The Sand-Dunes of the Libyan Desert. Their Origin, Form, and Rate of Movement, Considered in Relation to the Geological and Meteorological Conditions of the Region
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really important features. They represent different climates and different productive areas. The lower one is really part of the Mesopotamian plain; while the centre zone is the most productive, the country being well watered, having parallel limestone ridges, with fertile valleys between. In the highest zone are grassy hills which are pastured by the flocks of the Kurds. These flocks produce wool, and the sheep are marched down to the coast at Alexandretta; some reaching Malta and Egypt.

The PRESIDENT: In many of the lectures given here, I have noticed that explorers have thought it the best way to describe the country visited by giving a mile by mile and day by day description of their travels, without attempting to draw any general conclusions or wide generalizations, leaving that all to the reader. Now, it is obvious that the explorer himself ought to endeavour to focus the attention of his hearers on all the prominent features. I think Captain Dickson has set an excellent example in this respect, which you will probably appreciate even more when you come to read his lecture in our *Journal*. He has dealt with many questions in broad outline, and any one who wishes to travel in Kurdistan could learn a great deal of great value from this lecture. I am sure you will wish me in your name to congratulate Captain Dickson on his lecture, and to give your hearty thanks to him.

THE SAND-DUNES OF THE LIBYAN DESERT.*

THEIR ORIGIN, FORM, AND RATE OF MOVEMENT, CONSIDERED IN RELATION TO THE GEOLOGICAL AND METEOROLOGICAL CONDITIONS OF THE REGION.

By H. J. LLEWELLYN BEADNELL, F.G.S., F.R.G.S., Assoc. Inst. M.M., formerly of the Geological Survey of Egypt.

THE valuable series of articles on kumatology written by Dr. Vaughan Cornish and published in the *Geographical Journal* is well known to students of physiography. In one of these papers the dunes bordering the Nile delta are discussed, and recently, in an article formulating suggestions for the observation of sand-dunes by travellers in North Africa, Dr. Cornish has briefly referred to those remarkable elongated dune-massifs of the deserts to the west of the Nile.

The object of the present paper is to give a preliminary account of the geographical and economical aspects of the great sand accumulations of the Libyan desert, especially in relation to the geological and meteorological conditions which exist in this region. The subject is of far wider interest than might at first sight be supposed, as the welfare of thousands of souls in the oases of the Great Sahara and other deserts is intimately connected with the rate of movement and mode of accumulation of wind-borne sand. In some localities extensive and prosperous settlements have been overwhelmed and blotted out of existence, while in others the sand and dust-laden winds have been of positive benefit to the inhabitants. In the south part of the oasis of Kharga, for instance, broad terraces of cultivable loam have been gradually built up in the neighbourhood of the wells, the deposition of the wind-borne material being encouraged on account of its valuable fertilizing properties. The

* Research Department, January 20, 1910.

study of dunes is also of the first importance to those engaged in the reclamation and colonization of desert tracts. Instances might be mentioned, moreover, for example, in the maintenance of desert railways, where endless trouble and expense have been incurred which might have been largely if not entirely obviated, had those in charge of the surveying and laying out of the routes recognized the fact that desert dunes are not anchored or stationary hills of sand, but mobile masses advancing at a very appreciable rate in a definite direction.

In the course of nine years' survey and exploration work in the Egyptian deserts, as a member of the Geological Survey of Egypt, I have skirted or traversed many of the great sand-belts and dune-massifs lying to the west of the Nile. These traverses have enabled me to further our knowledge (as shown on the maps of the Rohlfs Expedition of 1873–74) of the geographical distribution in this region of the great accumulations of sand, and have afforded opportunities of observing the relations of the latter, firstly, to the geology, and, secondly, to the configuration of the country.

During the past three years, moreover, I have resided more or less continuously in the oasis of Kharga, one of the great depressions in the Libyan desert tableland, and have devoted such time as I could spare to a more detailed study of individual dunes, especially as regards their rate of movement, a subject with which, owing to the exigencies of ordinary desert travel, it is difficult for passing travellers to deal.

(*a*) *Geographical Distribution.* — The most important of the sand accumulations of the Libyan desert are shown on the accompanying plan (Fig. 1). It will be noticed that the sand occurs in two distinct manners; firstly, as narrow, elongated, well-defined belts, and, secondly, as irregular accumulations of varying form and dimensions. Not only the belts themselves, but the individual lines of dunes composing or surmounting both the sand-belts and the irregular sand-massifs, preserve a remarkable parallelism of disposition, everywhere lying approximately north north-west and south-south-east, parallel to the direction of the prevailing winds.

To the west of the 27th meridian east of Greenwich, practically the entire country south of the Miocene escarpment—passing to the north of Siwa and Jerabub—is buried under a great sea of sand. On the eastern side the country is far more open, the sand being confined to isolated belts and comparatively small irregular dune-massifs. The most remarkable of the former is that known as the Abu Moharik, which commences in lat. 29° 45′ N., at Arûs el Buqar (some 50 kilometres south-west of the Mogara swamp), in the low country to the south of the great east and west Miocene escarpment. From Arûs el Buqar the Abu Moharik sand-belt runs in an almost straight and unbroken line across the Libyan tableland into the depression of Kharga, through which it continues into the desert to the south. The average breadth of this

