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in Europe. May I add to that that he is an anachronism everywhere? The Turk has made himself impossible. He is not fit to rule over any people of a different race. As a private individual he has some virtues, but as a ruler he is impossible. Instead of being satisfied with turning him as a ruler out of Europe, we should turn him out of any region where he can oppress Christian subjects. There are parts of the interior of Asia Minor where the population is mainly Moslem, and where there are comparatively few Christians to be massacred or tortured, and in those places a weak Turkish Sultan may be tolerated. The Seljuk Turks for a long time held rule in Konia, and if it is desired to keep a Sultanate going a Turkish Sultan might be planted at Konia, where he would do no harm and probably become a respectable member of society. Thus we should get rid of any power he might exercise over the Christians of Armenia to the east or over the Greeks on the west coast, or over the Christians and Moslem Arabs of Syria in the south, in which regions he has been signalizing himself by perpetrating shocking massacres. There is no happier or more peaceful part of the Mediterranean shore, nowhere have people lived with more comfort and happiness than in the Lebanon, for although it was nominally part of the Turkish Empire, it was under an administration in which the Turks did not take an active part. But as soon as the war broke out the Turks entered the Lebanon, they cut down trees, destroyed villages, beggared and murdered the people, so that over large districts few people were left alive. When I saw it four years ago it was the most prosperous and tranquil part of the Near East. These regions must be liberated for ever from the domination of the Turk, and I am glad to see in that connection that His Majesty's Government has recently expressed its sympathy with the idea of allowing Jewish communities to be settled in Palestine. They might restore prosperity to that country, which has also languished so long under the rule of the Sultan. I should like, if I may, to be permitted to express, on behalf of those of us who are endeavouring to feel our way on Balkan and Eastern questions and have realized how difficult it is to discover satisfactory solutions, the obligations we are under to you, Mr. President, for the light which you have been kind enough to give us to-night.

STUDY OF A DUNE BELT

W. J. Harding King

MOST striking features of the Libyan Desert are the curious long, narrow dune belts running across the desert, roughly from north to south, in almost straight lines. The Abu Moharik belt, which is one of the most conspicuous of these, has a length which cannot be much less than 400 miles; but though it varies somewhat in width the average breadth is probably not more than 5 miles, about an eightieth of the total length. These belts consist almost entirely of crescent-shaped dunes. In places these dunes are scattered and stand isolated from each other, with areas of sand-free desert between them. In other parts the dunes are more closely packed; many of the crescents join together to form large clusters; and the spaces between the dunes are also sometimes covered with sand.

At one point the Abu Moharik belt is crossed by the Western Oasis Railway which connects Kharga oasis with the Nile valley. I visited this place in several successive years, and generally stayed there for a day or two when I did so, in order to study the dunes. During two winters I was camped near the railway for several weeks, and the second year surveyed the dunes on both sides of the line. At this part of the belt the dunes were at about their average density, and, as the desert between them was free from drift-sand, the exact boundary of the dunes themselves could generally be easily ascertained, which would not have been the case had they been lying on sand. Where the exact limit of a dune could be seen, it is shown on the plan as a continuous line. In some places however, owing generally to the roughness of the ground, the precise edge of the dunes was not very apparent : these parts are not outlined.

The plan of the dunes was made with a steel tape and prismatic compass. Whenever possible the traverses were made so as to close on their starting-points or on points in traverses previously made in this way ; they were then adjusted by the ordinary graphic process. Rectangular offsets were made from this framework of traverses to points on the edges of the dunes. In the case of the smaller traverses—such, for instance, as the one round the dunes 18 and 19—the closing error was hardly plotable. The maximum error was in the traverse round the big central dune-cluster lying just to the north of the railway, when some difficult ground had to be crossed to the south of the hill 7 ; the closing error in this case was just over 20 metres.

Some sections of the dunes were also made, with an ordinary service clinometer and a levelling staff which I made myself out of a deal board graduated in pencil by means of the steel tape. As the points fixed in this way were very close together, and the observations were always taken more than once, the inaccuracy of a clinometer as compared with a spirit-level was not of much consequence—especially as the clinometer did not require a tripod, which would have been very difficult to set up rigidly on the yielding sand.

The belt at this point is unusually narrow. Its whole width is shown at the point where the railway crosses it. Further to the north, however, it was nearly double as wide, as the north-eastern portion covered by the plan—the top right-hand corner—contained some fairly large dunes forming a continuation to the east of the northernmost cluster, and there were also some other dunes lying to the south of them which came down to about the level of the hill 7. But as these lay in very broken ground a survey of them would have been useless. Mr. Beadnell found as a result of the valuable weather observations made by him in the oasis of Kharga,* that on five days out of six, when the wind was blowing with sufficient force to move the sand, its direction was from the north, and that by far

* "The Sand Dunes of the Libyan Desert," by H. J. Ll. Beadnell, *Geog. Journ.*, vol. 35, p. 383.

the greater number of sandstorms were from the same quarter. The belt at this point consequently runs nearly due north and south. The portion

Fig. 1.—Plan of Dunes in the Abu Moharik belt, Libyan Desert

surveyed consisted of three large nearly equidistant clusters, with smaller dunes and dune-clusters scattered about between them. I have treated the dunes 23, 24, 25 and 26 as one group, because on level ground I think

the two compound dunes 23, 24 and 25, 26 would have combined. A low ridge, however, which lay between them probably prevented their doing so.

