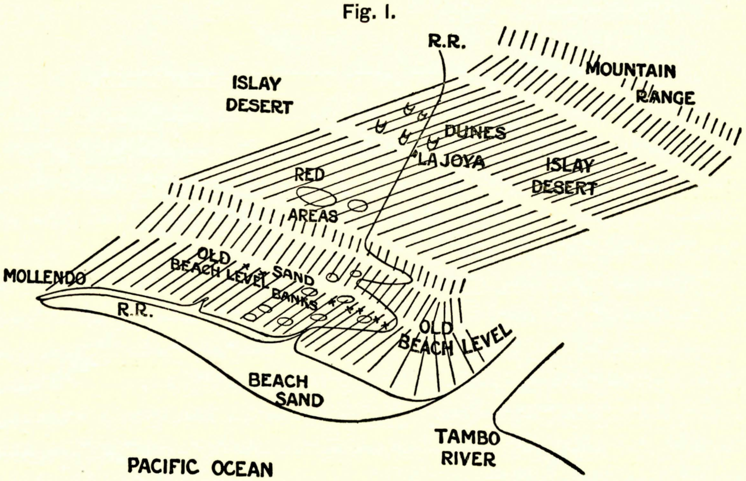
# The Crescentic Dunes of Peru.

By A. E. Douglass.

The memoranda herein presented were made in 1892, and largely published at that time in Spanish[1] with a view to their subsequent arrangement for some North American journal. In spite of the manuscript having been overlooked to this late date, it is thought to contain some new facts. Two years after this examination, Professor S. I. Bailey of Harvard Observatory visited and measured the same dunes. In his subsequent publication[2] he is but vaguely aware of these measures.

The dunes may be seen and even visited from the railroad trains passing between Mollendo, the seaport, and Arequipa, the principal city in southern Peru. They occupy the northern half of a perfectly barren waste called the Desert of Islay, which extends, as shown in the accompanying diagram (Fig. 1), out

Fig. I.




southward and westward from the great mountain masses of the Andes, like a shelf overlooking the ocean. The average slope of the desert is a trifle over one foot in a hundred. The dunes

[1] *El Kosmos*, No. 21, December 30, 1892, Arequipa, Peru.

[2] *Annals of the Observatory of Harvard College*, Vol. XXXIX., Part II., page 287.

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occupy the upper half of this slope, and are being driven upward by the strong combination of land-sea and mountain-valley breezes of that region.

The climatic conditions are peculiarly favorable for sand phenomena. The shelf on which they are located is midway between the low-lying winter fogs of the coast and the high-level summer storms of the mountains, and rarely partakes of either. It is an admirable example of a climate with practically no rainfall and a maximum daily variation of temperature. It rains on the average eight times in the year, but in each case the amount is too small to measure.[1] The average daily temperature variation in the thermometer shelter is 27.3° F.;[2] but on the exposed sand surfaces it is certainly over 100° F. The day breeze is almost uniformly from the south and attains a velocity of even twenty miles an hour, readily moving the sand, but not usually raising it into the air. In ten or fifteen trips across that desert no dust clouds were ever seen, though dust spirals were numerous. The reversed night winds are gentle, in no case observed being sufficient to reverse the wind waves on the sand.