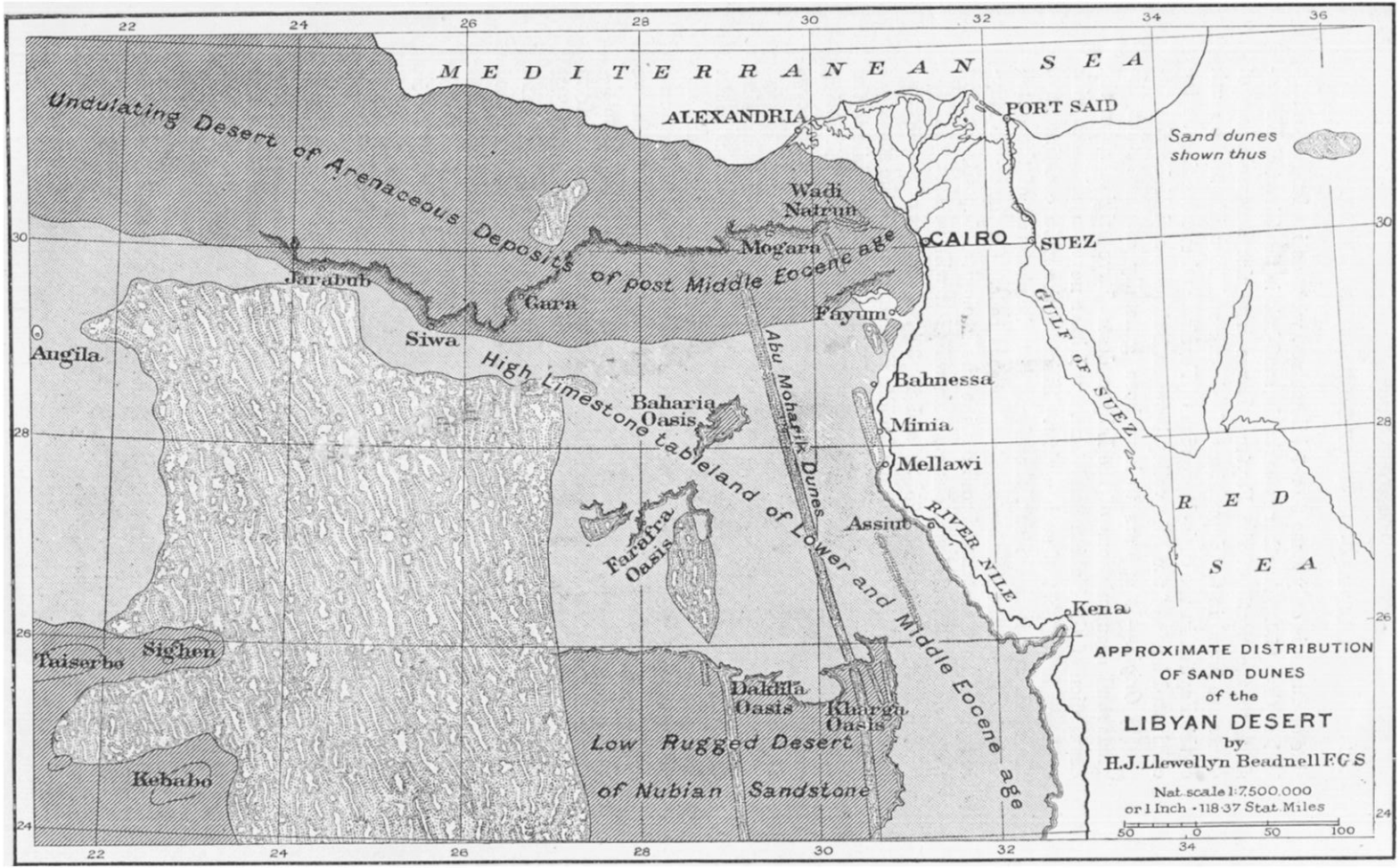


FIG. 1.

line of dunes is only some 6 or 7 kilometres, whereas its length cannot be less than 650. Another remarkable sand-belt is the Ghart el Khanashât, to the north of the Fayûm. Large irregular accumulations of dunes are found in the depressions of Gharak and Mouailla to the south of the Fayûm, in the oasis-depression of Farafra, and encroaching on the cultivated lands of the Nile valley between Bahnessa and Mellawi.

(*b*) *Origin.*—It appears to have been generally assumed that the great sand accumulations of the Libyan desert have originated in the denudation of the Nubian Sandstone, but I have never myself met with evidence in support of such a view. Silica is the main constituent of the sand, and it is evident, therefore, that the material of the dunes is derived from the weathering of arenaceous beds. On the accompanying plan I have shown in broad outline the geological deposits forming the surface of the Libyan desert, from which it will be seen that the central part, between lats. 25° 30′ and 29° 30′ N., consists of an elevated limestone tableland of Lower and Middle Eocene age. To the south lies a rugged, and generally lower, desert of Nubian Sandstone; while to the north, stretching to the Mediterranean sea, is found an undulating country of post-Middle Eocene age, very largely consisting of arenaceous deposits.

Now, there seems no shadow of doubt that the material composing the dunes, which so largely occupy the intermediate plateau, comes from the denudation of the arenaceous formations to the north, and not from the Nubian Sandstone to the south. The disposition of the dunes suggests such an origin, and positive evidence can be adduced, as we shall show, that at the present day the prevailing winds are from the north, and that the dunes have a steady and appreciable movement from north to south. The post-Middle Eocene formations occupy a wide belt along the northern side of the Libyan desert, and the supply of sand made available by the denudation of the arenaceous deposits exposed over this area is inexhaustible. During the passage of the sand across the great central limestone tableland the individual grains of silica doubtless become much rounded and reduced by attrition; the loss is, however, to some extent counterbalanced by the very considerable additions—in the form of calcareous grains—derived from the limestones forming the surface of the high desert.

It would be extremely interesting to sample the Abu Moharik dune-belt at different points along its course, in order to ascertain whether there is a sensible and regular increase of calcareous matter from north to south. Examination shows that in the oasis of Kharga, to the south of the limestone plateau, the dunes are by no means composed solely of siliceous grains, there being a considerable proportion of white opaque granules of limestone. A sample collected from one of the dunes in the central part of the depression was found on analysis to contain 7·7 per cent. of calcium carbonate.

