ART. VI.—*Post-Glacial Eolian Action in Southern New England*; by J. B. WOODWORTH.

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THE following paper is an account of some detached observations made by the writer while engaged in the survey of the pleistocene deposits of southern New England. The matters touched upon here are too detailed and of too little economic importance to find a place in the short descriptive text accompanying the forthcoming atlas sheets, and are hence published in this form. The field work during which the observations were made extended over the years 1889–1892, and was done under the supervision of Mr. N. S. Shaler, geologist in charge of the Atlantic Coast Division, to whom I am primarily indebted for the privilege of making this independent statement of my observations.

The action of the winds in New England in their geological bearing has been described in several communications. The most significant of these papers is that published in this Journal, in 1886, by Geo. H. Stone.* In this paper, Prof.

* III, vol. xxxi. pp. 133–138. The following is a list of papers by American authors in which carved and polished rock surfaces are described, and generally though not always ascribed to eolian action.

1855. W. P. Blake: Report of a Reconnaissance in Colorado. House Doc. 129, p. 27, and Pacific Ry. Reports, v, pp. 91, 117, 229–232, and this Journal, II, xx, pp. 178–181. 1861. C. H. Hitchcock: Report on Geology of Maine, pp. 266–268; 1870 Gen. Benj. Tilghman: U. S. Patent, No. 108,408; 1875. G. K. Gilbert: U. S. Geog. Surv. 100th Meridian, III, pp. 82–84; 1886 N. S. Shaler: Geology of the Island of Nantucket, U. S. Geol. Survey, Bull. 53; 1886.

Stone for the first time recognized the agency of wind-driven sand in carving rock surfaces. His studies were carried on in the State of Maine, where, he states, "in numerous places, both in Bethel and elsewhere near the mountains, I found boulders and even small stones which are now being sand-carved by the wind as plainly and incontestably as in Colorado."

The competency of blown-sand to carve rock surfaces.—There can be no question that sands driven by the wind have the power to cut away the surface of rocks on which they impinge. The observations of Blake in San Bernardino Pass, of Gilbert in the Great Basin, of Blanford and Oldway in India, and of numerous observers in the desert regions of the Sahara, the Sinai peninsula, and less arid tracts, point conclusively to the view that by means of this subtle agency the hardest rocks are reduced to detritus and receive a form peculiar to the manner of erosion.

Prestwich, in his *Geology* (vol. i, page 145), says: "On a land freshly emerged from the sea, both rain and wind had necessarily an infinitely greater effect than now, when it is covered with soil and vegetation. Soft and incoherent strata were then subject to rapid wear by surface waters, and loose materials to easy removal by strong winds, as sands now are on the coast, or on bare tracts inland by the like cause. In the same way volcanic ashes, Diatomaceæ, and seeds are transported for hundreds of miles, and so dispersed over wide areas. Sand, when carried by winds over rocks, is known to wear them smooth, and even to line their surface with scratches and furrows. In some cases, hard rocks, such as granite, quartz, and limestone, have been polished, and quartzite pebbles worn into symmetrical forms by this means. This occurs in countries where certain winds prevail at different times of the year, so that different sides of the pebbles are alternately exposed to the wind-action. In this manner regular pyramidal-shaped pebbles have been fashioned in New Zealand and Egypt."

This quotation sets forth in brief the class of effects which are sparingly observed in the district to which this paper relates. The explanation of the pyramidal-shaped pebbles given by Prestwich differs somewhat from that advanced by Walther, whose account of his observations and the history of opinion in Germany is so good that I venture to quote from his valuable monograph.*

Alex. Winchell: *Geological Studies*, p. 284; 1886. N. H. Winchell: *Geology and Nat. Hist. Survey of Minn.*, i, p. 541. R. D. Salisbury, *Annual Rep't, N. J. Geol. Survey*, for 1892, p. 155.

*Die Denudation in der Wüste und ihre geologische Bedeutung. *Abhandlungen der math.-physisch. Classe der Königl. Sach. Gesell. der Wissenschaften*, Band. xvi, No. iii, 1891, pp. 445-448.

