at a 5% confidence level.

Figure 3: The mean grain-size($\bar{X}_\varphi$)versus wavelengths of ripples and megaripples.



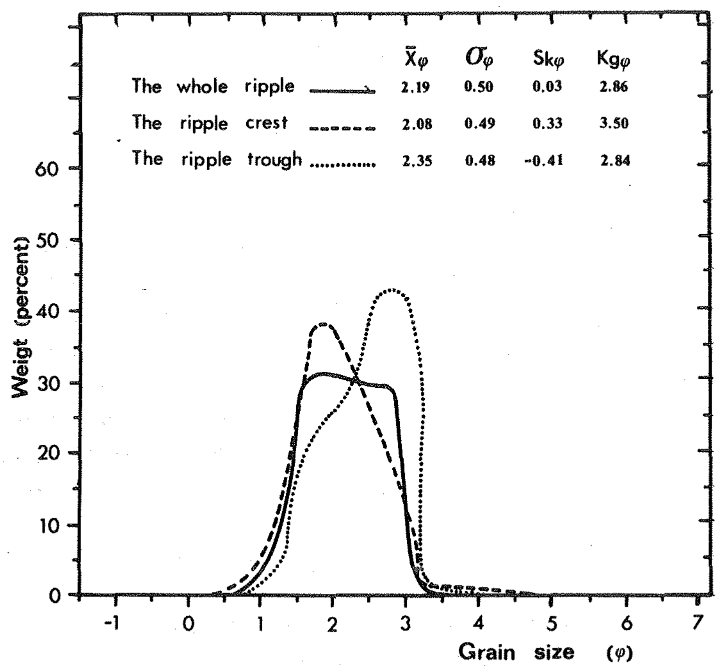
Skewness is considered to be one of the more delicate parameters for distinguishing sediments (Duane, 1964). In most cases, dune sand, as well as ripple sand, tends to positive skewness, as indicated by a "tail" of silt and very fine-grained sand (Vincent, 1984). The source of these fine sediments is dust that settles on the dune after dust storms, or the decomposition products of minerals other than quartz. In the present study, separate sampling on crests and troughs of ripples and megaripples showed that 84% had positive skewness. Among the 13 cases where skewness was negative, 11 were samples from the ripple or megaripple troughs, where most of the sand is relatively fine and the "tail" consists of coarse sand. In 90% of the results, the skewness of the whole ripple (crest and trough together) possesses positive values. Averages of skewness, as shown in Table 1, indicate that the lowest values are found at the two mid-slopes, whereas the crest has the highest value. The skewness values have a wide distribution with no significant differences between results at the various sampling points. In view of this, it seems that skewness values have no dynamic or sedimentological importance in the different environments of dune ripples.

Kurtosis values showed no significant trends. The kurtosis values of all the samples were above one; that is to say, leptokurtic. There was no significant correlation between mean grain-size and the kurtosis values.