It would be difficult to account for the presence of calcareous grains in the dunes of this locality on the assumption that the sand is derived from the Nubian Sandstone; though the denudation of the latter, in and to the south of the oases of Kharga and Dakhla, must give rise to a very large amount of siliceous sand, which goes to swell the bulk of the dunes which have invaded this country from beyond the limestone plateau to the north.

In desert regions, owing to the ground being unprotected by vegetation, there is nearly always an abundance of weathered material loosely exposed on the surface, the lighter portions of which are quickly swept up and carried along as soon as the wind attains even a moderate velocity. In the Libyan desert the temperature seldom falls below freezing-point, and the climate is so dry that frost plays but little part in the disintegration of rock-surfaces. The diurnal range of temperature is, however, very great, and this force—"insolation," as it has been termed—is very potent in the breaking up of the surface. The weathered material does not accumulate and form a protective soil-cap, but is carried away by the wind (deflation), the heavier siliceous grains effecting an immense amount of abrasion of the exposed rock-surfaces over which they are swept.

Changes of temperature, sand and wind are, indeed, the chief agents of erosion and transportation in the Libyan desert at the present day, and, since the incoming of the modern desert conditions, have not only produced the material which has in places accumulated and formed the dunes which are the subject of this paper, but have effected a vast amount of earth-sculpture over the surface of the region as a whole.

(*c*) *The Desert Winds.*—In the abrasion of rock-surfaces, in the movement and accumulation of the weathered material, the wind is the guiding power, while sand is the instrument or tool. The combination of the two forms a denuding force of no mean power, the sand-blast being capable of planing and grooving the exposed surfaces of the hardest of rocks.

The actual amount of erosion effected, and the rate of movement, distribution, and accumulation of sand-dunes, depend on the velocity, direction, and frequency of the wind, so that no conclusions formulated on these questions can be regarded as satisfactory which are not based on a study of the local meteorological conditions.

An extended residence in the oasis of Kharga enabled me to have meteorological records kept over a period, and of considerable sufficient exactness to yield valuable information concerning the direction and duration of the winds, the frequency with which they are visibly laden with sand, the occurrence of sandstorms, etc. In addition, I had observations made with a view to determining the air velocity required to enable sand to be carried in suspension, and the velocity attained by the wind in actual sandstorms.

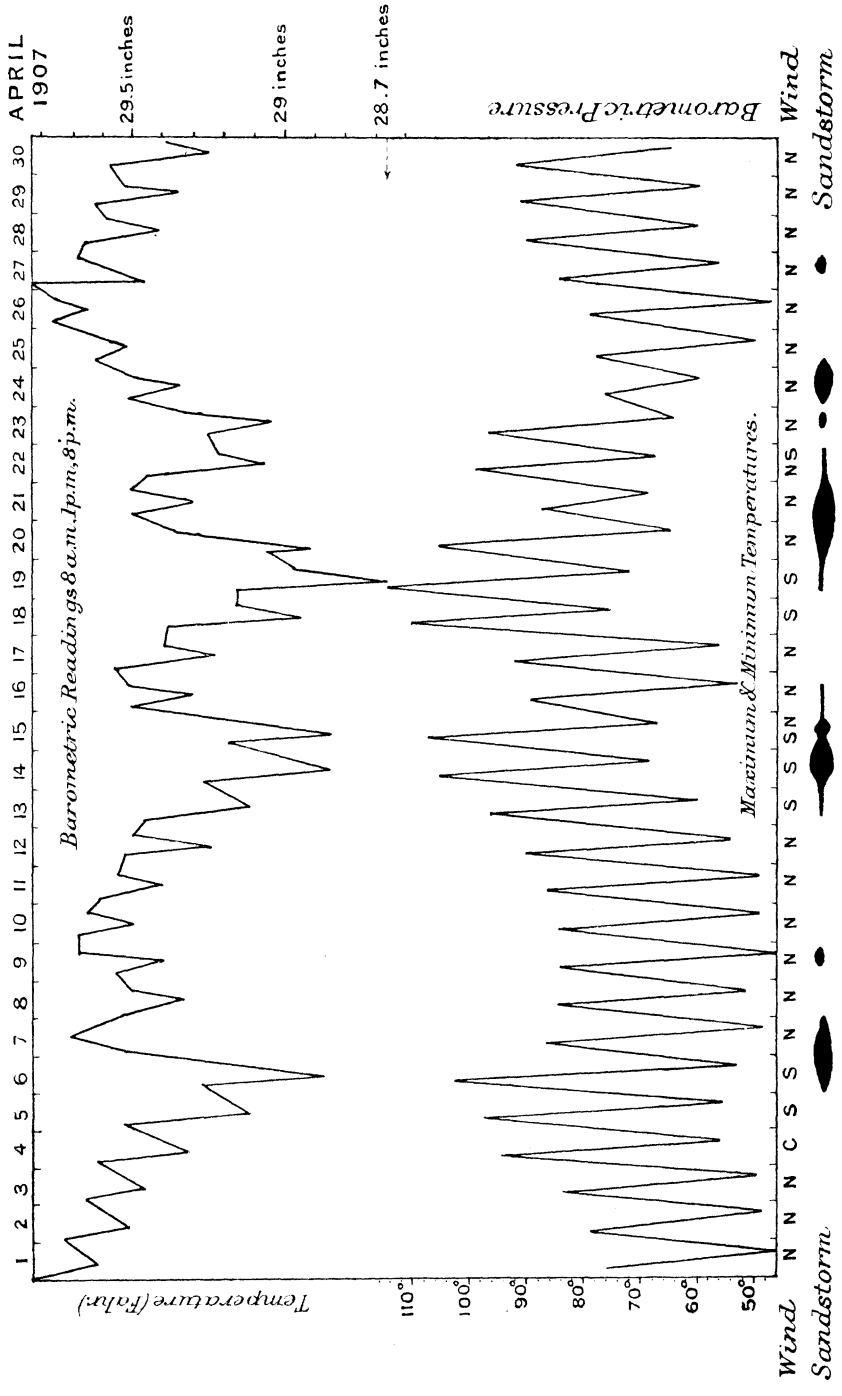


FIG. 2.