The following are some of the foreign papers relating to the formation of carved pebbles:

"It was so far as I know on the 5th of April, 1876, that G. Berendt for the first time called the attention of North German geologists to peculiar facets which are seen on pebbles in the glacial drift. Since this time, these so-called 'dreikanter, or 'Kantengerölle' have interested geologists, and a great deal has been written on this subject. They were regarded as the work of ice, of great pressure, etc., until Mickwitz in his treatise gave the right key to the puzzle, in that he proved that these facets are merely a phenomenon of smoothing by sand (*Sandschlifferscheinung*), a view which since then has merely been confirmed by Credner, Heim, Sauer, and others. Views at present differ only concerning the manner in which these planes were cut. I have collected a number of such edged pebbles in different parts of the desert: first I found them in Wady Araba in the Arabian desert, then between Giseh and Abu Roasch on the border of the Libyan desert; and Dr. Sarasin has found them in the Sinai peninsula.

"According to my observations," continues Walther, "it is limestone of the Cretaceous formation, of fine, compact, very uniform grain, which in Egypt forms dreikanter. I have not found other varieties of rock in this form. The Eocene limestones may be too soft, the Nummulitic rock too unequally hard, and the crystalline rocks, as I have to show in the following pages, so quickly decompose in the desert that they are not adapted for forming dreikanter.

"The number of corners ground on varies as much as does the size of the pebbles, and neither are causally connected. I found einkanter (pebbles with one edge or aris) a foot in diameter (fussgrosse) and nut-sized stones with five edges (fünfkanter) and conversely.

"The edges are of unequal sharpness, and I believe I have observed that the edges are merely due to the fact that two ground flat surfaces intersect each other so that the expression 'facetted pebbles' (*Facettengerölle*) appears to me to be more correct than edged-pebbles (*Kantengerölle*).

"A connection between the direction of the edges and the direction of the wind could not be found, and this seems to me easily understood since I did not observe constant winds, and

Johannes Walther: *Kantengeröllen in der Galalawüste*; *Berichte der math. phys. Klasse der Sachs. Gesell. der Wissenschaft*, Nov. 14, 1887; E. Geinitz: *Ueber Kantengeröllen*; *Neues. Jahrb. für Min. Geol. and Pal. Stuttgart*, 1887 (II), p. 78. Heim: *Kantengeschiebe aus dem norddeutschen Diluvium*; *Vierteiljahrsh. r. d. Furcher. Natur. Gesellsch.*, 1888. F. Wahnschaffe: *Beitrag. zur Lössfrage*; *Jahrbuch d. König. Preuss. Geol. Landesanstalt, Berlin*, 1890, pp. 328-346. A. Sauer und C. Chelim: *Die Ersten Kantengeschiebe im Gebiete der Rheinebene*; *Neues Jahrb. f. Min., etc.*, 1890, ii. A. Sauer: *Ueber die äolische Entstehung des Löss am Rande der norddeutschen Tiefebene*; *Zeitschr. für Naturwissenschaften*, Bd. lxii, Halle, 1889; *Neues. Jahrb. f. Min.*, 1888, Bd. ii, s. 300-304. Dames und Wahnschaffe: *Zeitschrift d. Deutsch. Geol. Ges.*, 1887, s. 226-227 und 229. A. Geikie in the 3d edition of his text-book refers to other papers.

since the direction of the wind in the desert often changes every hour.

"On the other hand, I have never found the faceted pebbles isolated, but always distributed among ordinary desert pebbles, which lay close together. The annexed drawings show the position of faceted pebbles with reference to other pebbles.* I have frequently observed the movement of the sand between such pebbles with strong wind (sandwind) and have come to the following conclusion concerning the formation of the facettes:

"The sand flows along in little streams over the ground and the pebbles lying on the surface form just so many obstructions and resistances to the small sand-courses. In front of a large pebble the sand-stream is parted, so as often to reunite behind the obstruction; often the divided streamlets run, isolated, some distance further, finally reuniting with neighboring ones. In consequence of this bifurcation and reunion of the small sand-streams, caused by the stones lying on the ground, such stones upon which two converging sand-streams strike, become provided with two facettes, of which each has been formed by a sand-stream. Since these facettes continually enlarge, they come finally to an intersection (*gegenseitigen Schneiden*) and form thereby an edge. Pebbles which are constantly washed by similar sand-streams, receive sharp edges; but if the direction of the sand-stream changes, then the edges and facettes will become indistinct and again effaced.

