ART. XXI.—*The Geology of the Bosphorus.*

[THE following notes are the result of a careful investigation of the rocks of the Bosphorus, made in company with Mr. W. T. Forbes, Instructor in Mathematics in Robert College.—GEORGE WASHBURN.]

THE straits of the Bosphorus conduct the waters of the Black Sea into the Sea of Marmora. The general direction of the stream is from N.E. to S.W. Its length is about eighteen miles and its average width about one mile. Its depth is about the same as the height of its banks, which rise abruptly from its shores from two hundred to six hundred feet. These banks are broken by narrow valleys and steep gorges at right angles to the course of the Bosphorus. This broken, hilly country extends inland for many miles on both sides of the straits.

The general character of the rocks is the same on both sides, but changes suddenly near Kavak, about six miles from the Black Sea, and again in the midst of old Stamboul at the mouth of the Marmora. The bleak and barren rocks above Kavak are such as might be seen if a passage were cloven through Mt. Vesuvius, and this volcanic region extends, with irregular boundaries, about six miles east and about fourteen miles west of the Bosphorus. Below Kavak, as far as the Sea of Marmora, there are stratified rocks of the Paleozoic age, which extend inland about sixteen miles on the European shore, and about twenty-five miles on the Asiatic. They are bounded on the former by Tertiary strata, and on the latter by Cretaceous.

The Paleozoic rocks.—These rocks were formerly called Silurian. M. Roemer afterward claimed that they were Upper Devonian. Tchihatcheff in his work on Asia Minor, Dr. Abdullah Bey in various articles in German scientific journals, and Mr.

Swan in an article published by Murchison, express the opinion that they belong to the Lower Devonian. This is now the generally received opinion. It is based upon the fossils found by these gentlemen, chiefly at Caudlija, Arnaout Knie and Cartal, on the Sea of Marmora; but even in these localities many fossils have been found which are rather characteristic of the Upper Silurian period, and the rich deposits which have been discovered by Mr. Forbes and myself at Hissar and Baltaliman appear to belong chiefly to this earlier formation, although they contain fossils usually considered as Devonian.

It seems probable, upon the whole, that in this vicinity there was no clearly marked separation between the Upper Silurian and the Lower Devonian periods; our fossils belong distinctly neither to one nor to the other, but rather to a transition period between the two. Dr. Abdullah Bey, in a notice of our investigations, lately published, acknowledges that the deposits discovered by us at Baltaliman are probably Silurian. He says: "Looking at the peculiarities of the local fauna of Baltaliman, we think that this must be considered in a different light. Its enormous richness in trilobites, which approach the forms characteristic of the Silurian formation, permits us to believe that we find ourselves here at the limit where the Upper Silurian formation is in immediate contact with the Lower Devonian of the rest of the Bosphorus."

He bases his opinion, that the rest of the Bosphorus is Devonian, upon the fact that de Verneuil, the distinguished geologist of Paris, examined a large number of his specimens and pronounced most of them Devonian; but even Verneuil acknowledges that some of them were characteristic of the Silurian period—that "there seems to be no clear line of demarcation between the Upper Silurian and the Lower Devonian." "The fossils and rocks of the Bosphorus have a remarkable resemblance to the Silurian deposits of Bohemia." Tchihatcheff notices that he has a specimen from Caudlijah upon which are found a Devonian brachiopod (*Chonetes sarcinulata*) and a Silurian trilobite (*Phacops longicaudatus*). We have ourselves a single specimen three inches square found at Baltaliman, which exhibits a perfect pygidium of *Phacops longicaudatus*, a *Pleurodyctium problematicum* and a *Spirifer subspeciosus*. These admissions of Abdullah Bey, de Verneuil and Tchihatcheff, and these facts, certainly confirm the views expressed above as to the age of the rocks of the Bosphorus. Another fact of at least negative value is that no trace of fish and no sufficient evidence of the existence of plants has ever been found in these rocks, both of which might be expected in the Devonian period.

The principal rocks found in this formation are sandstones, shales, and limestones, with more or less quartz either in veins

or in isolated blocks. The *sandstones* are of every variety, sometimes passing into true conglomerates, sometimes of a fine close grain, and with colors about equally varied, gray, yellow, and red predominating. The *shales* also vary in quality and color, some of them very nearly approaching slates, while others are marlites resembling some of those of the Tertiary period. All the soil which covers our hills, and is washed down to fill the valleys is formed by the disintegration of these shales, which is going on wherever they are reached by the air and rain. The *limestone* is generally of a dark blue tint veined with calcite and sometimes with quartz, often enclosing nodules of iron and often sparkling with iron pyrites. The stone varies much in texture and quality, and although generally blue, is found at various points of a black color and often of a reddish or yellow tint. In some cases the grain is very fine without any appearance of crystalization; in others the stone is so changed as almost to resemble marble; sometimes it is very hard and sometimes soft and crumbling. The better qualities, though expensive to cut, are much used for building purposes.