It will be convenient to confine attention to one period of twelve consecutive months, and that extending from April, 1907, to March, 1908, is chosen. The results of these observations are tabulated below.

OBSERVATIONS ON THE MOVEMENT OF WIND AND SAND IN THE OASIS OF KHARGA. FOR YEAR ENDING MARCH 31, 1908.

	Winds.				Sand and Sandstorms.					
	North.*	South.*	Various.†	Calm.	Wind carrying sand across open plain.‡			Sandstorms.		
					N.	S.	Var.	N.	S.	Var.
April, 1907 ...	21	6	2	1	6	3	—	3	2	—
May „ ...	19	—	8	4	7	—	—	—	—	—
June „ ...	29	—	—	1	15	—	—	—	—	—
July „ ...	29	1	—	1	6	—	—	2	—	—
August „ ...	22	—	7	2	7	—	2	2	—	—
September ...	30	—	—	—	14	—	—	4	—	—
October „ ...	28	—	1	2	6	—	—	—	—	—
November ...	23	2	—	5	9	—	—	—	—	—
December ...	24	1	1	5	5	—	—	—	—	—
January, 1908	20	6	3	2	—	6	3	—	—	—
February „	15	2	9	3	6	—	—	1	—	1
March „	21	4	3	3	9	1	—	1	—	—
Days ...	281	22	34	29	90	10	5	13	2	1
						105			16	
		337		29		121				
		Windy days.		Calm		Wind carrying sand.				

There is no reason to suppose that the period in question, from April, 1907, to March, 1908, was other than a fair average sample of the general climatic conditions obtaining at the present day in the Libyan desert; and although it is desirable that the observations be continued for a term of years, the results obtained from the twelve months' record tabulated above are sufficient for our present purpose.

The main facts established by these observations are, that the ratio of calm to windy days is very small, being 1 to 11·6; that on one day in three the wind attains a velocity sufficient to enable it to carry sand in suspension (and this across the open plain, away from the sand-belts); that five times out of six the direction of the wind is from the north; and that by far the greater number of the sandstorms is also from the north.

Space prevents me from doing more than call attention to the meteorological conditions—increasing temperatures accompanied by a falling barometer—which culminate in and are relieved by sandstorm weather, as shown so well in the accompanying weather chart for the month of April, 1907 (Fig. 2).

* Or within a few points. † Winds with distinct east or west points.
‡ Visibly charged with sand.

(*d*) *Wind Velocities.*—Observations made with an air-meter under different conditions of wind, on the open plains and on the dune-belts, show that—

(1) On the dunes the sand commences to move when the wind attains the velocity of a light breeze, or 13 miles an hour.

(2) On the open plains the wind becomes visibly charged with sand as soon as it approaches the velocity of a moderate breeze, or 23 miles an hour.

(3) Sandstorm conditions obtain when the wind exceeds the rate of movement of a moderate breeze, the maximum velocity actually recorded in the period under observation being 34 miles an hour, during a violent sandstorm on April 14, 1907.

N.B.—The observations were made about a metre above the ground. The terms "light," "moderate," etc., are used as in the Beaufort Scale.

(*e*) *Desert Barchans or Crescentic Dunes.*—The dominant form of dune in the Libyan desert is of crescentic or horse-shoe shape, a form specially typical of desert regions where there are prevailing winds in any one direction. These "barchans," * as they are called, are found of every size, and exhibit many variations of the simple crescentic pattern. In the region of the oases they are always disposed with the concave, steeply-inclined sides facing southwards. In some parts of the Libyan desert, more especially in the oases-depressions, the sand-belts are made up of numerous isolated and apparently promiscuously-disposed barchans; in other cases the dunes have joined together into a compact mass, in which the typical shape of the individual barchan is more or less obliterated. In the great sand-massifs the uppermost portions of the sand are arranged in longitudinal (north and south) ridges, made up of intergrown dunes of the barchan type; and the deep so-called "fulges" appear in most cases to represent the hollows immediately in front of the steep lee faces of individual dunes, the horns of which have met and united with preceding dunes.

Solitary barchans, being well-defined isolated masses, lend themselves to observation better than the large and continuous belts of sand. They occur of all sizes, from little baby crescents, a metre or two across their greatest span, to enormous masses 30 or 40 metres high and 200 to 300 metres in breadth. The angle of slope within the crescent of a barchan is most deceptive, especially when the dune is approached from the south side in bright sunlight. I have frequently heard it confidently stated that the inclination of the face of the dune cannot be less than 60° or 70° from the horizontal, and quite recently, in a published account of some dunes in the Nile valley, I noticed that the author estimated the inclination at from 40° to 50° degrees. Measurement, however, shows that the slope of the lee face never exceeds by more than 2° or 3° a third

* A short account of these dunes has already appeared in 'An Egyptian Oasis.' John Murray. London: 1909.

FIG. 4.—A BELT OF DUNES IN KHARGA OASIS, LOOKING NORTH OR UPSTREAM.

FIG. 5.—A BELT OF DUNES IN KHARGA OASIS, LOOKING SOUTH OR DOWNSTREAM.

