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GRAVEL SPREADS AND SPACED PEBBLES OF THE DARB EL ARBA'IN DESERT AND A MEANS OF DUNE STABILIZATION

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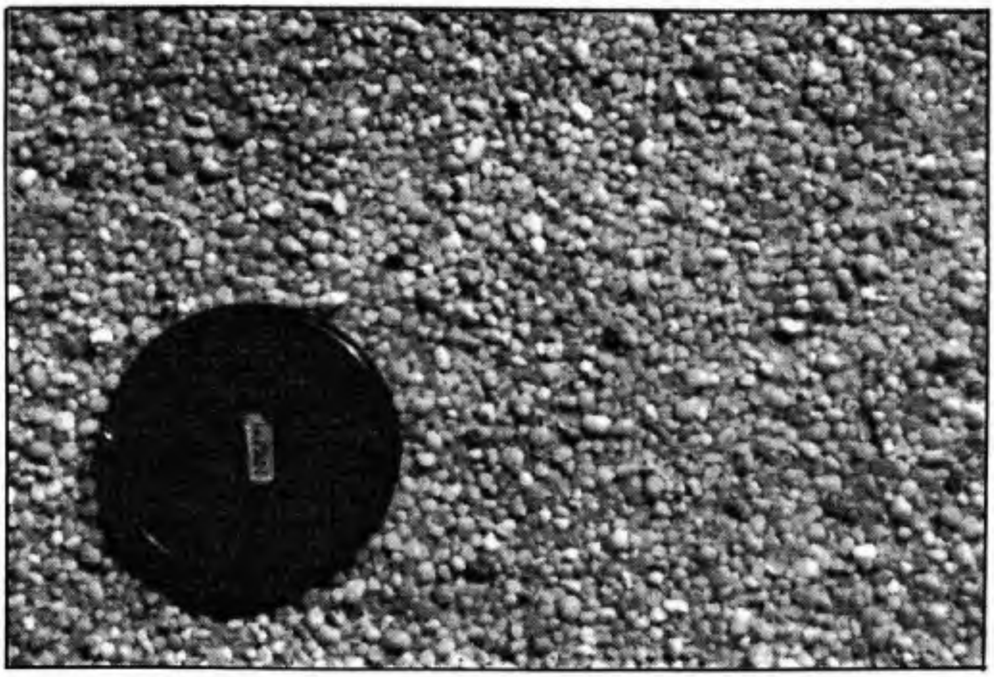
In the eastern Sahara (Fig. 1), the area bordered by the Nile Valley on the east, Libya and Chad on the west, Wadi Howar to the south in Sudan, and north to the limestone plateau of middle Egypt has been called the Darb el Arba' in Desert after the ancient caravan " road of 40 days" from Assiut on the Nile to Darfur in Sudan (Haynes 1982). With annual precipitation of <5 mm/yr and a frequency of 30 to 40 years between significant rainfall events, it is very likely the driest region on earth (Long et al. 1985).

Quaternary climates of the Arba' in Desert have cycled from relatively wet periods (pluvials) to hyperarid periods and have been approximately 180^0 out of phase with the glacial - interglacial cycles of the northern hemisphere (L'ezine and Casanova 1991). During the pluvials, probably never wetter than semiarid (200 to 300 mm/yr), ancient rivers drained the highlands of southwestern Egypt and northwestern Sudan and deposited alluvial sediments in lower areas. During the hyperarid periods, dominated by aeolian processes, the fine grained fluvial silt and clay are blown away, fine to medium sand is blown into dunes and sand sheets, and coarse sand and gravel spread out as aeolian lag deposits that protect (armor) substrates from further deflation (Haynes 1985). The net effect has been a lowering of the landscape by differential erosion whereby basins are deepened, the more resistant portions of the bedrock (Nubian sandstone) become escarpments and yardangs, and riverbeds become topographically inverted as either isolated gravel capped ridges, i.e. inverted wadis (Giegengack 1968) or as gravel sheets and spreads (Said 1980).