Grain-Size Distribution Curves

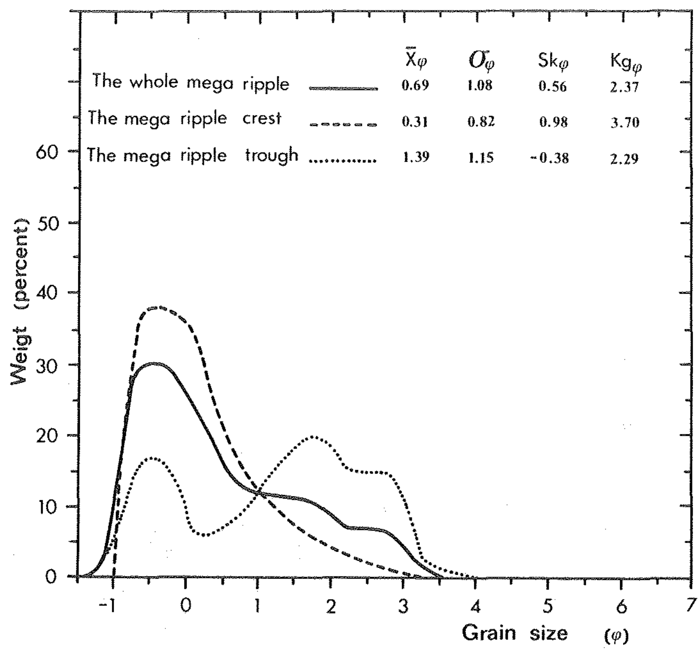
Figure 4 presents the grain-size distribution curve of a ripple in the middle lee slope (wavelength 10 cm), and its crest and trough separately. Figure 5 shows the same for a megaripple on the windward plinth (wavelength 40 cm). In the presentation of distribution curves of this sort, there is an error in the fact that we are taking the midpoint of each class; however, the purpose of this kind of presentation is to distinguish between the various modes, so it is more useful than cumulative curves. Such a presentation on the same scale with the same size groups permits a visual comparison of the distribution at the various sampling points and layers. In Figure 4, it can be seen that the distribution of the grain-size of an ordinary ripple is unimodal and almost symmetrical; the ripple crest is coarser with positive skewness; and the grain-size distribution of the trough is finer with negative skewness.

Figure 4: Grain-size distribution curves for a ripple of 10 cm wavelength at the middle lee slope of the dune.



The megaripple (Fig. 5) has a manifestly asymmetrical distribution with one distinct coarse mode and two subordinate finer modes. Asymmetry is more pronounced at the crest where the distribution is unimodal, the coarse fraction is marked, and the skewness is positive. In the trough the distribution is trimodal where the coarse mode is the lesser component and the major part is finer.

Figure 5: Grain-size distribution curves for a megaripple of 40 cm wavelength at the windward plinth of the dune.



Grain-Size Characteristics Below the Top Surface

Two additional layers were sampled below the upper layer of a megaripple and a ripple in order to study the contrast between grain-sizes of the surface layer subjected directly to wind action and the two immediate layers underneath.

The megaripple analyzed had a windward armoring of coarse grains. After peeling off its uppermost layer, the scarcity of coarse grains was remarkable (Fig. 6). The grain-size distribution of the surface layer of a megaripple of 40 cm wavelength is trimodal (similar to Fig. 5), with one prominent coarse mode and two small fine modes (Fig. 7). In the second and third layers, the coarse mode is reduced dramatically and becomes insignificant. The second and third layers are similar in grain-size distribution and statistical moments to the megaripple trough of the surface layer (Fig. 5).

This megaripple was formed on the plinth of the lee slope, which is composed of bimodal sand. The bimodality is concordant with the distribution of the finer two modes in the second and third layer immediately below the surface, as referred to above (Fig. 7). The coarse mode of the megaripple resulted from the concentration of very coarse sand as an armored covering of grains on its windward slope. Little sand of this grain-size is found below the surface, and almost nothing exists several centimeters below the surface.

Figure 6: A. Megaripple showing armored cover of coarse grains on windward slope and crest. B. Same megaripple with surface layer peeled off by spray adhesive. Note scarcity of coarse grains on crest and windward slope. The peeled layer is on the left side.