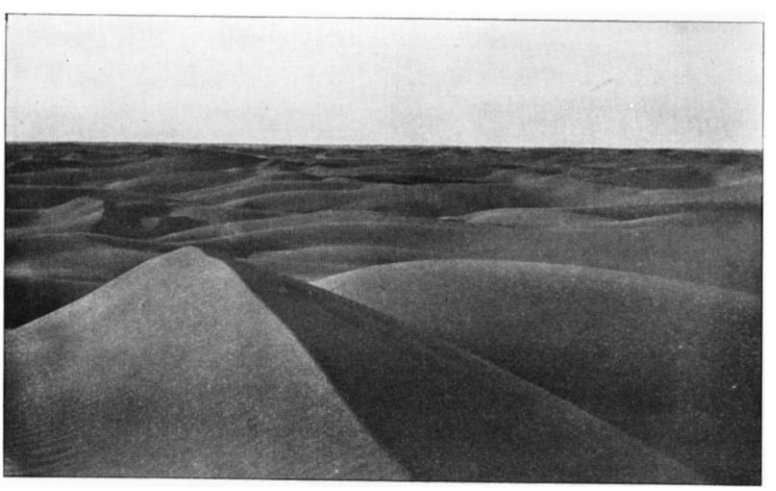


FIG. 7.—IN THE SEA OF SAND BETWEEN DAKHLA AND FARAFRA OASES.

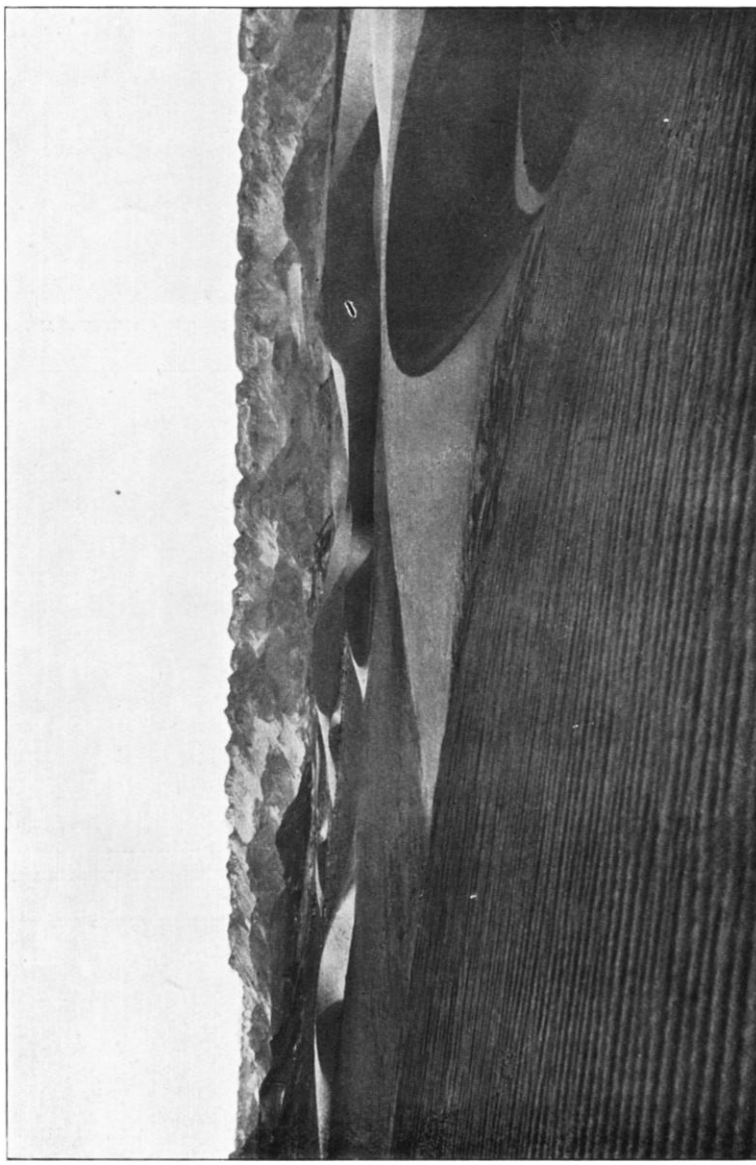


FIG. 6.—ISOLATED BARCHANS OR CRESCENTIC DUNES IN KHARGA OASIS.

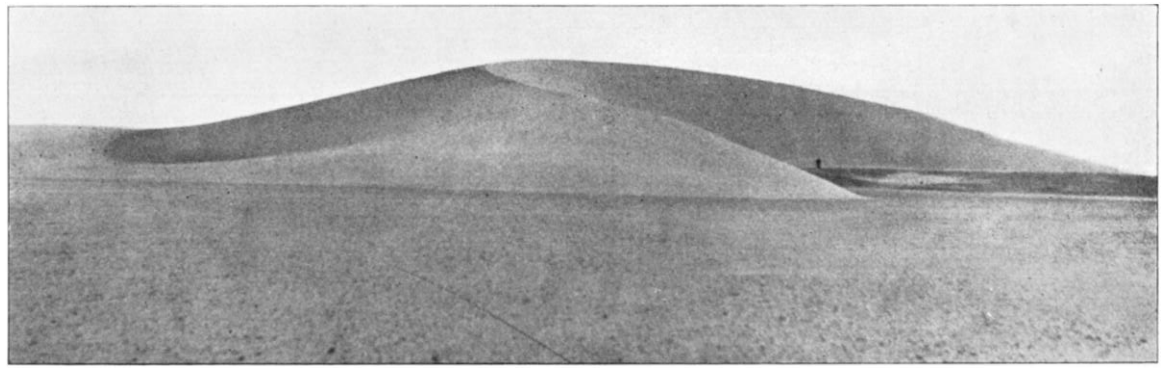


FIG. 9.—A TYPICAL BARCHAN: THE KHARGA ROAD DUNE.

FIG. 10.—A COMPLEX DUNE ON THE LIBYAN PLATEAU.

FIG. 8.—DUNES ENCROACHING ON THE CULTIVATED LANDS IN DAKHLA OASIS.