The *fossils* of the Bosphorus formations are found chiefly in the shales and in some kinds of the blue limestone, but very seldom in the sandstone. The stone which contains them is rarely used either for building or for lime, and consequently they are seldom found in the great quarries. The deposits on the Asiatic shore are more extended than on the European.

On the Asiatic shore fossils are abundant in the Giants Mountain, where they generally have a bright red color owing to the presence of oxide of iron. From Beicos, near the foot of the mountain, down to Caudilli they are found everywhere along the shores and on the hills, but especially at Caudlijah and Geukson. The hill between Caudlijah and Kurfess, which is crowned by a beautiful grove of stone-pines and covered by an old Turkish cemetery, is made up of fossiliferous rock, and has furnished most of the specimens of Tchihatcheff and Abdullah Bey At Geukson the best specimens came from a point about two miles back from the Bosphorus, where the Sultan has cut through a new road to his farm.

Between Caudilli and Scutari we have found nothing except on heights near Bulgurlu and on the road to Alem-dagh.

On the European shore fossils are found on the extreme northern boundary of the Paleozoic rocks near Yeni-Mahallé—also at Therapia and Kalender—but all of them in a worn state. At Yeni Kusi, Stenia, Emirghian, and in the main valley of Baltaliman we have found nothing near the shore and only here and there one on the hills, although these villages are opposite the rich deposits of Caudlijah.

But on the hills behind Hissar and in the valley beyond them, which opens into the great valley of Baltaliman, we have made our most interesting discoveries. We have wandered over these hills and valleys again and again without finding anything and with very little hope, but a more careful and determined search, to which we were led by accidentally finding a *Loxonema* in a detached rock, brought to light a quarry in the garden of the Sultan's brother-in-law, which contained rich deposits.

About two hundred feet higher than this garden and nearer the Bosphorus we found another Turkish garden, where the underlying rock was broken up last year to the depth of four feet, and this proved to be a garden of *trilobites.* While the work was going on we visited this place as often as the ugliness of the keeper could be mollified by a reasonable backsheesh, but the work was soon done, the vineyard planted, the melons growing and the *trilobites* buried.

The Turkish cemetery in front of Robert College contains rocks which furnish many fossils, but they are poorly preserved. At Arnaoutkuei there are old quarries, which furnished former explorers with most of their specimens and which are still full of fossils. No other deposits of any importance are known to exist on this side of the Bosphorus, though others may yet be found. At Kartal and Pendik, on the Sea of Marmora, the fossils are abundant and do not differ essentially from those on the Bosphorus.

Within certain limits, however, each of the principal localities on the Bosphorus is characterized by a fauna peculiar to itself. The vineyard spoken of at Hissar, for example, abounds in *Trilobites* with only now and then an *Orthis*, or a *Cyathophyllum.* The valley of Baltaliman, 200 feet below, is especially remarkable for the great abundance and variety of its *Orthids*, and the variety and beauty of its *Crinoids*, and *Trilobites* are common, but of different genera from those found upon the hill above. From the latter we have specimens of *Conocephalus*, *Bavarilla*, *Asaphus*, *Cheirurus*, *Phacops*, and perhaps others. From Baltaliman, we have a great variety of the *Cryphæus*, *Phacops*, *Conocephalus*, *Homalonotus*, including three of the *Phacops longicaudatus* and one of the *Homalonotus delphinocephalus* of great size. In the Geukson Valley on the opposite side of the Bosphorus, we have found specimens of the Homalonotus of great size—several of the *Homalonotus Gervillei*, of which we have found no trace anywhere else. This last is figured in the plates of Tchihatcheff's Asia Minor. He remarks in reference to it, that his plate is taken from a specimen found in Normandy, and that it is doubtful whether the small fragment found by Abdullah Bey really belongs to this

remarkable species. The three specimens found by us at Geukson are fully equal to the one given in his plate.