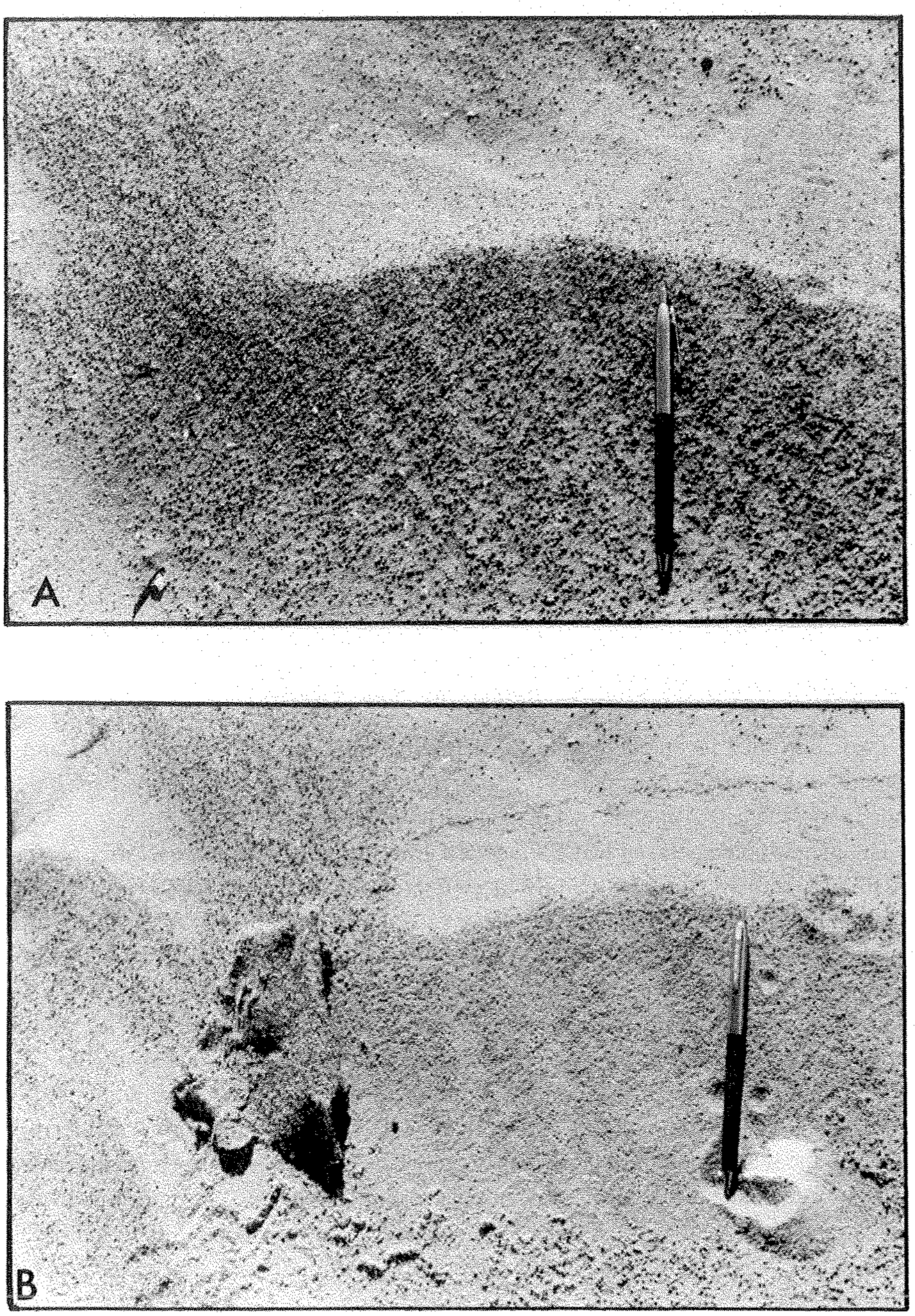
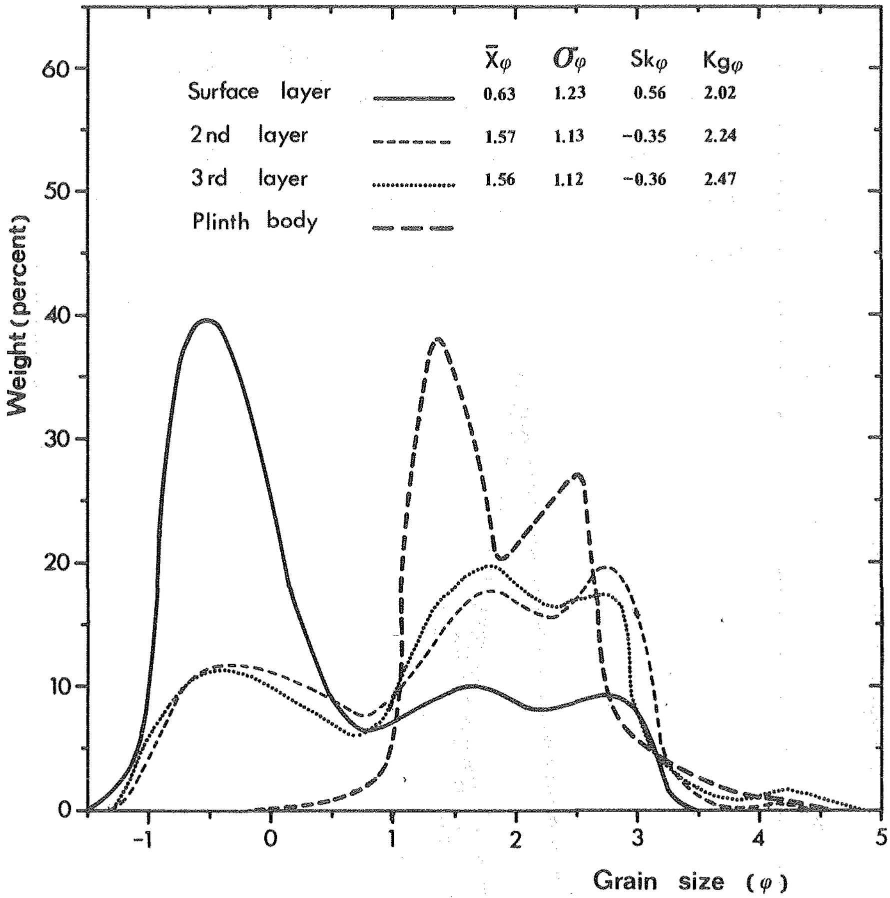