The smaller dunes can be divided into three classes. First there is the isolated horseshoe or crescent type, such as 10; then there are the small dune-clusters where a second horseshoe dune adheres to one of the horns of another crescent, such as in groups 18, 19 and 21, 22. The third type is the over whale-backed dune 3. This is the only dune of this class that appears on the plan, though another of the same kind lay on very sloping ground to the south of the western horn of the dune 23. It will be noticed that all these three types of dunes lie to the south—that is to say to the lee—of the horns of other crescents, which are usually larger than themselves. The dune 3, for instance, has formed off the western horn of 1; 4, 5, 6 and 10 off its eastern horn; 21 and 22 off the western horn of 11; while 18 and 19 lie just to the south of the low neck that divides the western side of the small dune 15 from the eastern flank of the much larger one 13.

The hollow 27 was a bare patch of desert lying under the lee of the large dune 14. It was bounded on the west by the flank of 13 and on the east by the dunes 15 and 16, which at the time the survey was made merged imperceptibly into each other.

The dune 20 need not be considered as, though it had to some extent assumed the shape of a dune, under the action of the wind, it was in a sense artificial, as the sand of which it was composed had been thrown over the line by the draught screen placed at this point to prevent the dune 17 from encroaching on the rails.

The position that these small dunes and clusters occupy in the plan is, I think, significant. When the wind blows over a crescentic dune it invariably shows a tendency to contour round its slopes instead of blowing in a straight line over the top; consequently, when the normal, northerly, wind is blowing over these crescents a considerable stream of sand is continually flowing to leeward past their horns, and in the cases where they have combined to form a group, over the cols formed at the junction of the flanks of two adjacent dunes of the cluster. When standing on the top of one of these dunes during a sandstorm I have often seen small sand-laden eddies with a vertical axis—miniature “sand-devils,” in fact—forming and reforming over an area lying to leeward of one of its horns. These eddies are caused, I think, by the obstruction that the dune offers to the passage of the wind, and closely resemble the very similar eddies to be seen in water on the down-stream side of the pier of a bridge past which a rapid river is flowing. When these eddies break up they must drop the sand they are carrying, and since they keep on forming and breaking up over the same area, a considerable amount of sand must be deposited by them during a single sandstorm. If the point where the sand is deposited is slightly sheltered from the wind, enough sand may collect there to cover

the ground to a sufficient depth to allow it to ripple, and when once the rippling has been formed other sand-grains blowing over the surface will get caught in the troughs of the ripples, and the heap of sand thus collected will continue to increase in size and height until it develops into a whale-backed dune.

In one place I found no less than three small whale-backed dunes lying in a line up and down wind, in a manner that suggested the probability of recurring eddies. A fourth dune seemed to be forming at the end of the string. The obstruction that set up the eddies in this case was apparently the shoulder of a small ridge that jutted out from a long north and south hill which lay to the west of the dunes.

These whale-backed dunes in course of time develop mostly into dunes of the crescentic type. But in order to deal with this development it is necessary to consider their exact shape. Fig. 2 shows a cross-section of the whale-backed dune 3 taken from east to west. There was a difference in level between the two ends of the section, which is shown at the break in the base line. This cross-section was made some time after I took those that ran up and down wind. The latter were taken after a gale from the prevailing direction, but unfortunately in the interval between the two surveys a rather strong wind from the west blew for a couple of days which has given the dune a rather lopsided cross-section.

These sections are not strictly speaking curves, but are formed by a series of short straight lines joining the points that were actually fixed, as indicated by heavy dots on the sections. The dotted curves are those which the sections seem most closely to resemble. The curve for comparison with the cross-section is an ordinary camber, constructed on a base line consisting of the western part of the base shown in the section, produced till it met the downward continuation of the curve of the dune on the east, as shown by the dotted line. A camber can be constructed by erecting a perpendicular CD at the centre of its base AB, joining AC, and producing it to meet BE, erected perpendicularly to one end of the base AB, and dividing BE and BD into the same number of equal parts. The intersection of lines drawn from A to these divisions on BE with perpendiculars from the corresponding divisions of BD give points in the curve. [It is easy to show that the camber thus described is part of a parabola.—ED. J.G.]

Fig. 2 shows also in two parts the section of this dune—taken in the direction of the prevailing north wind—over its longest diameter; there was again a slight difference, shown in the base line, between the level of the ground at the two ends of the section. But as the direction of the wind could not possibly have been affected by the shape of the land lying below the sand, I do not think that this difference in level can have had any effect upon the character of the curves, though it of course produced a slight alteration in their proportions. This section shows very clearly the great length of this type of dune in proportion to its height.