Aside from bedrock outcrops much of the surface of the Arba' in Desert is made up of alluvial hamadas, sand sheets, and gravel spreads (Haynes, Maxwell , and Johnson 1993). Active sand dunes override all other deposits and, along with playa deposits, represent a relatively small part of the surficial deposits, except for the Great Sand Sea where dunes predominate.

Fig.1 Map Of The Darb El Arba'in Desert Showing Locations Of Sample Sites.

The sand sheets are composed of alternating lamina (Fig.2a)of fine to medium quartz sand, usually less than 10 mm thick, separated by single grain thicknesses of quartz granules (1.5 mm to 2.5 mm diameter) (Maxwell 1982), essentially as defined by Folk (1971) for the Simpson Desert of Australia. and by Warren (1972) for the Tenere Desert of the Western Sahara. Individual granules, well rounded to subrounded, form compact surface lags of one grain thickness (Fig. 2b). Recent research has shown sand sheets to be dynamic with annual variations in thickness and spectral response (Maxwell and Haynes 1989, 1993). The sand of some barchan dunes may derive from sand sheets (Haynes 1989).



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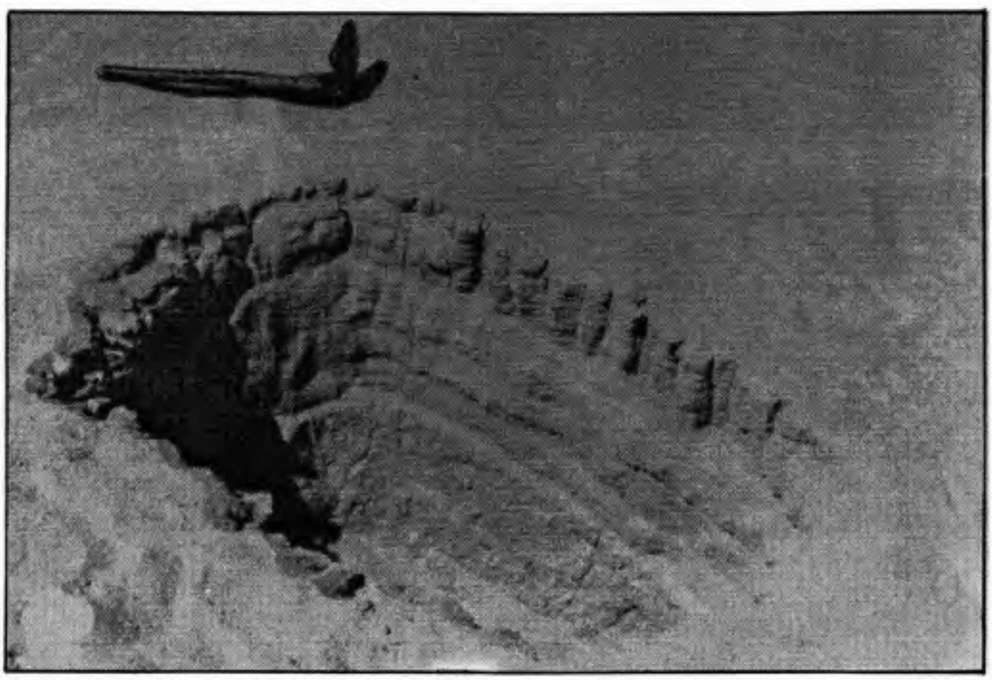

B

Fig.2 a. Granule Armored Surface Of The Selima Sand Sheet East Of The Gilf Kebir And South Of Black HilL. Lens Cap Is 54mm Diameter, Label 5mm Wide (Fig.1, Loc.1).

b. Test Pit On The Atmur El Kebiesh Showing Sand Sheet Soil Stage 2 Over A Stage 1 Over A Stage 3.