"In other words, planes are cut on the pebbles, whose development forms edges, and on this account the word 'faceted-pebble' (*Facettengerölle*) it seems to me best expresses the process of their formation, for the edge is secondary."

The attention which is paid to this subject in Germany and the indications which point to even the slight action of wind-blown sands are evident from what Karl v. Fritsch says in his *Allgemeine Geologie* (Stuttgart, 1888), p. 302.

"Wir können in Norddeutschland die grossen erratischen Blöcke an den Wegen, Brückenfeilern, etc., nicht betrachten, ohne wahrzunehmen, dass sie fast alle auf der nach der herrschenden Windrichtung (meist Nordwest) liegenden Seite hin eine eigenthümlich flachgrubige oberfläche und einen stärkeren Glanz als liewärtz zeigen. Giebt es auch solche Feldsteine bei denen das erwähnte Verhältnisse nicht wahrnehmbar ist, so kann man die Ursache ihrer Rauhigkeit fast jedesmal erkennen. Sobald ein erratischer Block eine längere Reihe von Jahre unverändert liegen geblieben, fehlen diese spuren der Winderosion nicht."

Localities in which eolian action was observed in southern New England: Island of Martha's Vineyard.—At a number

* The drawings are not reproduced in the present paper.

of points on the highlands of this island wind-bared spaces were found, in some of which occur polished and worn pebbles. Such places are common on the east side of Menemsha Creek near the road which goes southward to Chilmark. At other points on the island, both in the highland region and on the morainal plain, I found carved and polished pebbles in positions where sands are not now blowing. One carved and polished pebble was found with its carved faces uppermost by the side of an old cart road in a field surrounded by woods, and in a location where no winds have blown sand since the foresting of that portion of the island. The facets still retain their peculiar polish. Another pebble partially buried in the soil had been covered over by a lichenous growth. It, too, had long been exempted from the action of the wind by the forest and soil. Near the mouth of Paint Mill Brook, on the north shore of the island, and at an elevation of about 20 feet above the sea, the glacial gravels underlying the soil, for the depth of 3 or 4 inches contain numerous examples of pebbles with a high polish and the facets and edges peculiar morainal plain near West Tisbury, all indicating the former to eolian pebbles. Similar pebbles were found on the activity of the process here described at a time before the growth of forests and the soil prevented the blowing of sand.

The section in Matakeset Creek.—The most important occurrence of faceted-pebbles known to me in this field was met with in September, 1889, in the extreme southeastern part of the island in the banks of a ditch opened between Matakeset Pond and Katama Bay, and which is known as Matakeset Creek. In this ditch, then newly opened, there was exposed to view a continuous line of sculptured and polished pebbles lying at an average depth of from one to two feet beneath the surface. The pebbly layer rested upon a semistratified deposit of sand and gravel constituting the marginal portion of the broad plain which fronts the Martha's Vineyard moraine on the south. The pebbly layer was overlaid by a deposit of fine, wind blown beach sand, stained black by humus, and surmounted by a thin layer of mould which nourished a growth of stunted beach grass. These sands are no longer blowing, but immediately to the south of the ditch at the distance of an eighth of a mile is a line of dunes fringing the shore, the inward migration of whose sands has not suffused the beach grass on the old wind-blown deposit. The layer of sand-carved pebbles is about three inches thick. The pebbles vary in size from the very smallest polished pebbles to boulderets six inches in diameter. Many of these show no carving or polishing on one side, this being particularly the case with the underside where it was in contact with the underlying

gravels. This layer could be traced for a long distance either side of the point where I crossed the ditch, and thousands of characteristic facettèd pebbles may be obtained from the layer. It was a noticeable fact that no facettèd or polished pebbles occurred in the exposed faces of the underlying gravel section. The geological conditions of this section lend support to the idea that facettèd pebbles are the product of eolian action. The location of this eolian pebble bed out on the southern margin of the frontal plain of the Martha's Vineyard moraine and on a surface which bears no marks of ice-advance excludes, it seems, the agency of strictly glacial causes from effecting the shape of these pebbles. They are evidently glacial stream pebbles reshaped *in situ*.