Fig. 2.—Sections of whale-back Dune 3

Fig. 4.—Development from whale back to crescent

Fig. 3.—Sections of Dunes 18 and 19

The dotted curve is a cycloidal curve of the same proportions. For practical purposes this may, I think, be taken as the shape of the dune. I say "for practical purposes," because in addition to any abstract scientific value of data of this kind, they have a considerable practical value as well, for when once the curves of these dunes are known, their cubic contents can be easily calculated—a question of some importance when it has, for instance, to be decided whether a dune shall be carted away in order to prevent it from encroaching, or whether some other method of dealing with it shall be adopted.

The curve of the lee section I was unable to identify; but its nature can be gathered from the heights of the section taken at tenths of its length. Putting the extreme height as unity, the others were as follows:—

1 = 1.00	6 = 0.66
2 = 0.99	7 = 0.53
3 = 0.93	8 = 0.39
4 = 0.85	9 = 0.24
5 = 0.76	10 = 0.12

The windward curve of the whale-backed dune, as it increases in height in process of development into the crescent shape, somewhat changes its character, becoming rather more "hump-backed" than in its initial stages. This can be seen in Fig. 3, which shows a section taken up and down wind of the dune 18. The dotted curve is here the same cycloidal curve with which the windward section of the whale-backed dune 3 was compared.

Before discussing the development of the lee curve of the whale-backed form it is necessary to consider the rather vexed question of the formation of the flat face, or "slipping cliff," as Dr. Cornish calls it, that is so often to be seen on the lee side of a dune. Dr. Cornish's theory is that this lee face is formed by a "back-acting eddy" that erodes the down-wind side of a dune. His views on the subject of these eddies are given in a diagram in his paper, "On the Formation of Sand Dunes" (*Geographical Journal*, vol. 9, p. 298), in which an obstruction such as a wall is shown with the wind blowing from the left at right angles to its face. He believes that under these circumstances there is an eddy on either side of the wall that revolves in the direction of the hands of a watch, and as a considerable part of his theory of sand-dunes is based upon the existence of these eddies, it is necessary to examine them rather carefully.

For my part I do not think that either of these eddies exists, except perhaps in the shape of a very occasional flaw—that is to say, a temporary gust of wind that has no appreciable effect upon the shaping of the dunes. Take first the eddy on the windward side of the obstruction. I once made some experiments with ordinary smoke rockets, allowing their smoke to be carried over the top of the wall by a high wind blowing practically

at right angles to it. I could see no trace of this eddy. The smoke was carried up from the ground-level, as shown in a photograph, to the top of the wall in a curve with its concave side to the direction of the wind, and though I burnt several rockets to thoroughly test the point, there appeared to be no tendency to eddy at all. The smoke rose from the ground-level to the top of the wall slowly, as compared with the velocity of the wind in the open, showing a certain amount of stagnation in the air near the base of the wall. Once, however, it had reached the top it was whirled so rapidly away to leeward and became so dispersed that photographs taken on the lee side of the wall did not show enough smoke to enable the course of the wind to be determined, and I was obliged to repeat the experiment on a small scale by allowing the smoke to drift over a plank about a foot wide, in order to obtain the necessary data from the photographs. Here again the photograph showed no sign of an eddy.

Apart from these smoke experiments, the existence of an eddy such as Dr. Cornish describes under the lee of an obstruction is, I think, quite contrary to all experience. If a man is standing with his back against a wall, say 10 feet high, when the wind is blowing at right angles to the other side of it, it is a well-known fact that he is "in the lee" of the wall, or in other words that he is out of the wind. Probably the eddies under the lee of an obstruction of the shape of a dune would differ somewhat from those in the lee of a wall, but so far as I have seen a back-acting eddy does not form there. I spent some weeks camped on the lee side of a barchane in a tent the back of which was within a few feet of the foot of the dune. During an ordinary wind from the normal direction the tent was completely sheltered. When a sandstorm, however, was blowing flaws of wind occasionally struck down from the north on to the roof of the tent with considerable violence; but though I was all the time on the look-out for eddies from an abnormal direction, I do not remember having seen one blow directly into the door of the tent; it was however not uncommon for them to come into it diagonally from the direction of the horns of the crescent.

Perhaps Dr. Cornish may have been misled in this respect by Darwin's theory of the small eddies that form in the troughs of ripples under water, for I do not think it by any means follows, because eddies of this kind may exist, an inch or so in diameter, in an inelastic and comparatively viscous medium like water, that similar eddies will be found in an infinitely more elastic and less viscous medium like air, and on a very much larger scale. An eddy occupying the trough of really large dunes might easily be 200 yards in diameter. If such an eddy as Dr. Cornish supposes existed, and it was of sufficient force to have any influence at all in modelling the dunes, the first evidence of its presence would obviously be on the rippling. The rippling on the lower part of the windward slope would be reversed. Personally I have never seen rippling of this description after a normal wind had been blowing. I have always found that the rippling at the

lower windward end of a dune that was not peaked faced in the same direction as it did at the top, and in the case of very low dunes, like the whale-backed one that I have described, the rippling forms a continuous series from the windward end over the summit and down the leeward slope to the very bottom, clearly showing that the wind follows closely the curve of the dune from one end to the other. In the case of a peaked dune the wind tends to follow the contours.