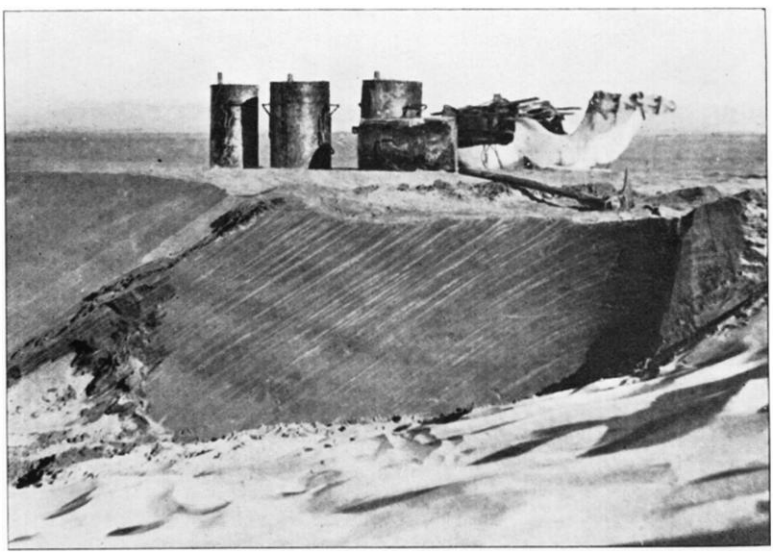


FIG. 11.—SECTION SHOWING INTERNAL STRUCTURE OF A BARCHAN.

of a right angle, as, unless held together by vegetation or compacted by moisture, it cannot exceed the "angle of rest" of dry blown sand, which varies from about 31° to 33°.

In normal weather the leeward southerly face of a barchan is a straight, unrippled, even slope of loose sand from top to bottom. When a light or gentle breeze is blowing from the north, the dune is observed to "smoke" at the top of the crest, the sand being blown up the much more gentle and markedly-rippled windward slope, and dropped over the crest on to the steep, smooth, southerly face. In a light breeze the bulk of this sand falls on the upper part of the slope, equilibrium being adjusted from time to time by a downward sliding of the superficial layers.

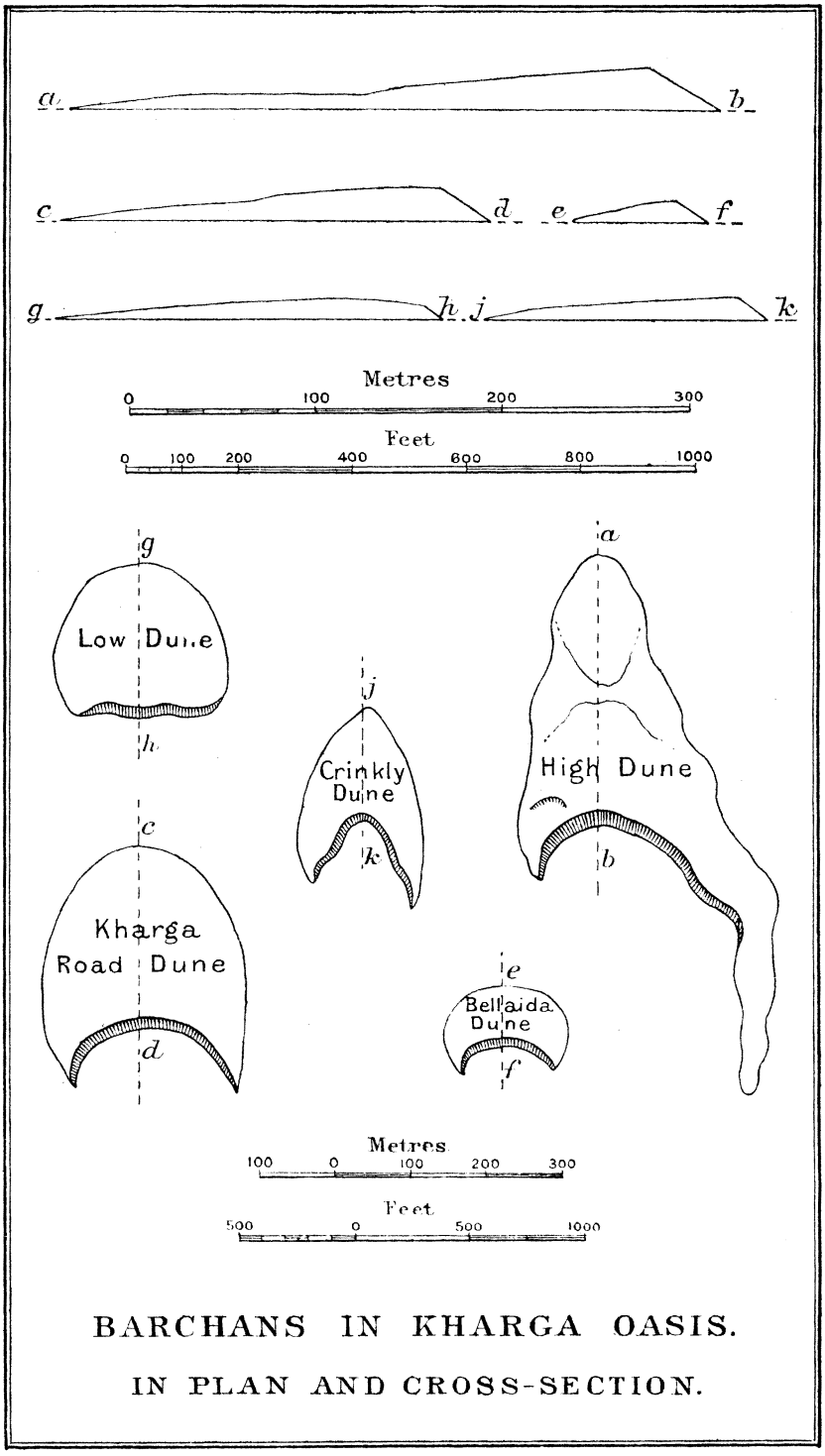
In one of his articles, Dr. Cornish * writes as follows:—

"The upper part of the lee slope of the more developed and middle part of the dune is the well-known straight cliff which has a soft, unrippled, slipping, plane surface. It has been customary to ascribe this slipping cliff to the pushing of sand-grains over the crest by the forward action of the wind and their downward rolling. This explanation implies that the cliff is constantly refaced by sand-grains thus driven forward from the surface of the windward slope. What I saw on this and other dunes during my stay in Egypt convinced me that this notion is incorrect. The cliff is due to undercutting by the backward-acting eddy."

