ART. XVIII.—*Geological Notes on the Pribilof Islands, Alaska, with an Account of the Fossil Diatoms;* by G. DALLAS HANNA.

The Pribilof Group of Islands, which consists of St. Paul, St. George, Otter, Walrus and Sea Lion Rock, lies in Bering Sea approximately 200 miles from other land in three directions. The islands were discovered in 1786 and are primarily known as the breeding grounds of the Alaska fur-seal herd. They have been more or less regularly visited by naturalists since the time of Ilia Wossnessensky, 1840-48; consequently they have come to be better known biologically than any other area of similar size in Alaska. Many titles to publications pertaining to the group belong to botany and zoology but by far the greater number concern diplomatic matters arising from international controversies over fur seals. Geology and paleontology have received a share of attention.

Location.

The islands are situated on the "Bering Sea Plateau," that level tract of submarine land forming the bottom at about 40 fathoms over the northeastern part of this body of water. They are near the southern boundary of the limits of the winter ice-sheet which conforms approximately with the boundary of the plateau.

The existing fauna and flora on the islands are derived from Asiatic and American sources so divided as to preclude the theory that they have been united to either continent since the lava outflows from which they are largely built. St. Matthew Island, Cape Newenham and the Aleutian Islands lie north, east and south respectively, about the same distance.

General Geological Features.

The bulk of the elevated masses is composed of lava and scoria arranged approximately in horizontal layers or forming cones. At the water line the outcroppings are in many places—and especially on the seal rookeries—basalt which has been blackened on the surface by the action of the sea-water. Above the sea or inside this basalt the color of the rocks is usually gray, olive or red

with included crystals of yellow feldspathic minerals. At one point on St. George Island the lava is built up to an elevation of 1012 feet. Some large cones, however, as Polovina on St. Paul, are composed almost exclusively of red and black scorias.

The evidence is conclusive therefore that violent volcanic action has built the islands as they exist to-day and that all traces of these disturbances disappeared before the advent of man. Casual inspection would lead one to believe they were built from the ocean floor but there are several points where a true conception of the geological formation can be had. One of the best of these is at Tolstoi Point, St. George Island. Here massive jasper[1] with grains and seams of quartz extends about 100 feet above the sea. It it without stratification. The same rock occurs above sea-level at Garden Cove, St. George Island, and that it comes near the surface at several other places on the islands is shown by the numerous pebbles and bowlders of this material on the beaches.

This massive jasper formed land masses at the Pribilof Islands before the volcanic action which built the forms which now exist. This is shown conclusively at Tolstoi Point, St. George Island, by the layer of sand rock which lies immediately above. This contains large quantities of water-worn bowlders and pebbles, water-worn shells, etc. It varies in thickness from two to ten feet and is also found at Sea Lion Rookery, Garden Cove (St. George Island), Ardiguen Rookery, Tolstoi Point, and Zapadni Point (St. Paul Island). At some of these places the sand rock does not extend high enough to expose the underlying strata but near the top of each exposure there are similar beach formations.

Immediately on top of the sand rocks there are thick beds of lava. The entire surface of all the elevated group as it stands to-day is covered with this (and scoria), so that any animals or plants which may have existed on the previous land masses must have been wiped out. The highest point which this former beach line (covered with lava) reaches above the sea at the present time is about 100 feet so that it may be safely inferred this represents the total amount of elevation of the ocean floor during the volcanic period.

[1] The identifications of the minerals as given herein were made in the Division of Geology, U. S. National Museum, under the direction of Dr. George P. Merrill.

Black Bluffs Exposure.

For many years this was believed to be the only locality on the Pribilofs where fossiliferous rocks occurred. The first collections from it were made by a Russian naturalist, Wossnessensky, in 1847-48. It appeared to Dall[2] who summarized the information on the deposit up to 1896, that the early explorations yielded Miocene fossils in a lime stratum. This had completely disappeared, however, at the time of the Elliott investigations, 1872-74. In the light of recent collections it seems somewhat doubtful if Miocene fossils were ever found here and that possibly some error in locality may have been made.

Fortunately a good collection of shells has been made from this exposure because the sea is fast tearing it away. All the later gatherings were from nodules which were water-worn and occurred in the layers of scoria at the base of the cliffs. At the present time (1918) these are exceedingly scarce. The sea has eroded the hill inward beyond its crest and as the layers slope downward and backward those at the base which contained the fossils are beneath the sea. Since these nodules were detached from the parent beds and thrown up by volcanic action they do not represent the age of the layers in which they were found, and it might be possible for fossils of more than one age to have thus become mixed. Despite its imperfections this exposure is very important because of the study which it has received. A list of the mollusks found has been published. (See bibliography.)

Other Sedimentary Rocks.

Besides the exposure just mentioned there are several others on the islands where sandstones *in situ* outcrop. These are as a rule near the surface of the sea and, as stated above, are underlaid by massive green jasper. In some places this was not sufficiently elevated to appear above the water but the bowlders and pebbles which may be seen on the beaches are indications here of the rocks beneath the sand rocks.