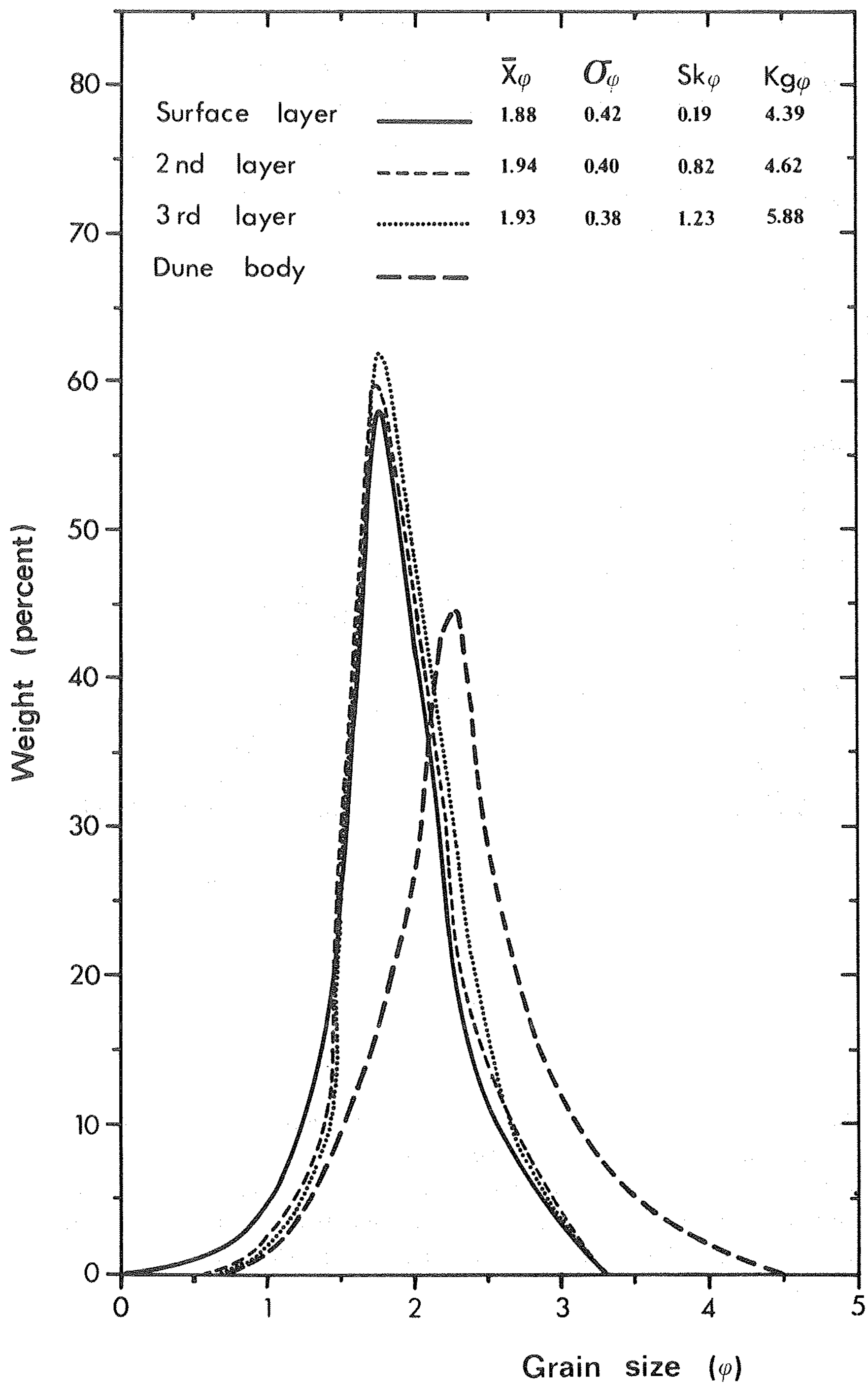