In the many instances on this island of soil-covered surfaces which have evidently undergone exposure to wind-blown sands, I am not certain of the time of the action, for it is obvious that since the process is now going on in places so it may have been active at any time in the past, the process being interfered with by the renewal of the vegetative coating. But the wide spread occurrence of buried or partially inhumed eolian pebbles, with worn sand, points strongly to the conclusion that the process has been more active than it now is.

Providence atlas sheet.—On the surface of the sand-plain in East Providence, R. I., is a bowlder 3 feet in length and 2 feet high, the southern face of which has been scored, worn and polished, evidently by the long continued action of blowing sand. The surface about the bowlder is now grass-covered. South of Providence in Auburn, bowlders exhibit traces of the same action. In many places on the west side of Narragansett Bay, the surface is covered by blown sand.

Boston atlas sheet.—Eolian pebbles occur in the soil near Fresh Pond in Cambridge. The pebbles of the Roxbury conglomerate, in a ledge, in Dorchester, exhibit the peculiar spoon-shaped and polished surface due to wind-erosion. Carved slates occur on the surface of kames in the soil along the Charles River in the vicinity of Mt. Auburn cemetery.

Boston Bay atlas sheet.—A bowlderet 6 inches in diameter bearing crateriform faces and possessing a high polish was found on Grover's cliff in Winthrop, the cobble having come evidently from the upper surface of the drumlin.

Narragansett Bay atlas sheet.—Eolian pebbles occur near the head of a glacial sand-plain half a mile north of the Warwick Neck Station in Warwick, R. I.

Dedham atlas sheet.—I found a pitted eolian pebble on the surface of a kame at Holbrook station on the Old Colony railroad.

Rate and Angle of Wear on Pebbles.—The observations made by W. P. Blake early led to the use of the artificial sand-blast in the arts. The conditions under which erosion takes place in the arts have been studied experimentally by Thoulet and are set forth in his paper, "Experiences synthétiques sur l'abrasion des roches par le sable."* The results of these experiments include observations relating to the rate of wear at certain angles of incidence which appear to me to be significant when compared with some of the pebbles which I am about to describe. "The abrasion," states Thoulet, "is so much the more energetic when the rock upon which it acts is more nearly vertical with reference to the direction of the sand which strikes (horizontally), and it diminishes very rapidly in intensity directly as the inclination becomes lower than 60 degrees." "Oblique incidence too (from 30° to 45°)† increases the rapidity of the cutting effect, probably because the issuing particles of sand are not met and their force deadened by the rebounding ones." From these experiments we should be led to expect the wear on a nearly vertical surface of a pebble to proceed slowly in nature, to go forward more rapidly after a time when a surface had been worn down to a plane inclined about 30° to the vertical, and again to wear very slowly when the plane had been worn down to an angle of 60 degrees with the vertical. The result of this varying rate of wear would be that on a pebble plain exposed to sand-blasting, the carved pebbles would soon pass through the maximum rate of cutting and would remain long near the angle of 30° of inclination to the horizon. An examination of several well-facetted pebbles from Martha's Vineyard shows this feature in a marked way. It is necessary, however, in order to ascertain this mature state of erosion, to establish the soil-line or horizontal plane in which the pebble lay at the time of its carving. This can frequently be done with pebbles found *in situ*. The smaller pebbles by the erosion of the sand and gravel about their bases have frequently been overturned, and eroded on all sides. It is evident that where inversion takes place regularly and frequently that facets may fail to develop and that the pebble may slowly waste away in the manner of those described by Gilbert on the plains of Colorado.

Lithological characters of the pebbles.—There is a certain relation between the sand blown upon the rocks and their

* Compt. Rend. Acad. Sci., t. civ, p. 381; also Annales des mines, Mars-Avril, 1887, pp. 199-224.

† The experiments conducted by Gen. Tilghman in connection with his patent are described by G. F. Barker in Johnson's New Universal Cyclopedia, vol. iv, pp. 62-65.

mineralogical constitution. The most perfectly symmetrical pebbles are a variety of compact quartzite, or even vein quartz. Finely crystallized granitic rocks also exhibit good facets, but the quartz is apt to stand out above the feldspar. Quartz-porphyrries, felsites and other massive rocks exhibit forms related with original fragmental contour and mineralogic construction. Pits are reamed out where minerals have decomposed, and grooves are worn often regardless of structure but commonly along lines determined by weakness in the rock. Facets show no prevalent relations to joint-planes or bedding; but often one can see that a joint-face has been cut and polished.