Ardiguen Rookery, St. Paul Island.—The sand rock at this point extends from the water to a height of 15 or 20 feet. Above it there are lavas of about the same thickness. All form a perpendicular cliff with loose rocks piled at the bottom. The elevation has been caused by

[2] Seventeenth Annual Report U. S. Geological Survey, 1896.

a fault which extends across the peninsula, and under one low cliff back of Gorbatch Rookery the strata are barely perceptible. There is an excellent deposit of fossils at Ardiguen but a collection has not been made.

Village, St. Paul Island.—The digging of a well in the St. Paul village in the spring of 1918 disclosed the fact that sedimentary rocks outcrop 60 feet above the sea near the north end. Here also they are sand rocks and lie beneath several feet of lava, the blocks of which had obscured the lower layers. At about 10 feet above sea-level there is a layer of gray marl which was bored into 30 feet without penetrating. The sand rocks contain a few mollusks and the marl contains some diatoms, neither of which have been studied.

Tolstoi Point, St. Paul Island.—The total height of the cliff here is about 200 feet. The sand rock again outcrops and at one fault reaches an elevation of about 100 feet. It extends for about half a mile along the base of the cliffs, offering an admirable opportunity for the collection of the fossils which are found in great abundance.

The upper layer of this sand rock is coarse-grained, very hard in most places, and contains volcanic cinders, water-worn pebbles and beachworn shells. At the highest point there was apparently a beach sand mound at the time of the lava outflow because the sand has blown away beneath and left an overhang which shows in striking manner the waves of lava as they ran down.

Three other indistinct layers can be traced beneath the hard upper layer. All are fossiliferous and decrease in hardness and coarseness toward the water. The lower layer has the consistency of marl and has springs of fresh water at one point which flow throughout the winter. It is composed largely of diatoms with some clay and fine sand. All of the layers were found to contain diatoms but they were most abundant in the lower. It is the material found in this deposit which forms the basis of this report.

A collection of mollusks was made by the writer from 1914 to 1918 and these have been studied and reported upon by Dr. William H. Dall.[3] They showed the age of the deposit to be about the same as the one at Black Bluffs

[3] Jour. Wash. Acad. Sci., vol. 9, No. 1, pp. 1-3, Jan., 1919.
Dall, William Healey. 1896. Report on Coal and Lignite of Alaska, 17th Annual Report of the U. S. Geological Survey.

and more recent than the St. George deposit mentioned below.

In addition to mollusks and diatoms, a bryozoan was found in this deposit; also the remains of several vertebrates which were too incomplete for positive identification. Among these were the tusk and a vertebra of a walrus; a vertebra and a carpal bone of probably a hair seal; some vertebra of a fish; and some ribs.

Zapadni Point, St. Paul Island.—The outcrop here is a bed of gravel about 25 feet thick lying beneath about 75 feet of lava. All form a perpendicular cliff. The gravel is loose and at one point forms a slide. No fossils have been found.

This is the last of the known deposits on St. Paul Island but the water line has not been examined from Southwest Point to Northwest Point. That the sand rock comes close to the surface near the head of the Salt Lagoon on both sides is indicated by the springs of fresh water which remain open through the winters.

Tolstoi Point, St. George Island.—The sand rock here is on top of about 100 feet or more of massive jasper and in some places is composed almost entirely of fossil mollusks. As stated before there has been a beach here at one time. The cliffs are almost 300 feet high and provide nesting sites for many thousands of water birds in the summer time. The sand rock is coarse-grained and varies in hardness in different places. It contains, besides mollusks, pebbles and bowlders, and several fragmentary bones (probably fish) were found. No diatoms however have thus far been seen from it. Numerous large springs flow down the cliffs from the ledge.

The collection of mollusks made here has been examined by Dall with those from St. Paul Island and he states that they indicate the St. George strata are the older. They seem to be Pliocene.

Sea Lion Rookery, St. George Island.—The old beach line again outcrops here and is found on top of the jasper about 50 feet above the sea. It is composed largely of rounded bowlders of large size, and there are several springs of excellent water flowing from it.

Garden Cove, St. George Island.—Here the formation is similar to that of Tolstoi Point just considered, except that no fossils but diatoms have been found in the sand rock. (Careful search, however, has not been made.) A

crack in the stratum permits the egress of one very large spring and in the stream flowing from it fresh water diatoms in pure gatherings can be had in great abundance. The sand rock outcrops on toward Cascade Point an unknown distance. As far as it has been traced it has large numbers of springs flowing from it and it is underlaid by massive igneous rock. On top there is the characteristic lava in horizontal layers.

The diatoms found in one small pocket were not well preserved nor abundant but the species were all represented in the gatherings from Tolstoi Point, St. Paul Island.

Although these are the only known sedimentary deposits on St. George Island it must be said that the water line around Cascade Point and around the Big Cliffs from Staraya Artel Rookery past Dalnoi Point and to Zapadni Rookery has not been examined.

Otter Island.

The west end of this island has been elevated so that about 75 feet or more of sandstone has been exposed. It has not been carefully examined. On the opposite end of the island may be seen an excellent crater which has been cut into by the sea on one side.

Age of the Islands.