Figure 7: Grain-size distribution curves for surface layer of megaripple and two layers of immediate underlying sand at the lee side plinth of the dune, as compared with sand sampled below the megaripple.



The grain-size distribution of the surface layer of a ripple sampled at the crest of the dune (wavelength 15 cm), is fine and medium-grained and unimodal (Fig. 8) and shows almost no difference with the underlying second and third layers. Unlike the megaripple, the ripple lacks an armored surface and there is no difference in grain-size between the surface layer and the two underlying ones. However, the ripple's sand is coarser than that found within the body of the dune several centimeters below the surface (Fig. 8).

Figure 8: Grain-size distribution curves for surface layer of ripple and two layers of immediate underlying sand at the crest of the dune, as compared with sand sampled below the ripple.



SYNOPSIS

At the sampling site, megaripples are limited to the plinth of the dune where the underlying dune is composed of bimodal sand. Ripples are formed on the surface of the dune, whose body is composed of unimodal fine sand. The wavelengths of ripples vary from 8 to 20 cm, and those of megaripples, from 25 to 50 cm. No continuity exists between ripples and megaripples. The average grain-size of the ripple surface layer is coarser than that of the dune on which the ripples are formed. The sand at the crest of ripples is coarser in grain-size than that of the trough. This feature is much more significant for the surface of megaripples, where the coarse sand forms an armored cover layer on most of the windward slope.

Coarse particles advance by creep, while the fine ones do so by saltation, this being a much quicker and more efficient process of transportation. Because of their greater momentum, fine particles, which are the dominant fraction, concentrate on the depositional areas of the lee side of the dune, where they form the laminae. They are exposed to transportation again in the ripple troughs on slopes that are subject to erosion. The finest grains on ripple troughs correspond in their size to grains composing the dune body.