The symmetry of the pebbles gives them an artificial appearance in many instances. The original symmetry of rounded water-worn pebbles has been preserved by the production of balanced planes on opposite sides of the fragment. Pyramidal, triangular pebbles are common. The smaller pebbles by reason of the facility with which they may be undermined and overturned by the wind, are more generally carved on all sides than the larger ones.

Nomenclature.—In Germany sand-blasted pebbles receive specific names depending upon the number of edges which are developed by the intersection of facettes. The term faceted-pebble proposed by Walther has already been given in this country to a product of glacial action.* Since some of the sand-carved pebbles are faceted, some grooved, and others merely pitted, I would suggest that “glyptolith” (*glyptos*, carved; *lithos*, stone) might be employed, in the sense of a rock surface carved by wind-blown sand. “Eolite” has already been appropriated for a rock made by the deposition of sand by æolian action.†

That the blowing of sand by wind must have been wide spread in the interval between the disappearance of the last ice-sheet and the occupation of the land by plants, is shown by the fact that even now wind-blown sand and sand-blasting is to be observed at numerous points on the sand-plains in this district. The question is to determine whether the glyptoliths found in grass-covered tracts or in wood-lands are due to a phase of general deflation preceding the incoming of the recent flora, and are, therefore, indicative of an eolian phase succeeding the deglaciation of the district, or whether they are due to secular wind erosion acting now and then as the opportunity is offered by the removal of the soil and the exposure of sand to the wind. My own observations have not been sufficiently extended to come to a definite conclusion in regard to this matter, particularly since in many places the

* Chamberlin: 7th Annual Report, U. S. G. S., p. 209, 1888.

† T. M. Reade: Geol. Mag., dec. ii, vol. ii, pp. 587, 588.

process of sand-carving is now evidently going on; but I am led by the distribution of many of the pebbles which I have collected to think that sand-blasting was formerly more prevalent than it now is in this district.

Relation of land to sea-level.—It is obvious that the carving and polishing of rock surfaces by the sand-blast is essentially a subærial phenomenon. Although the sand carried by water-currents as in the case of the Colorado, shown by Newberry, furrows and polishes the rock of its bed, the sands of the littoral are not known to produce the facets and polish characteristic of the typical glyptoliths. This is probably due to the frequent turning and rubbing of pebbles even where they lie in the zone of sands driven by wind along the beach. It follows that where we have these eolian pebbles carved at any time in the past, we have evidence to show that at that time the land was above the level of the sea. As yet the coast region of New England along which submergence at the close of the last glacial epoch has been suspected has not been examined with this point in mind.* The evident antiquity of the Matakeset examples on Martha's Vineyard and the direct superposition of the eolian pebbles on the wind-eroded surface of the overwash or frontal plain indicates that next after the deposition of the glacial gravels it was subjected to wind-erosion. This evidence indicates that if the land there was submerged after the retreat of the ice, the period of depression was brief and is locally without any trace of its geological effects.

Among the problems which these eolian pebbles may be looked to for a solution is the question of the former elevation of the continental shelf in recent geological times. It is therefore of the utmost importance that the pebbles and boulders occasionally dredged up from the surface of the "banks" off the New England coast should be carefully scrutinized with the view of determining whether or not they bear marks of eolian erosion. If, as there is reason to believe, these banks were during late Tertiary or in the pleistocene period, like Martha's Vineyard and Nantucket now, above the sea-level, we should find on them the kind of evidence which occurs on the islands named.

Cambridge, Mass.

*Since this was written, Prof. W. M. Davis has presented in the current volume of the Proc. Boston Soc. Nat. Hist. a paper announcing the occurrence of faceted eolian pebbles at numerous points on Cape Cod in geological situations showing the subærial deposition of at least a part of the glacial gravels of that peninsula. See also paper by the same author read at the December meeting of the Geol. Soc. Am., held in Boston, 1893.