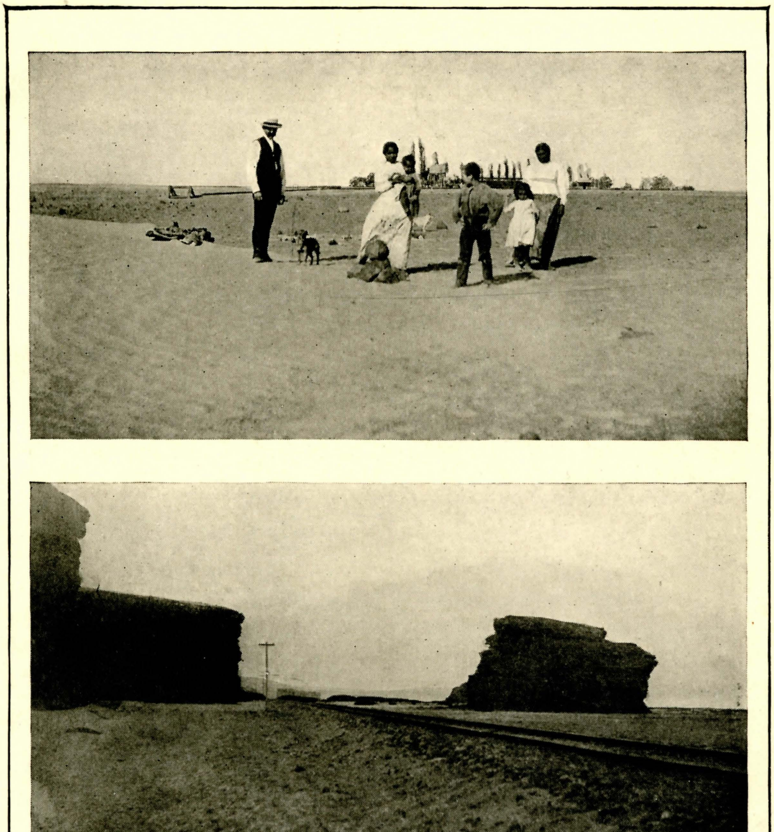
## NUMBER OF DUNES AND GENERAL FEATURES.

Taken altogether, the dunes must number many hundreds, and perhaps thousands. Their restriction to the upper half of the desert is without apparent reason. The only special desert characteristic accompanying them is the fairly large number of boulders in their vicinity.

Between La Joya, the central station on the desert and the beginning of the out wash slopes, " bajadas," from the neighboring mountains the dunes exhibit their perfect form. Upon the slopes they lose their perfection of shape while apparently preserving their individuality. Under favoring conditions they regain their form, and at seventeen miles north from La Joya are noted as " numerous."

Professor Bailey's result of 61 feet a year as the average rate of travel[3] is far more reliable than could have been obtained from the three visits of the writer; at which time, however, a rate of between 56 and 70 feet a year was derived.

[1] *Loc. cit.*, page 261 (rain table).
[2] *Loc. cit.*, page 237.
[3] *Loc. cit.*, page 291.