I believe that when the wind passes over, say, a wall at right angles to it, it sweeps on the windward side upwards towards the top in a curve such as I have photographed, the lower layers to some extent forcing up those that overlie them, and probably producing some degree of compression on the top of the wall. Beyond the obstruction the wind sweeps on in a downward curve, and eventually strikes the ground with considerable force at some distance to leeward. This down-draught of the wind, which is perhaps the result of the re-expansion of the compressed air, has probably a considerable effect in eroding the troughs of parallel systems of dunes. Below the layer of the wind on the lee side of the obstacle there is a space, roughly triangular in shape, of practically stagnant air, which however during a high wind is occasionally disturbed by small flaws. Between this triangular space and the current of air flowing over it small eddies a few inches in diameter frequently form during a gale.

These eddies, it is true, have a horizontal axis like those in Dr. Cornish's theory; but they do not, I think, play the part that he assigns to them. As a rule they form at some distance from the face of the dune and are much too small to reach the ground. Even if they did so they would, I think, have no effect upon the sand, as they revolve in the manner of the wheel of a moving cart; consequently while the circumference of the eddy is spinning round its axis, the axis itself is carried down wind; so the lower edge of the eddy, which would be the one to affect the dune, is stationary, or practically so, relative to the ground, and has not the necessary velocity to set the sand in motion. I do not think that the slipping face on a dune is in any way due to an eddy, but that it follows necessarily from the character of the curve into which the wind shapes the dune and from the nature of the sand itself.

The process of the development of a whale-backed dune into a crescent can be divided into certain definite steps. The stages shown in the diagram with a continuous line are based upon actual surveys; those with a broken line on dunes which I have seen, but not surveyed; while the dotted line shows a theoretical form (Fig. 4).

In the first of these stages the highest point of the dune is near its centre, and if it is lying on a horizontal even surface, the ground plan, I believe, would be approximately that of an ellipse.

The second stage is reached when the summit of the dune gets pushed further down wind; this I think produces a corresponding change in the ground plan. In these whalebacks and crescents the cross-section that

has the longest base passes through the summit of the dune, and consequently the dune's greatest width—taken across the wind—travels down wind at the same speed as the highest point. The elliptical ground plan consequently assumes a pear-shape, with its maximum breadth towards the leeward end.

I am not sure whether the character of the lee curve of a whale-backed dune remains the same, as the ratio of height to base alters during its development into a crescent. I think it is more probable that it undergoes a change somewhat similar to that of the windward curve. But for our purpose the question is not one of great importance, in view of the fact that it certainly remains of an ogee character—that is to say, that it is a compound curve composed of a convex section on the top of the dune merging into a concave one at its foot. In all curves of this description it will, I think, be found that as the base of the curve decreases in length in proportion to its height, sooner or later a stage is reached when a portion of the curve, near the junction of the concave and convex sections, exceeds the angle of rest of dry sand—which is approximately 30° to the horizontal; and then the sand at that point slips down to form the flat face on the lee side of the dune.

The section Fig. 3 of the whale-backed dune 18 shows that for a dune of this shape the leeward slope reaches the angle of rest of sand when the length of the base is about $2\frac{1}{3}$ times the height of the dune.

The flat lee face at first does not extend to the ground-level: it cuts back into the convex curve at the top of the lee side of the dune and buries a part of the concave curve at its base, but leaves the remainder of it as a sort of "apron" at its foot as in Fig. 4 (3). This is the third stage in the development of the crescent. Dunes in this condition are not often seen, as this stage is of short duration. As the sand is blown up the windward slope of the dune over the summit it falls in successive layers on the flat face, which consequently advances down wind and soon covers over the small "apron" of sand at its foot. The lee face then reaches down to ground-level and the dune has reached its fourth stage.

When in this condition the ground plan of the dune on its lee side is only slightly concave and the dune cannot be said to have assumed the true crescentic form. The tendency, however, of the wind to contour round a crescent dune, combined with the increase of density in the flying sand near the ground during a sandstorm and the greater rapidity with which the lower parts of the flat face at its ends advance, as compared with the higher central portion, cause the two ends of the lee face to advance down wind more rapidly than the centre and to form the two horns of the crescent—this forms the fifth stage, and the dune is now what I believe to be usually considered a typical crescent. For convenience of comparison, I have shown all the sections and plans in the diagram as being of the same length, but in most cases there would be a change in the length of the dunes during the process of development.

Besides the simple crescent there are other types of dunes which are to be seen in this belt, but which I believe to be more or less abnormal forms. One of the commonest of these has the curious cusped form of ground plan on the interior of the crescent. This is very apparent in the dunes 6 and 10; it is, I believe, produced by a wind which, after following round the lower flanks of the dune, sweeps into the lee side of the crescent in large vertical eddies that erode the inner side of the horns of the crescent.