Grain-size is an important factor, though not the only one, in determining the wavelength of ripples. The finer the grains, the smaller the wavelength. However, it seems more likely that wavelength is affected by sorting, since saltation is much more efficient on poorly sorted sand (Ellwood *et al.*, 1975). There is a significant correlation between standard deviation (sorting) and mean grain-size values. The sand of ripples and megaripples is positively skewed (having a "tail" of very fine-grained sand in the distribution curve). Only in some cases is the ripple trough negatively skewed ("tail" of coarse sand).

Megaripples, trimodal in grain-size distribution, are formed on bimodal sand. The coarsest mode is added onto the bimodal distribution because of the megaripple's tendency to form an armored surface layer on the windward slope, where all the coarsest grains accumulate. Ripples are unimodal in grain-size distribution with no difference between the surface layer and the two immediate underlying ones.

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REFERENCES

Ahlbrandt, T.S. (1979) Textural parameters of aeolian deposits. In McKee E.D., (ed.) *A Study of Global Sand Seas*. U.S. Geological Survey Prof. Paper 1052.

Allen, J.R.L. (1968) *Current Ripples*. Amsterdam: North-Holland.

Apfel, E.T. (1938). Phase sampling of sediments. *Journal of Sedimentary Petrology*, 8:67-68.

Bagnold, R.A. (1941) *The Physics of Blown Sand and Desert Dunes*. London: Methuen.

Duane, D.B. (1964) Significance of skewness in recent sediments, Western Pamlico Sound, North Carolina. *Journal of Sedimentary Petrology*, 34:864-874.

Ehrlich, R. (1964) The role of the homogeneous unit in sampling plans for sediments. *Journal of Sedimentary Petrology*, 34:437-439.

Ellwood, J.M., Evans, P.D. and Wilson, I.G. (1975) Small scale aeolian bedforms. *Journal of Sedimentary Petrology*, 45:554-561.

Folk, R.L. (1971) Longitudinal dunes of the northwestern edge of the Simpson desert, Northern Territory, Australia, 1. Geomorphology and grain size relationships. *Sedimentology*, 16:5-54.

Greeley, R. and Peterfreund A. R. (1981) Aeolian "megaripples": Examples from monocraters, California and northern Iceland. *Geological Society of America, National Conf. Abstracts*, 13:463.

Greeley, R. and Iversen, J.D. (1985). *Wind As A Geological Process*, Cambridge: Cambridge University Press.

Otto, G.H. (1938) The sedimentation unit and its use in field sampling. *Journal of Geology*, 46:569-582.

Sharp, R.P. (1963) Wind ripples. *Journal of Geology*, 71:617-636.

Sharp, R.P. (1966) Kelso dunes, Mojave desert, California. *Geological Society of America Bulletin*, 77:1045-1074.

Tsoar, H. (1983) Dynamic processes acting on a longitudinal (seif) sand dune. *Sedimentology*, 30:567-578.

Tsoar, H. (1985) Profile analysis of sand dunes and their steady state significance. *Geografiska Annaler*, 67A:47-59.

Vincent, P.V. (1984) Particle size variation over a transverse dune in the Nafud as Sirr, central Saudi Arabia. *Journal of Arid Environments*, 7:329-336.

Walker, J.D. (1981) *An Experimental Study of Wind Ripples* Unpublished M.Sc. Thesis. Cambridge, MA: Massachusetts Institute of Technology.

Warren, A. (1972) Observations on dunes and bi-modal sands in the Tenere desert. *Sedimentology*, 19:37-44.

Watson, A. (1986) Grain-size variation on a longitudinal dune and a barchan dune. *Sedimentary Geology*, 46:49-66.

White, J.R. and Williams, E.G. (1967) The nature of a fluvial process as defined by settling velocities of heavy and light mineral. *Journal of Sedimentary Geology*, 37:530-539.