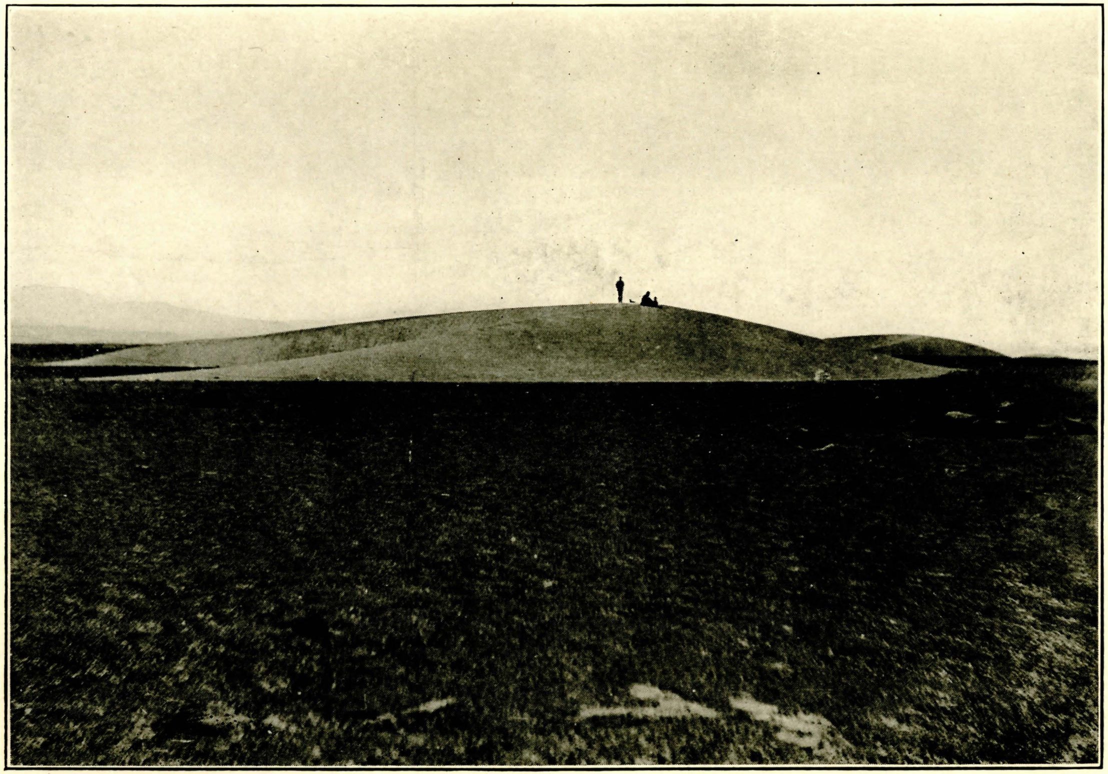


VIEWS IN THE ISLAY DESERT, PERU.

1. Monument placed, April 5, 1892. 2. Los Sombreros (The Hats.)

3. La Joya Station, looking south.

From photographs by A. E. Douglass.



SAND DUNE NO. I, EAST OF LA JOYA, PERU.
From a photograph by A. E. Douglass.

On April 5, 1892, the small monument used in Professor Bailey's first measures was erected and the photograph (reproduced in Plate X.) made of it.[1] The view shows the extreme south edge of the dune. On June 4 small piles of stones were placed at the principal points (G, H, I, M, Fig. 2) of the outline of this dune, Dune II., so that its complete change of place, shape, and size could be measured. It is well to have this on record in case of future visits.

As is of course well known, the dunes move points forward, the round convex edge facing the wind. On the dunes here referred to the wind had blown the sand into exactly transverse waves averaging $6\frac{1}{4}$ inches apart and $\frac{1}{2}$ inch high. The height of the dune in the centre was one tenth of the transverse diameter. On the windward slope one sank 4 or 5 inches into the sand, and in the softer slopes within the crescent to the knees. When the wind was fresh the rustling of the moving particles was heard, as noted by Professor Bailey, while on the soft interior slopes the sand dropped down like snow. With cirrus cloud in the sky the following sand temperatures were observed:—

| | Depth in sand. | Windward slope. | Leeward slope. |
|---|---|---|---|
| March 10, 1892, | $\frac{1}{2}$ in. | 114.0 F. | *Above* 133 F. |
| Noon. | $4\frac{1}{2}$ in. | 92.7 | 110.8 |
| Air temp. 75° F. | 9 in. | 83.8 | 103.0 |

EQUILIBRIUM OF SIZE AND SHAPE.

In the accompanying figure (Fig. 2), which was made directly after the visit to the dunes, I is the same dune east of the railroad station, measured two years later by Professor Bailey. The following are the respective dimensions, no change in size and only a slight change in shape being indicated:—

| | A. E. D. March 10, 1892. | S. B. March 24, 1894. |
|---|---|---|
| | Feet. | Feet. |
| AFB | 80 | 159.5 |
| FC | 90 | 96 |
| AEB | 485 | 477 |
| ED | 70 | 71 |
| DC | 30 | 31.5 |

[1] In Plate X. (1) the monument is in the middle of the picture; "Los Sombreros" (in 2) are conglomerate stacks separated from the present shore-line by a quarter of a mile of recently made land, consisting almost entirely of the "Beach sand" (6) described in the table.