That the fossil-bearing sandstones were elevated at the same time that the violent volcanic disturbances which covered the islands with molten rock occurred seems certain from the fact that volcanic cinders are found in more or less abundance in the topmost portions of the sedimentary layers. If the age of the sand rock can, therefore, be accurately fixed this will determine the age of the islands as they exist to-day to a fair degree of certainty and this fact would be of value in the study of such animals as the fur seal. From the study of the mollusks mentioned it seems to be post-Pliocene on St. Paul Island and Pliocene on St. George Island. A study of the diatoms indicates that the age of the two islands is the same and that it is more apt to be Pliocene than a later period.

If the age of the Tolstoi Point (St. Paul Island) beds is post-Pliocene it would be expected that the characteristic

species of diatoms as well as mollusks found therein would be found in the waters round about at the present time. But this is not the case. The common fossil species are exceedingly rare or entirely absent from the region to-day. Likewise the dominating species to-day, *Coscinodiscus asteromphalus* has not been found as a fossil. In fact several genera which would be expected such as *Campylodiscus, Arachnoidiscus* and *Aulicodiscus* were not found.

The violent volcanic disturbance which was required to pile up the mountains of lava has required a considerable period of time (years), for all traces to disappear. But only two slight earthquakes, or signs of volcanic action, have been recorded since 1786 when the group was discovered. This together with the fact that a mountain of hard lava more than 1,000 feet high has been more than half eaten away by the sea indicates that the islands in point of years are very old.

Still there is no evidence that an ice sheet of greater weight than those visiting the shores to-day has ever visited the islands. This makes it seem doubtful if they had cooled at the time of the glacial descent. Few plants and animals have become sufficiently differentiated to receive separate specific names from those of neighboring land; geologically therefore the group must be very young.

The original size of the Pribilof Islands and the rate of erosion form a subject of interesting speculation. That they were originally very much larger than now cannot be doubted because many mountains and hills facing the sea have been more than half eaten away and slope backward. One important fossil-bearing deposit has disappeared within historical times. Unless volcanic disturbances come to the rescue they must all eventually be torn down, become reefs for the restless surf to break over, and, at last, cease to exist.

It should be stated here that the reports of the finding of bones of fossil elephants on the Pribilof Islands are probably attributable to practical jokes which have been played on credulous naturalists in the past. No such bones have thus far been found that were not planted by man, according to reports of eye-witnesses to some of the pranks.

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List of Diatoms from Tolstoi Point, St. Paul Island.[a]

[a] The identifications of the species were either made or checked by Dr. Albert Mann of the U. S. Department of Agriculture who is an authority on these organisms.

1. *Amphora ovalis.*—Several specimens showing considerable variation found.
2. *Cymbella gastroides* Kutzung.—One valve only.
3. *Navicula (Stauroneis) phoenicenteron.*—One valve only, which differs slightly from living examples of the region.
4. *Navicula peregrina* Ehrenberg.—Two valves only.
5. *Navicula rhynchocephala* Kutzung.—One specimen.
6. *Navicula*, new species.—One broken valve of an undescribed *Navicula* was mounted.
7. *Chetoceros cinctum* Gran.—Several specimens found.
8. *Thalassiothrix nitzschoides* Grunow.—Exceedingly abundant and variable in size and shape.
9. *Melosira sulcata* Ehrenberg.—Several varieties of this excessively variable species were found in the deposits.
10. *Raphoneis amphiceros* Ehrenberg, variety.—The beading of specimens found is exceedingly coarse; center rows have only 4 beads.
11. *Actinoptychus splendens* Ralfs.—One specimen.
12. *Actinoptychus undulatus* Ehrenberg.—Two specimens.
13. *Actinoptychus*, new species.—An undescribed form of this genus was found to be abundant and somewhat variable. It is especially characterized by the large size of the beads.

14. *Stepanopyxis appendiculata* Ehrenberg.—Two specimens.
15. *Stepanopyxis grunowii* var. *inervis*.—Very abundant and spines absent on the valves.
16. *Coscinodiscus pustulatus* Mann.—The abundance of this diatom characterizes the deposit. It is excessively variable, only the more perfect examples approaching the original figure. Valves are dissimilar in shape, one being a section of a sphere while the other is a rounded cone. The species has heretofore been found but once, and then in deep water in Bering Sea.
17. *Coscinodiscus decrescens* Grunow.—Two specimens only.
18. *Coscinodiscus undulosus* Mann.—One specimen of this remarkable diatom was found.
19. *Coscinodiscus tuberculatus* Greville.—A very abundant and variable diatom.
20. *Coscinodiscus subtilus* Ehrenberg.—Two coarse examples.
21. *Coscinodiscus radiatus* Ehrenberg.—Very common and variable in size.
22. *Coscinodiscus marginatus* Ehrenberg.—Abundant and variable in size.
23. *Coscinodiscus fimbriatus-limbatus* Ehrenberg.—One specimen.
24. *Coscinodiscus excentricus* Ehrenberg.—One specimen.
25. *Coscinodiscus*, new species.—Four specimens of an undescribed species probably belonging to this genus were found. The markings are so remarkable that Dr. Mann could not say with certainty that it was not a *Melosira*.