On the larger dunes it is not unusual to find the upper part of their lee-slopes broken up by small slipping cliffs that are quite distinct from the main flat face lower down; these small facets I believe to be the result of

Fig. 5.—Effects of reversal of wind on section of a Dune

violent gales that blow from the opposite direction to that of the prevailing wind.

The first effect produced by a wind of this kind is to deposit (as shown in Fig. 5, *b*) a small mound or ridge of sand at the top of the lee face—using the term “lee” with reference to the direction of the prevailing wind. The top of the dune is then “turned.” If the wind continues to blow for a considerable time or with great violence it gradually begins to convert the flat lee-face into the cycloidal or windward curve, and the dune then presents the section shown in Fig. 5, *c*. Sections of this type with a low facet high up on the dune are, I believe, the permanent shapes of large dunes which are subject to two nearly equal winds blowing—as is the case at

El Wad in the south of Algeria—from approximately opposite directions at different times in the year. Where the effects of the two winds on the dunes nearly balance each other a large dune becomes practically stationary, or at most oscillates slightly to and fro over the same spot, with perhaps a slight tendency to creep forward under the influence of the stronger of the two winds.

In the case, however, of the smaller crescent dunes of this part of the Libyan Desert, though an unusually powerful gale from the south may temporarily convert them to this form, the northerly winds so greatly predominate that the top of the dune is very soon turned back again (as shown in section *d*) so as to face towards the south. For a time it then has a small flat facet high up near its summit. This facet is only a small one, and since the surface of the dune to leeward of it falls rapidly away towards the south, the prevailing wind carries a considerable amount of sand over the upper face and deposits it some distance away on a portion of the dune, near to the point where the top of the slipping cliff originally lay. This part of the dune is sheltered from the direct action of the wind; the sand consequently rapidly accumulates at this point (as shown in *e*) until it exceeds its angle of rest, when it slips down, the lower face is reformed, and we get the section shown in *f*. Nearly all the sand blown over a dune of this shape falls either on the upper facet or the portion of the dune at its foot—hardly any of it reaching the lower face. The upper facet consequently soon catches up the lower one, and the two then form a continuous surface and the dune has gone back to its original shape as shown in *a*.

In addition to their development from a whale-backed dune there are other ways in which these crescents are formed. Sometimes a small dune of this description will split off from the lee side of a large dune-cluster. Two years after I surveyed the dunes near the railway I visited the place again to see what changes had taken place in the sand. The small dune 15, lying to the south of the hollow 27 at the time of the survey, appeared to form an irregular part of the dune 16. Before my second visit however a deep col had developed between it and 16, and on the west it was completely detached, owing to the hollow having extended so far to the south as to cut entirely through the low neck of sand that formerly bounded it in this direction. The dune 15, being small, travelled more rapidly than its neighbours and had already advanced a considerable distance down the western flank of 16. The dune was so nearly detached from the main cluster of which it had originally formed part, that there is no doubt that after a few more weeks it would have become completely separated from it.

Another process by which crescent dunes are frequently formed is by development at the end of the horn of a larger one. An instance of this is seen in the case of 19 attached to the horn of 18. And another case appears in 22, which has developed off one of the horns of 21. The dune 22 appears

on the map to have been originally about the same size as its parent dune 21, but in reality it was much smaller and lower. It had, however, undergone a considerable lateral development owing to the fact that the railway at that point ran over a slight embankment against which the sand had accumulated. I saw the two dunes 18 and 19 in every stage of their development. My attention was first drawn to them by the native foreman in charge of this section of the line, who said that he thought that a new dune was forming. All that was to be seen of them at that time was an irregularly shaped patch of ground that seemed to be more thickly covered with sand than the desert immediately surrounding it. At that time I was on my way out to Dakhla oasis, so could not stay to wait for developments; but some months afterwards, when returning to the Nile Valley through Kharga oasis, I found that the level of the sand had risen considerably and that the ground plan of the dune was quite regular—in fact the irregular patch of sand-covered desert had become a very low but typical whale-backed dune. In the following year it became much higher and developed into a crescent: no sign, however, of the second dune was to be seen.

The next year was that in which it was surveyed, and it appeared as shown in the plan, with the smaller crescent attached to one of its horns. When I first saw it that year there was a very small third crescent attached to the neck of sand that joined the two dunes, the arrangement of this group of three dunes being then rather similar to that of the dunes 4, 5, and 6. This small dune can be seen in a photograph, but shortly after the view was taken it disappeared during a violent sandstorm and at the time of the survey no trace of it was to be seen. Two years later, when I next saw them, these dunes not only showed a marked increase in size, but the smaller dune had broken off from the larger and had passed completely over the rails, while the larger dune, which was lagging behind, in a few months would have come on to them.