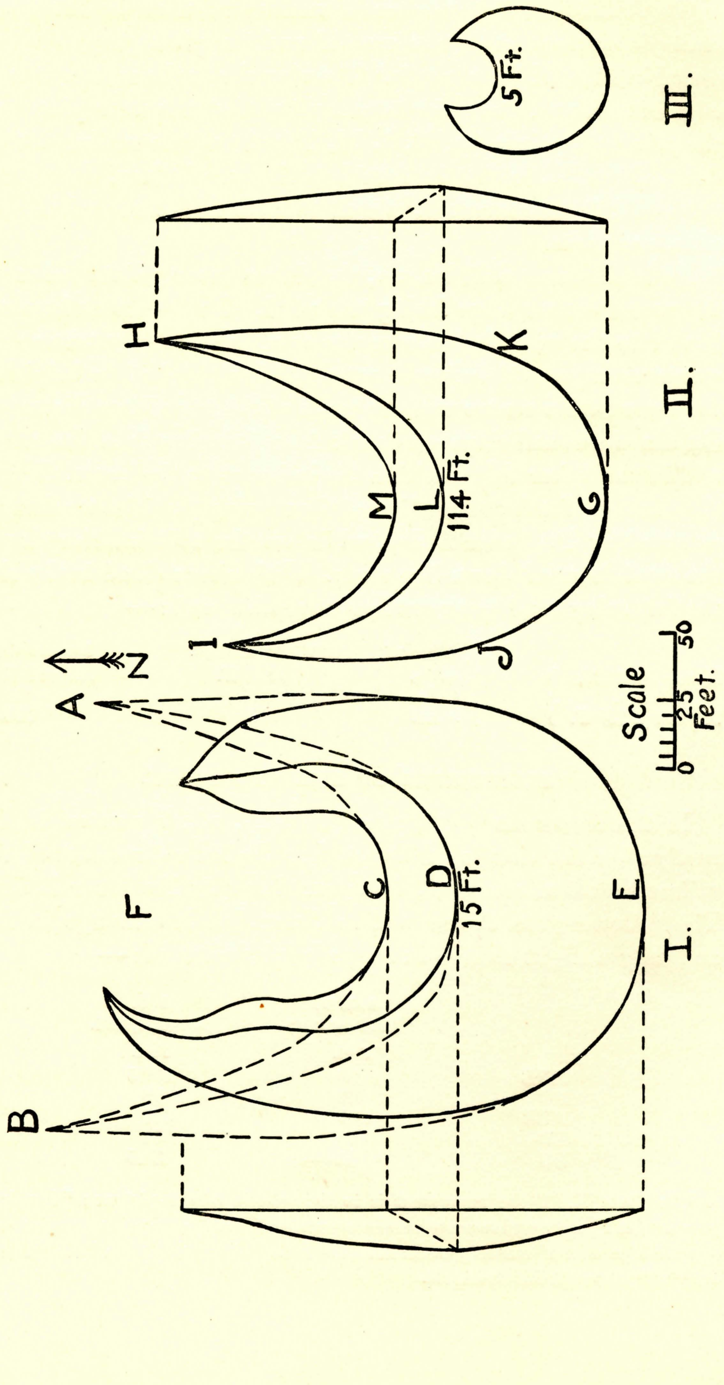



Fig. 2.

The following figures express some general features of the prevailing shape: —

| | I 1892, D. | I 1894, Bailey. | II 1892, D. | III 1892, D. |
|---|---|---|---|---|
| Transverse diameter ....... | 150 ft. | 160 ± ft. | 114 ft. | 50 ft. |
| Longitudinal radius, measured from windward edge to highest point.......... | 70 ft. | 71 ft. | 60 ft. | about 25 ft. |
| Ratio longitudinal to transverse radius ............ | .9 | .9 | 1.0 + | about 1.0 ± |
| Height .................. | 15 ft. | 15 ft. | 11.4 ft. | 5 ft. |
| Ratio height to transverse diameter................ | .10 | .10 | .10 | .10 |
| Average length of cusps from inner curve.............. | 120 ft. | 127 ft. | 92 ft. | about 15 ft. |
| Ratio length of cusps to longitudinal radius.......... | 1.7 + | 1.8 − | 1.5 + | 0.6 |

The first ratio between the transverse and longitudinal radii shows an almost perfectly semicircular plan of the windward half. This appears to be the curve of equal exposure to erosion. The ratio of height to transverse diameter is also a very constant quantity. The transverse section of the dune is very nearly the segment of a circle, Dune II. having 160 feet vertical radius and an arc of over 40°. The last ratio, that of cusp length to longitudinal radius, is dependent on the size of the dune. It is apparent that the smaller the dune, the less sand relatively goes into the cusps. By extrapolation from these ratios one finds that at three or four feet of height the cusps would disappear. It seems doubtful if such a heap of sand could retain its concentration and therefore its existence.