This explanation has never commended itself to me—at any rate, as regards the dunes of the Libyan desert—and an examination which I recently made of the internal structure of a typical barchan in the oasis of Kharga seems to conclusively prove that the older view is the more correct. About sixty gallons of water were carefully poured out at a point on the summit of the crest of the dune, after which a trench—running north and south, at right angles to the trend of the ridge—was cut through the consolidated mass, which was then plainly seen to be made up of well-stratified layers dipping regularly southwards at a little over 30° (Fig. 11). Each layer had in turn formed the lee face of the dune. There is no doubt, therefore, that, at any rate in the case of the isolated barchans of the Libyan desert, the dunes progress, and the steep southerly leeward faces are formed and renewed, by the sand which is constantly blown up the northerly windward faces and dropped over the crests in the manner already described.

In Kharga oasis I have never observed southerly winds hold for a sufficient length of time to do more than slightly modify the general form of a large barchan, though during their continuance the progress of the dune is arrested, the outline of the crest becomes markedly

* "On Desert Sand-dunes bordering the Nile Delta," *Geographical Journal*, vol. 1, p. 7.



BARCHANS IN KHARGA OASIS.

IN PLAN AND CROSS-SECTION.

FIG. 3.

altered, ripple-marks appear on the steep southerly face, and an apron of sand of greater or lesser dimensions forms at its foot.

(*f*) *Rate of Movement.*—The rate of movement of desert dunes has never, so far as I am aware, been studied in any great detail, and the few figures with which I am acquainted, regarding the movement of coast dunes, appear mostly to be based on observations extending over only short periods of time. Dr. Franz Czerny * states that, according to Koch, the dunes on the Baltic coast in Courland move at the rate of 18 feet a year, and according to Bramontier † the dunes of Gascoyne were, at the end of the eighteenth century, moving at the rate of 20 to 25 metres a year. Dr. Vaughan Cornish ‡ found the average rate of advance of the crest of a dune near Ismailia to be about three-quarters of an inch an hour, the measurements being made in April, 1899, during two or three days when northerly winds prevailed. Mr. C. R. Enock has estimated the movement of barchans in South America as amounting to as much as 1 or 2 feet an hour in a brisk breeze.§

Observations extending over two years show that in the Libyan desert the dunes progress steadily southwards at an average rate of 15 or 16 metres a year. The greatest recorded movement of a barchan in twelve months amounted to 20·6 metres, the lowest to 10·2 metres.

The five dunes, of which the measurements are given below, and which are shown in plan and section in the accompanying illustration (Fig. 3), are situated in different parts of the oasis of Kharga. The low, high, and crinkly dunes are members of the dune-belt which runs near and parallel to the eastern wall of the depression; the Kharga road dune lies in complete isolation on the open plain in the centre of the oasis-depression; while the Bellaida dune, in the district of that name, is one of a belt of barchans to the west of Jebel Têr, on the west side of the depression.

Name of dune.	Maximum measurements in metres.			Notes.
	Height of crest.	Length N. to S.	Breadth E. to W.	
Bellaida dune ...	10·5	70	160	The highest point of each dune is the actual crest above the steep southerly slope, except in the case of the low dune, where the highest point is 60 metres to north.
Low dune	4	205	230	
Crinkly dune ...	11	150	160	
Kharga road dune ...	17	230	260	
High dune	20	350	260	

* "Die Wirkungen der Winde auf die Gestaltung der Erde," *Petermanns Mittheilungen*, Erganzungsband xi., 1876-77.

† Reclus, 'La Terre,' vol. 2.

‡ *Op. cit.*, pp. 4, 5.

§ *Geographical Journal*, vol. 31, p. 684.

The dunes move in the same direction as the wind, and the amount and rate of movement depend directly on the duration and velocity of the wind. As stated above, the barchans in the oasis of Kharga were found to commence to move when the wind attained a velocity of about 13 miles an hour, and in light and gentle northerly breezes (13 to 20 miles an hour) to progress steadily in a southerly direction without loss or gain of sand, the superficial layers being rolled gently up the windward slopes and dropped over the crests on to the steep lee slopes facing southwards. In stronger winds, when the air becomes everywhere charged with sand, the dunes progress still more rapidly, and may, according to circumstances, be either gaining or losing in actual bulk. Much sand is blown away to the south, while additions of material are received from the north. When sandstorm conditions prevail (30 miles an hour or over), the rate of movement reaches a maximum, amounting to between 2 and 3 centimetres an hour.

Between June 29, 1907, and July 8, 1908, a period a few days in excess of twelve months, the dunes under observation moved from north to south as follows:—

Bellaida dune	18·78 metres
Low dune	18·38 „
Crinkly dune	16·18 „
Kharga Road dune	10·80 „
High dune	10·94 „

The average movement of the five dunes works out at 15 metres, the results indicating that the rate of movement depends in large measure on the size of the dune. The larger the dune (in longitudinal section, from north to south), the greater the amount of material to be moved, so that, as a general rule, small barchans progress more rapidly than large ones.

The following table shows the monthly movements of the five dunes during the year 1908. On the whole the results agree closely with those for the period quoted above. The months of August, September, and October of 1908 were, however, remarkable for three prolonged periods (of five, ten, and nine days respectively) of sandstorms from the north, and the movements of the dunes for those months are in consequence very high. It would seem that strong winds affect the high dunes more than they do the lower ones, as, owing to the excessively marked movements of the high dune in the latter months of the period, its total progression for the year almost equals the average of the three smaller dunes. Curiously, however, the movement of the isolated dune on the Kharga road varied little.