I admit I am not quite certain how these adherent dunes are formed; but I think that possibly they originate in a pile of sand, deposited in the same way as the heap that produces a whale-backed dune, by an eddy formed off one of the horns of a crescent, which first reaches the rippled stage under the influence of a gale from a slightly abnormal direction, or say, to take the case of this dune belt in Kharga oasis, from the north-east. A heap of sand formed in that way would be situated between the horns of the crescent, instead of in line with one of them, and a very small low dune in this position would be practically unaffected by a wind from the prevailing northerly direction, as it would be sheltered by the larger dune. This large dune, however, would advance under the influence of this wind towards the smaller one.

Winds from the east and west would only cause it to oscillate slightly, though they might blow a detached dune, such as 3, formed off a horn of another, under the lee of the larger dune. Southerly winds however,

which sometimes blow with considerable force, would drive it back upon the larger and consequently slower-moving crescent lying to the north of it, so that both the normal and reverse winds would cause these two dunes to approach each other, until in course of time the two would meet and combine.

A marked peculiarity of these adherent dunes is the tendency they show to spread out in the direction of the second horn of the crescent to which they are attached. This is very noticeable in the case of 22. The cause of this is presumably that the flank of the adherent dune is to some extent sheltered on that side, and consequently is not so much eroded by the wind as the outer flank. It is noticeable too that the sheltered side of these dunes appears in a cross-section to be considerably higher than the outer flank. As the small attached dune increases in size it becomes less sheltered from the wind by the larger, and consequently is pushed more rapidly down wind, and finally breaks off from it altogether.

The greater part of the surface of all these dunes is composed of hard strongly crusted sand; but this caking of the surface is curiously local. In walking over the dune 23, for instance, my footprints usually only crushed the ripples, but here and there I found places where I sank suddenly in up to my ankles, though no indication of the absence of crust was to be seen on the surface until I actually trod upon it. The very local character of this caking of the sand can be gathered from the photograph, which shows two of these soft patches, the extent of which is shown by the deep footprints, the sand all round these patches being crusted quite hard. In the background of this photograph the dunes 21 and 22 can be seen. At one place on this same dune I not only broke through the crust as I walked over it into the soft sand below, but about a square foot of the surface of the dune suddenly fell into a hollow beneath when I trod on it, leaving a hole about a foot deep, into which the sand from the surface trickled down, cutting grooves in the perpendicular side of the hollow as it did so.

In many places the desert consists of stiff clay, which owing to the heat of the sun forms cracks, perhaps 10 feet deep and a foot or two across. Sometimes this clay is covered with sand heavily crusted on the surface. This type of desert is, I believe, known to the Bedouin as *Noser*. Often when crossing a patch of desert of this type one of my camels has stumbled, and when he moved on left a hole behind him 7 or 8 feet deep, showing that he had trodden on the sand-crust covering a fissure in the clay. A more uncomfortable surface to trot a camel over it is impossible to imagine. But though the presence of a crack of this kind in the clay will account for a hollow beneath the sand that covers it, I have been unable to see how it can exist in the mass of a sand-dune.

This crusting of the dunes undoubtedly sometimes has an effect upon their shape, though I do not think a very appreciable one. The dune 13 when viewed from below showed a distinct peak, quite different from the normal outline of a dune of this type. On climbing up on to the dune I

DRAUGHT SCREEN TO PROTECT RAILWAY

CAMP WITHIN CRESCENT DUNE 21 FROM S.S.E.

LARGE DUNE WITH TOP TURNED NEAR EL WAD SOUF

SOURCE OF DUNE BELT AT MOUTH OF GORGE

found that while the top of it, as a whole, was only very lightly crusted, there was a ridge of hard-caked sand running up and down wind, the southern end of which formed the peak that I had seen from below. This crusting was of very limited extent, as can be seen from the photograph of my tracks. On the top of the ridge the rippling only was trodden through; but on either side of it the footprints are of some inches in depth. This peak was of a permanent, or at any rate semi-permanent, character, for I noticed it in three successive winters. Its persistence for such a long period is very curious, as during that time the dune must have advanced some 45 or 50 metres. The top of it too must have been repeatedly "turned" to some extent by southerly gales in every year, as shown in the photograph.

A sample of crusted sand from El Wad in the Algerian Sahara that I sent to the Natural History Museum was most kindly analyzed for me by Dr. G. T. Prior, who found that the cementing material consisted of carbonate of lime, and that the sand was free from the micro-organisms I had expected. Two other samples of caked sand collected at Ismailia in Egypt were also analyzed by the kindness of Mr. A. Lucas, the Superintendent of the Government Laboratory in Cairo. In this case the cementing material was found to be of a different character. The analysis was as follows:

				No. 1. %	No. 2. %
Total matter soluble in water	...	...	...	0.08	0.20
Chlorine	...	...	...	0.018	0.02
Equivalent as common salt	...	...	...	0.029	0.03

Both samples contained only a trace of carbonate. Sample No. 2, which was taken from the trough of a dune, contained "a little finely divided clayey matter;" but sample No. 1, which was taken from the top of the same dune, was free from this.