The ratios noted above supply valuable material, but it is by aid of the general crescentic shape that we finally discern the explanation of the permanence and uniformity of individual life which renders these dunes interesting. It is evident that so long as the air passes over these dunes in the form of a sheet, the layers nearest the ground will have least velocity. The maximum transporting power will be at the top of the dune, and the effect will be to scatter it broadcast. This is precisely the way flowing sheets of water treat piles of sand. But air is very elastic and but slightly viscous, and may easily be thrown into a whirl. If the air movement, then, is not extreme in either direction, — that is, too slow or too fast, — but yet rapid enough to produce eddies behind the dune, a sloping double vortex is evidently formed such as is frequently seen above a locomotive smokestack. This occurs, for example, when there is a strong updraught of smoke which the wind carries at a low angle and causes to rotate in a double whirl with an uprushing centre, descending sides, and inrushing lower currents. The effect of such a whirl on the dune is both spreading and centralizing. The vortex will tend to cut off the top of the dune and at the same time sweep inward all particles in the lee of the sides. If the dune is too high, the vortex will be thrown too high in the air and the former effect will exceed the latter, flattening the top. If the reverse is the case, the sweeping effect will excel and the dune will be concentrated. The height ratio is therefore the one which produces the most efficient vortex. It is evident that a sand-heap may be too low to produce a vortex at all. It then spreads out.

A factor of no small importance in the preservation of shape is without doubt the daily high temperature of the sand while the wind is blowing. As noted above, there is at least 20° F. difference in temperature between the two slopes. The relatively lower temperature on the windward slope shows that the particles lifted by the air give up much of their heat to it. This expands the air and assists it in rising to form the vortex. Very likely this is positively essential to the formation of the vortex. In this respect, then, there is a great difference between the dune and the surrounding sand levels, where the particles have little, if any, motion. The relative function of moving sand and stationary sand pavements in the formation of dust whirls would be an interesting study by itself. At night, when the sand becomes exceedingly cold, its chilling effect on the air must strongly oppose the formation of vortices. It might even make a reversed vortex whose direct effect would be to spread the dune out. Perhaps this has something to do with the broad wing shape of the cusps in the Carrizo dunes of California, referred to below.

One other possible factor may be found in minute charges of static electricity arising from friction. This is suggested by the appearance under the microscope of the surrounding desert surface. It consists, amidst larger particles, of dune sand to which are clinging innumerable particles of highly subdivided quartz. There are banks of this quartz loess in the desert, to which reference will be made below. They carry only about one per cent of soluble matter, and the sticky appearance can hardly be due to a hygroscopic salt.

## COMPOSITION AND ORIGIN.

Samples of sand were collected from the dunes and neighboring points, which present some interesting features of composition and origin. The description and distribution of the different sands follow. The dune sand (1) is a clean, homogeneous, gray mass of loose particles, while the surrounding desert surface (2) is a thin, fine-grained pavement of a brown color capable of retaining footprints indefinitely. Near by are occasionally found small banks of a creamy white loess (3), whose particles, averaging a little over .005 mm. in thickness, seem to act as the binding material in the desert pavement. Toward the lower edge of the desert shelf and some ten miles south of the dunes are large areas of a pronounced red color, so effective that the view of them from a distant mountain peak warranted great pains to determine their character. The red color was found to be due to large rounded grains of red quartz averaging 2 to 3 mm. in diameter (4). This showed the origin in the dunes of occasional grains of red quartz whose average size was 0.1 to 0.5 mm., the diminished size being due to attrition in their ten-mile trip.[1] On the lower slopes extending from the shelf to the shore-line the white loess and the clean gray dune sand appear again in large quantities (5); and finally at sea-level the recent beach formation covering a number of square miles is almost exclusively of the same clear gray sand (6). Subsequent mountain trips in the Cordillera disclosed a dark gray sand (7) somewhat resembling the others, at an altitude of 11,000 feet.