Alluvial gravels commonly underlie sand sheets and where exposed to deflation may be sources for the sand and granules of the sand sheets (Haynes 1989). Gravel spreads are here defined as gravel size particles spread out upon surfaces of finer grained sediments. The gravel spreads, usually of fine to medium pebbles, commonly display more or less equal spacing between individual pebbles that rest upon a much finer grained matrix such as dune sand or playa clay (Fig. 3). For a sandy substrate this phenomenon is dscribed by Bagnold (1941) : " Under moderate winds the scattered pebbles are not moved forward by impact, so they have no tendency to collect, as do large sand grains, to form the crests of ripples. On the contrary, we find a new mechanism operating whereby they tend to disperse, especially under removal conditions, to the most uniform distribution possible. "

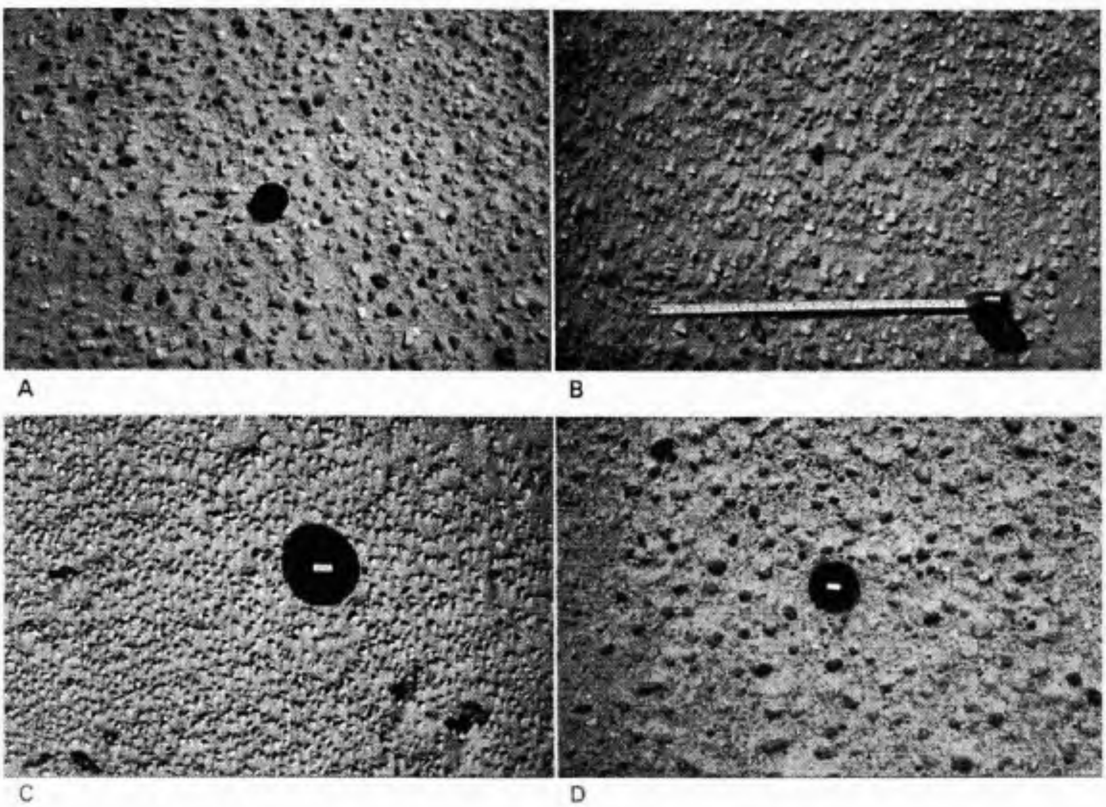

Fig.3 Four Photographs Of Pebble Spreads

- *a) Pebble Spread On Sand And Gravel Alluvium (Fig.1, Loc.2) South Of Gebel Nabta. Lens Cap Is 54mm Diam.*
- *b) Another Pebble Spread On Sand And Gravel Alluvium (Fig.1, Loc.2) South Of Gebel Nabta. Upper Scale In Inches, Lower In Centimeters.*
- *c) Carbonate Pebble Spread (Fig.1, Loc.5) On Dune Sand Northeast Of Kharga Airport, Kharga Depression. Lens Cap Is 54cm Diam.*
- *d) Pebble Spread On Early Holocene Playa Mud (Fig.1, Loc.6), Bir Kiseiba. Lens Cap Is 54cm Diam.*