MOVEMENT OF DUNES IN THE OASIS OF KHARGA, 1908.

Name of dune.	Low.	Bellaida.	Crinkly.	Kharga road.	High.	Average monthly movement.
January	1·27	1·74	1·10	1·19	0·74	1·21
February	1·01	1·54	1·45	0·38	0·46	0·97
March	1·15	1·41	0·85	0·65	0·76	0·96
April	2·25	2·40	1·63	1·20	1·19	1·73
May	1·04	0·65	0·98	0·15	0·30	0·62
June	2·34	2·45	2·07	1·45	1·89	2·04
July	0·45	1·09	1·71	0·44	0·47	0·83
August	1·77	2·16	1·58	1·11	2·13	1·75
September	2·65	2·82	3·18	1·65	3·35	2·73
October	2·70	2·33	2·45	1·30	3·22	2·40
November	1·10	1·60	1·25	0·70	2·65	1·46
December	0·25	0·40	0·65	0·00	1·40	0·54
Total movement during period, in metres ...	17·98	20·59	18·90	10·22	18·56	

(*g*) *General.*—The limits of the present paper preclude going into further details regarding the relation of the sand accumulations to the general configuration of the desert surface. Suffice it to say that, although in many instances sand-belts are found to continue, regardless of topography, in almost straight and unbroken lines, as a rule lowlying areas and depressions become centres of accumulation, while on the highest and most exposed portions of the plateaux blown sand seldom collects in any great quantities. Other important questions are the effects of vegetation and moisture in the fixing of dunes, and the raising of the cultivated lands in certain parts of the oases as the result of the constant accumulation of blown sand and clay dust. These I have described elsewhere.

The vast amount of earth-sculpture which can be accomplished by a combination of sand and wind is now generally admitted. It has even been suggested * that under the impact of blown sand ordinary limestone may become hardened and be rendered crystalline; but, as I have stated elsewhere,† until it can be shown that the crystalline limestones, which are of such common occurrence in the Libyan desert, bear some definite relation to the desert surface, and that a rock can withstand the wearing action of blown sand for a sufficient period to sustain internal physical alterations, the theory can hardly be expected to obtain credence.

Finally, I wish to place on record my appreciation of the assistance I have always so willingly received in my study of sand-dunes from Mr. P. von Adametz and Mr. C. Bayly, and last, but not least, from the late

* Dr. W. F. Hume on "The South-Western Desert of Egypt," *Cairo Scientific Journal*, August and September, 1908.

† *Cairo Scientific Journal*, January, 1909, p. 27.

Dr. H. H. Baker, whose recent and sudden death in British East Africa is so much deplored by those with whom he was for so long intimately associated in the oasis of Kharga.

Dr. STRAHAN: The paper for this afternoon's consideration is on the Sand-Dunes of the Libyan Desert, by Mr. H. J. Llewellyn Beadnell. Mr. Beadnell has recently returned from Egypt, and we welcome his attendance at this meeting.

Dr. STRAHAN (after the paper): This is an important communication on a subject which has been a good deal before the Society of late years, and which I think may, with great advantage come before the Society again, for it is essentially of geographical interest. I hope to hear a good discussion upon it this afternoon.

Dr. VAUGHAN CORNISH: I congratulate Mr. Beadnell on the excellent work he has done. It is a great satisfaction to me to see desert dunes made the subject of residential research. It is hardly possible for the passing traveller to carry the study beyond the pioneering stage. The observations of the rate of movement of the barchans in connection with a systematic record of wind velocities is much the best thing of the kind which I have yet come across. A very interesting point comes out in respect to the change of *tenue* when we pass from gentle and moderate breezes to a period of storms. During twelve months, when the winds were mostly moderate, the barchans progressed in the inverse order of their cubic contents, and the highest dune moved slowest. But in a succeeding period of three stormy months the highest dune moved at a greater speed than any of the others. When the winds are light the lee of a high dune is a place of calm and shelter. When, however, the wind is violent, it is on the lee of the highest cliff that the strongest vortex is induced, with the greatest power of transporting sand in suspension.

With regard to Mr. Beadnell's remarks upon my description of the action of the vortex on the lee of the dunes near the Nile delta, I must point out, first, that they were transverse ridges and with loose sand below the troughs, not barchans isolated on hard ground. Secondly, I wrote more particularly of what takes place when the wind is blowing with at least moderate velocity. In very light winds no doubt the sand drops gently over the crest. I do not think the stratification found by Mr. Beadnell is really an argument against my description. The process he describes culminates in bodily sliding. So does that described by me, and both processes give the same stratification in the cliff.

The barchan has great morphological interest. Its ichthyomorphic character was pointed out in my paper on Snow Waves in the *Journal*. It is not itself a completed structure. It is like part of a flat fish, say a sole, and the rest of the fish is represented by the space where the wind is eddying and sweeping back to the barchan the loose sand on the ground.

In conclusion, I should like to ask Mr. Beadnell if he finds the movement of sand is dependent only on the velocity of wind, or if he has observed that the sand is thrown into suspension in an excessive degree by winds blowing during an electrified condition of the atmosphere.

Mr. LAMPLUGH: May I ask whether, in the country Mr. Beadnell has examined, he has seen anything that would throw light on the curious sand-bults of South Africa, where huge masses of sand covering a great part of the Kalahari and surrounding country appear to be blown sand, and yet present no definite blown-sand forms. These long, broad, flat-topped "bults" or swells are now all covered with bush and are fixed. In the parts that I traversed, I tried to find traces of degraded or altered dune-forms in them, but could never do so. I notice that Mr. Beadnell shows on his map a long river-like belt of sand, made up of dunes, running across a stony desert. Does he think it possible that a belt of this