Some physical characteristics of four of these sands are given in the following table: —

[1] Thanks are due Mr. V. H. McCord, then Superintendent of the Southern Railroad of Peru, for permitting even passenger trains to be stopped to make these collections.

| | | Dune Sand (1) | Beach Sand (6) | Mountain Sand (7) | Carrizo Sand (8) |
|---|---|---|---|---|---|
| Density | | 2.75 | 2.72 | — | 2.66 |
| Weight 1 cc. dry sand | | 1.45 gm. | — | — | — |
| Non-magnetic. | Percentage | 91.6 | 91.0 | — | 100 (?) |
| | Approximate average weight per particle | .000 005 gm. | .000 020 gm. | .000 020 gm.[2] | .000 028 gm. |
| | Average size [1] | .183 mm. | .287 mm. | .336 mm.[2] | .330 mm. |
| | Proportion colored | 28% | 21% | — | — |
| Magnetic. | Approximate average weight per particle | .000 007 gm. | .000 015 gm. | — | — |
| | Average size [1] | .182 mm. | .251 mm. | — | — |
| | Percentage white (impurities) | 33% | 25% | — | — |

[1] Measured while lying on flat surface. Hence true average is less than this.

[2] No distinction made here between magnetic and non-magnetic.

A remarkable peculiarity of all the sands except the red quartz (4) is that nearly all the particles are intensely angular, with shiny surfaces and brilliant facets. This singular fragmentation is thought to be due to temperature strains caused by the day and night variation, which in protected places is without doubt over 100° F., all above freezing-point.[1] In this fracturing we probably have the origin of the loess.

The eighth sample of sand was collected by Dr. D. T. MacDougal, Director of the Carnegie Botanical Laboratories, from the Carrizo dunes in California near the Salton Sea. It is 98% quartz, almost every particle being well rounded. These dunes have been described by Professor C. F. Tolman, Jr.[2]

Some of these sands, though widely separated, are so remarkably alike that Professor Tolman has kindly made an examination of them, which follows:—

1. Dune sand.

   Shape: 10% rounded or semi-rounded; the rest angular, cleavages and crystal form governing.

   Sizes: (See above table.)

   Quartz: 50–60% of all fragments; conchoidal fracture surfaces scarcely affected by transportation.

   Feldspar: 10%?; largely plagioclase, lath-shape forms, (indicates basic flows as original source of same).

   Apatite: occasional?

   Mica: 5%?; biotite and one flake muscovite noted.

   Magnetite: 5% (?) rounded.

   Hornblende: up to 20%; some augite.

2. Surface sand just passed over by dune.

   Contains same material as dune sand; also very fine loess, apparently attached to large grains, and much large material (feldspars and quartz).

6. Beach sand.

   Similar both in minerals and shape to dune sand; more feldspar and less quartz than in 1; some grains of feldspar contain hornblende not yet broken out.

[1] Near the coast, where the daily range is less, numerous weather-worn beach pebbles up to a foot in diameter were found split into pieces which could be fitted together.

[2] C. F. Tolman, *Journal of Geography*, 1909.

7. Mountain sand.

Contains feldspar, hornblende and augite, magnetite, quartz, olivine and undecomposed rocks (basalt schist, etc.). (By long water transportation could become essentially like the beach sand.)

The extraordinary identity between the dune and beach sands suggests at once that the former is derived directly from the latter. This is such an evident possibility that it is well to consider again the geographic relation between them. The coast extends from southeast to northwest with a strong antarctic current and exclusively south or southwesterly winds. The Tambo River pours immense volumes of this sand into the ocean some twelve miles southeast of the locations herein considered. The antarctic current deposits enormous quantities of this sand along the coast as far as Mollendo, the railroad terminus, some ten miles northwest, thereby forming broad flat beach land averaging from four to seven feet above mean tide level. The width of this made land was found at one point to be 3500 feet. By the rate of deposition it would not be a very serious matter to form some conception of the age of the present beach level.