I once spent some hours during a sandstorm in experimenting on the shapes into which the wind would mould a bucketful of sand when poured out on to the top of a box. The results were very puzzling. After the wind had been allowed to play upon it for some time, the sand invariably assumed one of two forms. The first may be described as cigar-shaped—that is to say, a long narrow ridge lying up and down wind, with pointed or rounded ends and a curved cross-section. This form always maintained its character until the wind had blown it practically all away.

The second shape was approximately that of a D with the curved portion of the letter pointing up wind. The straight leeward side formed a distinct flat face, with the sand lying at the angle of rest, though the miniature dune was only about a couple of inches in height. With such a small pile of sand it was not possible to take accurate measurements of the curves; but they appeared to be of the same character as those of a full-sized crescent dune. The box on which the sand was heaped was of japanned iron, and if it had had a rougher surface for the grains to

cling to I have little doubt that the D shape would have developed horns and become a typical crescent. While wasting away under the action of the wind this form usually maintained its character so long as it can be said to have had any definite shape at all. But occasionally, before finally disappearing, it altered its ground-plan to that of a very diminutive "cigar-shaped" dune.

The curious fact about these experiments was that I found it quite impossible to foretell which shape the original heap of sand would take, nor could I discover what caused the pile at one time to develop into the cigar-shape and at another into the D form. The shape that these miniature dunes ultimately took did not seem to be in the least affected by the form of the original sand-heap. Sometimes the bucketful of sand was emptied in a cone-shaped pile in the centre of the box, at others into a ridge running up and down wind, and at others again into a similar ridge across the wind. But it appeared to make no systematic difference whatever to the result; sometimes one form would appear, and sometimes the other.

The amount of sand laid out cannot, I think, have had any effect upon the result. Though I did not actually measure it, the bucket was always practically filled, and the amount of sand left in the resulting dunelet could never have been much more than a tenth of the original amount. The sand used for the experiments was always of the same kind, being taken from the dune on which the box stood. As the box itself was placed on the summit of the dune, hardly any wind-borne sand could have reached the heap on the top of it, so the supply of sand during the shaping of the pile could have had no bearing upon the question.

The only solutions of the problem that I can offer are that the form that the miniature dune eventually took depended either upon the arrangement of the grains of sand on its surface relatively to each other at some critical period of its development, or upon changes in the velocity of the wind: extra strong gusts producing, say, the cigar shape and milder ones the crescent.

The narrowness of these belts of crescent dunes is very remarkable, but can, I think, be easily explained. I have seen the windward end of many of the smaller belts and have found that they invariably originate from a very narrow source. In one place, for instance, to the north-west of Kharga oasis, the continuous cliff of the limestone plateau that here forms the northern wall of the Kharga depression was broken by a gorge leading northwards. Beyond this opening lay a chain of small valleys, bounded by precipitous cliffs some 200 or 300 feet in height. The eastern and western walls of the southernmost of these depressions converged at a fairly acute angle on to this gorge and so formed a sort of funnel, running roughly in the direction of the prevailing wind. The sand carried down by this wind consequently came to a focus at this point, with the result that a sandhill had formed in the narrowest part of the opening and a

small line of crescent dunes stretched away for a mile or two to the south. The sandhill blocking the gorge was apparently stationary. The line of dunes to leeward of it were evidently offshoots from this parent dune, as one of them was still attached to it.

A dune which breaks off in this way from another dune or from a stationary ridge of sand can move only in the direction of the wind. The dunes which develop from its horns will also move in the same direction; so too will those that break off from a fixed dune behind them; consequently the whole series of dunes will follow the same path and form a long line running in the direction that represents the resultant action of the wind upon them. A belt of dunes formed in this way must be narrow, as it cannot well exceed in breadth the source from which it originated.

The rate of advance of the down-wind end of one of these belts is not by any means the same thing as the speed with which the individual dunes of which it is composed are travelling, for the leeward end of the belt is continually receiving additions in the form of new dunes thrown off by the old ones. These new dunes, being much smaller than those to windward of them, at first advance much more rapidly. But as they progress down wind they increase in size. Their advance is effected by the sand-grains blown over the top of the dune falling on the sheltered lee side and continually refacing it, so the rate of progress of a crescent dune under given circumstances is directly proportional to the height of its slipping cliff.

When viewed from some distance away to the east or west, the dunes of which these belts are composed often appear to be arranged at approximately equal distances apart and irresistibly suggest a succession of sea waves. This equidistant arrangement is not, I think, produced by any wave motion, as suggested by Dr. Cornish, but is due to entirely different causes.

When a wind that brings no sand with it blows over a dune, it reduces its bulk with every sand-grain that it blows off its lee end. But in normal circumstances this eroding action of the wind is more or less compensated by the sand that it brings with it on to the dune, a certain proportion of the grains brought in this way becoming caught in the troughs of the ripples and remaining behind to replace those that are lost.