In fact, the spacing appears to be a function of the size of the coarse particles' diameter (Figs. 3 and 4). To test this assumption, four photographs (Fig. 3) were used to measure the distance (x) between centers of the nearest neighboring clast to within 0.5 mm. Average pebble size was determined from minimum and maximum dimensions to within 0.5mm. All photo distances were converted to true dimensions by using the scale in each photograph, a 54 mm diameter lens cap in all cases except one where a metric measuring tape was used.

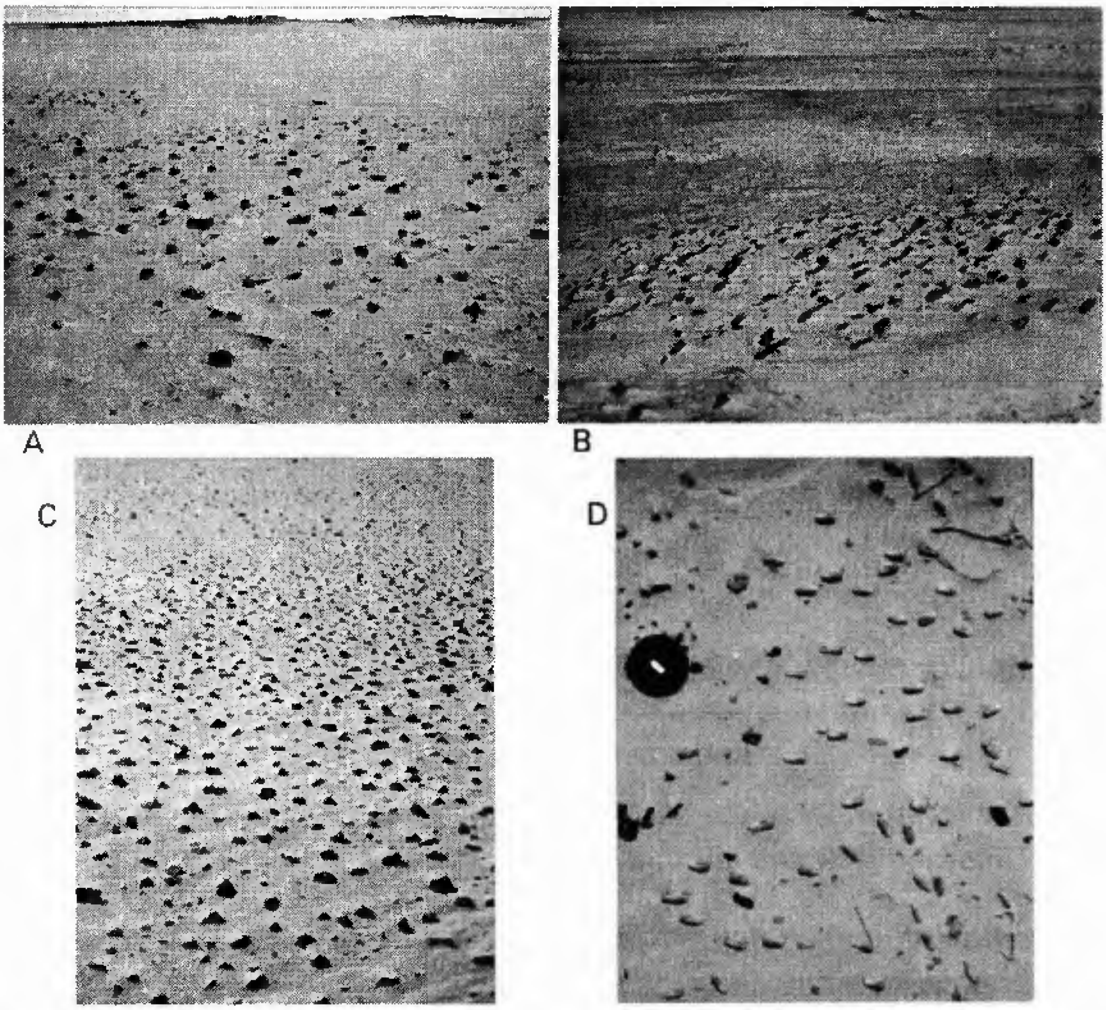

Fig.4 Four Photograph Of Pebble To Cobble Spreads.

a) Cobble Spread On Holocene Mud Of Nabta Playa (Fig.1, Loc.3), 1976. Black Cobble In Lower Foreground, Left Of Center, Is About 12 x 16 cm.

b) Imbricated Cobbles On Playa Mud (Fig.1, Loc.4) Northeast Of Gebel Nabta, 1977. Lowest Cobble At Lower Left Is About 10 x 12 cm.

c) Cobble Spread Of Neolithic Fire-Cracked And Artifacts On Early Holocene Dune Sand, Nabta Playa (Fig.1, Loc.3), 1974. Rectangular Rock At Lower Left Edge Is About 7 x 14 cm.

d) Spread Of Date Seeds In Dune Sand At Bir Safsaf (Fig.1, Loc.7), 1973.

A plot of the average distance between centers against the average minimum particle diameter for each photo as well as each quadrant shows a clear relationship between minimum clast diameter and the particles' spacing (Fig. 5). The average spacing varies between 1.4 and 1.8 times the minimum particle diameter.