The sands are blown back upon the uplands, and with banks of white loess constitute the numerous sandbanks filling the hollows for perhaps three fourths of the way up the 3000-foot slopes to the edge of the desert. From the crest of these slopes one may look back seven miles to the surf on the shore, or forward across the gentle slope of the desert, a few low, scattered hills near by interrupting the distant view. No more banks of this sand are found until the dunes are reached. The inference is apparent, and was formed at the time, that the dunes are composed of beach sand blown by the wind up, onto, and across the desert.

The most difficult matter to explain is, why should the dune form only at the centre of the desert? If a sand-heap must be three or four feet high and thirty or forty feet in diameter to obtain permanence, how can it originate in the centre of a perfectly flat desert when the only possible formation would be in the lee of a small boulder not over 20 inches high? While it is difficult to understand the method of formation at any point, yet the probable place is at the lower edge of the plain, where low rocky mounds and certain wind variations might give them a start.

Only one possibility has occurred to the writer as a cause of this gap of twenty miles between the dunes and the other advancing sandbanks. It is that the present dune sand did not come from the present beach level, but from an older beach formation a thousand feet higher, whose sands have blown away, but whose pebbles and shells still show prominently on the surface and in the railroad cuttings. The evidence of this former beach level is conspicuous. The cuttings show it superbly in the form of great layers of rounded pebbles interspersed with streams of volcanic mud and tufa. If this hypothesis is correct, the peculiar limitation of dunes to the upper half of the desert signifies simply the exhaustion of the original supply of sand. The ones measured, then, are simply the last of the dunes. The exhaustion took place several thousand years ago, for, from the known rate of travel, these same dunes left the crest some two thousand years back, and it must have taken them an equal interval to climb the two thousand feet up the steep slope from the old level. The previous period, from the abandonment of the old beach until the exhaustion of its sands, must also have been very great, and we have no sure means of placing any limit to it. Judging, however, from the immense quantities of sand blown across the desert and up against the steep foothills, the minimum limit is likely to have been 10,000 years.

The specimens collected on the mountain at an elevation of 11,000 feet bear a strong resemblance to the dune and beach sands. At the time of collection it was thought that this might be sand blown up to these great altitudes from the desert. But a cursory examination showed its particles to be larger than either of the others, and accompanied by much foreign — and softer — matter. This shows its relationship to the others, if any, to be that of forefather rather than descendant. It shows, however, a supply of great magnitude from which the few swift rivers may obtain the quantities which they transport to the ocean. The ocean currents make beaches of it, from which the winds carry it back to the mountains. Thus there are indications of a cycle in which the rôle of the winds as mountain builders is the most interesting and novel part.

## SUMMARY.

We find that the crescentic dunes of Peru are very accessible to the traveller when once in that part of the world; that climatic and topographic features are favorable to their formation; that their numbers are great; that the observed rate of travel is about 60 feet per year (Bailey); that they preserve their shape year after year, excepting the position of the cusps, and change their size very little if at all; that the larger the dune the more sand proportionately goes into the cusps, and that three or four feet in height by thirty or forty feet in diameter is probably a minimum size; that they are composed of a fine, even-textured sand blown up from beaches some twenty-five miles distant and three or four thousand feet below, while immediately about them is a fine crusty desert pavement composed of the same sand bound together by a superfine loess of quartz. The most satisfactory explanation of the crescentic shape of the dune is that it is a vortex form, self-preservative because in winds strong enough to move the sand it causes a double vortex whirl which restores to the centre the scattered particles. For the restriction of the dunes to the upper half of the desert without apparent cause, we find a possible explanation in the recent elevation of that coast out of the ocean. And in the similar sand at 11,000 feet altitude upon the mountains we find suggested a large cycle consisting of destruction by weather and water and reconstruction by the winds.