The sand that comes on to a dune is not all brought to the bottom of the windward slope by the wind, but consists also of those grains carried by the wind at a higher level that are intercepted by the dune's upper part. During a wind the layers of air near the ground not only travel much slower than those above them, and consequently have less erosive force, but they are much more heavily loaded with sand. Consequently the lower a dune is the more sand it will intercept and the less it will be eroded by the wind in proportion to its height—and for both these reasons the faster it will grow.

At a certain distance above the ground the air is practically free from

sand. As a dune begins to exceed this height it exposes an increasingly larger surface to the erosive power of the wind without any corresponding gain in the increase of the amount of sand deposited upon it. So as a dune increases in height a balance is soon struck between the erosive action of the wind, tending to decrease its bulk, and the depositing action tending to increase it. The growth of the dune is consequently stopped.

Since all the dunes of the same district are presumably subject to about the same weather conditions, they will all be affected alike by the winds that prevail in the neighbourhood. So the full-grown dunes will not only tend to be of about the same size, but as they will all have increased in bulk at about the same rate, they will all have travelled approximately the same distance during the process of their growth. If they were thrown off a dune that was fully grown at the time, they will when fully developed themselves remain at a constant distance from it; and those dunes, like 19, that have formed from an intermediate dune that was not fully grown, will tend to catch up the full-grown dunes ahead of them and become incorporated with them to form a cluster. This I believe to be the explanation of the recurrence at regular intervals in these belts of large dunes and dune-clusters all travelling down wind at about the same speed.

Dr. Cornish made, I think, a very good point when he suggested in one of his papers that sand-dunes form themselves in some cases on lines of least resistance. This is not, of course, so in the case of dunes upon which winds from a variety of quarters have left their impress; but the windward portion of the whale-backed dunes, which are subject to such a strongly prevailing wind that after a gale from this direction the effect of all other winds upon their shape may be disregarded, must I think be a form of this description; for if one part of a dune departs from the true shape while the remainder of its surface conforms to it, obviously that part will offer greater resistance, with the result that the wind will act more strongly upon it and so wear it away more rapidly than the remainder of the dune. By perpetually removing these deformed portions the wind will gradually cut the whole dune to the true shape. I made a number of experiments on this point by digging pits and raising piles of sand on the top of a dune; but invariably the heaps were dispersed and the holes filled up and the dune returned to its original shape.

In the case of a whale-backed dune which is continuously rippled from the windward to the leeward end—showing that the wind closely follows the curve of the dune—I believe that its lee side is simply the space, sheltered by the upwind part of the dune from the direct action of the wind, which has become filled up with sand, the surface of which the current of air just grazes in its passage; for obviously any point on a long low curve like this, over which the sand is blowing, that is not reached by the wind, would tend rapidly to fill up, while any protrusion above its surface would be so eroded by the wind that it would rapidly disappear.

I agree, too, with Dr. Cornish in thinking that these shapes might

perhaps be worth studying by those interested in forms of least resistance, especially by builders of air craft, where the wind velocities to be dealt with would not be greatly in excess of those of the desert wind. When much higher velocities have to be considered, as in the case of projectiles, possibly new factors would be introduced which would make a comparison useless. The same difficulty too might apply to the use of these forms in water, though a race between a boat built on "wave lines" and one on "dune lines" might be instructive.

If it should be proved that these whale-backed dunes are forms of least resistance to the mean wind velocity, probably the shape that passes most easily through the atmosphere might be found experimentally, for a wind of any required speed, by causing a current of air of that velocity to blow for a sufficient length of time over a pile of dry sand to bring the heap to the true shape.

THE FUTURE OF INTERNATIONAL SCIENCE

IN the *Journal* for November last we remarked on the attempt of Prof. Bakhuyzen to keep alive the International Geodetic Association during the war, to the intent that on the conclusion of peace a General Conference should be held to decide upon the future of the Association. Our conclusion was that the attempt is doomed to failure, since so many scientific men of the Allied Powers are resolved that they will never again have dealings with men of the nation that has destroyed all possibility of sincere and cordial relations. In opposition to this feeling one sometimes hears it said that Science has no political boundaries, with the implication that we shall do wrong to refuse a renewal of the old international co-operation. To this argument there is an interesting reply in a note written to the *Journal des Débats* of 17 October 1917 by M. Emile Picard, the eminent Secrétaire perpétuel de l'Académie des Sciences. "The old International Associations, which were a springboard for Germanism, must therefore be regarded as dead." M. Picard's development of this theme will seem to our readers well worthy of preservation in a scientific journal of the times.

LES RELATIONS SCIENTIFIQUES INTERNATIONALES APRES LA GUERRE.

Les Allemands font en ce moment les plus grands efforts pour que, à la fin des hostilités, les relations scientifiques internationales reprennent dans les mêmes conditions qu'avant la guerre. Certains savants des pays neutres jouent le rôle d'honnêtes courtiers, s'efforçant de rendre la vie à des groupements internationaux morts depuis trois ans.

Il importe de déclarer bien haut que toutes relations personnelles

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