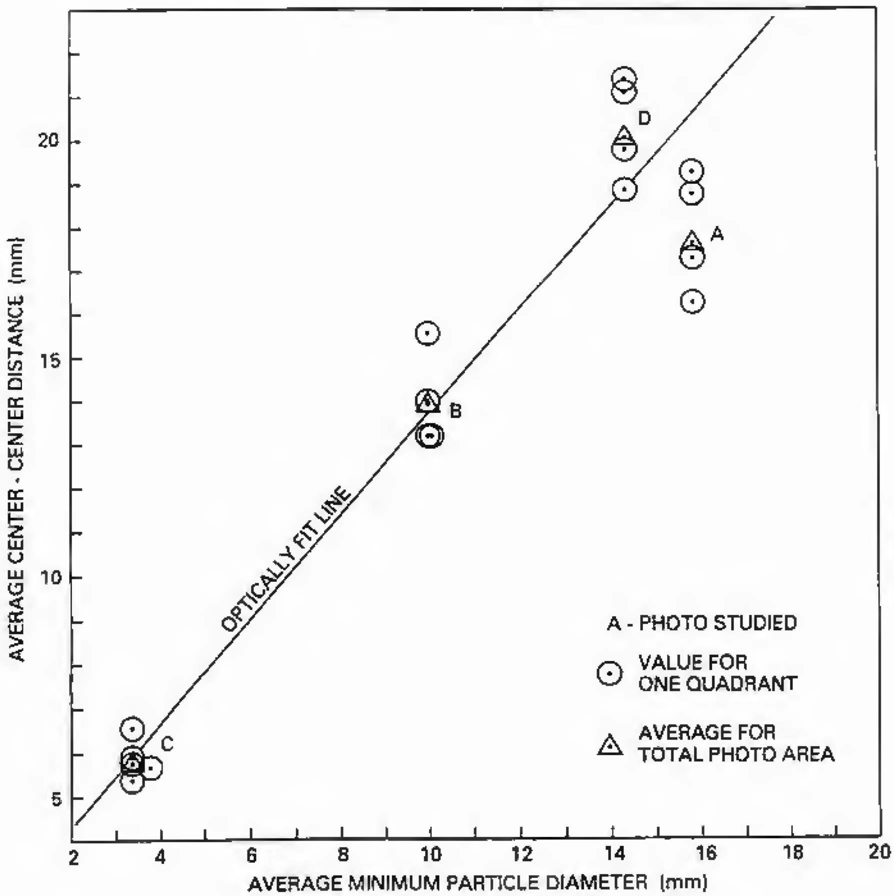

Fig.5 Plot Of Average Center To Center Distance Vs Average Minmum Particle Diameter For Photos A,B,C, & D Of Fig.3.

As Bagnold (1941) points out, pebbles are not moved by saltating sand and tend to disperse as dune sand is removed. This phenomena has been used a mechanism for stabilizing, and even lowering, barchan dunes. According to Barclay (1907) loose pebbles and"grit" sprinkled over a barchan's up-wind (stoss) slope caused the dune to "disintegrate," eventually leaving nothing but the gravel lag behind. Furthermore, Bagnold (1941,180)states:

"Once a covering of such grains {pebbles }has spread over a fresh deposit of fine sand, the latter's power of collecting like material for its growth is much reduced, and may cease altogether. For, as we have seen, a covering of large grains increases the limiting rate at which fine sand can pass over and away from the surface. The dune is *killed.* This is no doubt the true explanation of the experimental and long-known fact that a dune can be stabilized and even made to shrink by sprinkling pebbles over it."

In addition to deflecting saltating sand grains the pebbles apparently set up vortex currents that assist in getting the barchan sand into the air stream and eventually to leave the dune. Too few pebbles would have little or no effect, but too many would armor the surface preventing sand removal as well as accumulation thus stabilizing the dune. The initial spacing is not critical as long as an adequate number of pebbles per unit area are applied. The wind will rapidly equalize the spacing and adjust it according to the size of the coarse fraction.

The optimum spacing can be estimated by making use of Figure 5. For an average grain diameter of 15 mm the spacing will be approximately 20mm between grain centers.Equal spacing amounts to the center of each pebble being at the apex of an equilateral triangle of 20mm on a side. A ratio of the area of pebble in each triangle to the total area of the triangle yields a figure of approximately 5200 pebbles per m^2. A quartz pebble of 15mm diameter and $2.7 g/cm^3$ density will weigh 1.77 g requiring 9.19 kg/m^2. For Bagnold's barchan (Haynes 1989), with a length of ~200m and width of ~275m, the area is approximately 141,390m^2 requiring a maximum of 1050 tons of medium pebbles (~15mm diam.) for experimental dune removal. Perhaps considerably less would suffice, but this needs to be determined empirically.

To test these possibilities we propose that several active barchan dunes be sprinkled with fine to medium grained pebbles and monitored by measuring the height, length, width, wingline, and movements at least once a year for ten years in conjunction with repeat photography and satellite imaging. In addition to monitoring the subject dunes the area down wind should be watched to see if and where a new dune may form from the deflational sand. In order to evaluate the pebble size factor three barchans may be sprinkled with pebbles of three size, e.g. 0.5cm, 1.5cm and 3cm and a fourth with an unsorted mixture. The latter experiment may prove that sorting is unnecessary for practical application.

If successful this simple technique would be more efficient and aesthetically pleasing than such techniques as tar coating or oil soaking dunes or planting shelter belts or physically removing sand from roads as is done in Kharga village today. Barchans of the Abu Moharik dune chain in Kharga Oasis (Fig. 1) would be logical subjects for the experiment because, (1) dunes there are a significant problem, (2) they have been studied (Embabi 1982), and (3) there are facilities there of the Egyptian Geological Survey that could provide a base of operations for the field work.

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