Almost all the fossils of this part of the Geukson Valley are very large and peculiar to the locality. The *Spirifer* exists everywhere, especially the *Spirifer subspeciosus*. The same may be said of the several varieties of *Pleurodyctium* especially the *problematicum* and *Constantinopolitanum;* also of several species of *Cyathophyllum*. Many varieties of *Orthoceras* and *Trochoceras* are found at Arnaoutkuei and Caudlijah; a few at Baltaliman and Geukson. We have found in all ten or twelve species, the names of most of which we do not know, but among them is the *Trochoceras Barrandei* of de Vernueil, which is probably a misnomer; it is probably a *Lituites*. The species of *Orthis* are found in all the localities, but most abundantly at Baltaliman; from this single quarry we have at least thirty species, including a number of new ones, to two of which Dr. Abdullah Bey has given the names of Mr. Forbes and myself. The genus *Leptæna* is especially characteristic of Caudlijah, where at least twelve or fifteen species exist in abundance; at Baltaliman it is hardly found at all. The *Pterinea elegans* also is common at Caudlijah and Geukson, but is not found at Baltaliman. *Rhynconella*, *Strophomena* and *Chonetes* and species of other genera abound in various localities. Crinoids and corals of many kinds, and some of them of great beauty, occur at all the points mentioned. Should we have the good fortune to receive a visit from some thoroughly competent paleontologist, we shall submit the Robert College collection to his consideration and publish a full catalogue of our specimens. At present there are many which we cannot determine.

The Eruptive Rocks of the Bosphorus.—These rocks may be divided into two groups, those which are massed at the northern extremity of the Bosphorus, and those which are found in dikes at different points in the midst of the stratified rocks. These two groups are of different ages and of different origin, and must therefore be considered separately.

It is our impression that we have at the northern extremity of the Bosphorus the remains of a true volcano. The general appearance and structure of the rocks is the same as of those about Vesuvius or Etna. We find trachyte, diorite, basalt, vast collections of conglomerate of every kind of coarseness, often composed of masses of black doleritic porphyry with other forms of rock which are very difficult to determine. These are often regularly stratified, but in other localities in immense masses, broken only by irregular fractures.

As there is no visible crater from which all these rocks could have been thrown out, nor indeed anything which looks like a

crater of eruption, we must suppose that this crater is now hidden beneath the waters of the Black Sea, possibly at some little distance from the shore. It is certain that these volcanic rocks extend out under the sea, to some distance, and there is nothing in the nature of the case to make it improbable that there was once a vast volcano there, which vomited out all the eruptive rocks on both sides of the Bosphorus as far down as Kavak, and afterward in some later convulsion of nature sank below the surface of the sea. We have found nothing in the rocks to determine at what period this volcano existed, but we think it may be asserted that it was not contemporaneous with the eruptions of the lower Bosphorus.

The only historical evidence upon the subject is the tradition of the Cyanean rocks or the Symplegades. There are certain rocks near Fanaraki which now bear this name, but without a shadow of right. These rocks are mentioned by Strabo, who alludes to the ancient story that they were floating islands. He says that in his day two islands existed at the mouth of the Bosphorus, about twenty stadia apart, one near the European and one near the Asiatic shore. The rocks now called Cyanean are on the European coast, with no corresponding ones on the Asiatic, and they have evidently been connected with the main land within a short period of time. Their geological composition is exactly similar to the nearest point of the coast which is only *fifty feet* distant, and is connected with the island by a continuous ledge of rock, with deep water on either side, but with not more than two to three feet of water above the ledge. The sea breaks here with tremendous force and has evidently worn this passage through the rocks. If Strabo ever saw the islands of which he speaks, which is doubtful, they have since disappeared, either worn away by the sea or sunk beneath its waters. Homer, in the Odyssey, says of these rocks: "These then are lofty rocks, and near them the vast wave of Amphitrite resounds; the blessed Gods call them the Wanderers: here neither birds pass by nor the timid doves which carry Ambrosia to father Jove; but the smooth rock takes away some one of them, and the father sends another to make up the number. From this has not yet any ship of men escaped, which ever has come to it; but the wave of the sea and the *storms of destructive fire* take away planks of ships and bodies of men together. The Argo alone," etc. From this passage, I think it may be inferred that the Cyanean rocks were active volcanoes, and that at least the tradition of such volcanic islands was current in the time of Homer. What is said of the birds confirms the idea, for it can hardly be imagined that birds could be caught by the islands coming together though they might be by volcanic eruption.

It is possible then that the volcanic remains at the mouth of the Bosphorus belong to the present geological period, that the centers of eruption were already surrounded by the sea in the time of Strabo, and that they have since sunk below the surface. This seems to me, on the whole, the most plausible theory in regard to the Symplegades. They were volcanic craters that made the passage into the Black Sea extremely dangerous, and sometimes, perhaps, filled up the channel by their eruptions, thus giving rise before historic times to this well known fable.

The second group of eruptive rocks upon the Bosphorus has no apparent connection with the first. There is no evidence of any volcanic action below Yeni Mahallè. We find hundreds of dikes in the stratified rocks filled with material which is evidently eruptive, but which differs from the great volcanic domain of the upper Bosphorus in composition almost as much as in form. It is true that a few of these dikes are filled with trap, almost black, but ordinarily we find some variety of porphyry, especially dioritic porphyry. The most interesting illustration which we have of an eruption of this last is found in the valley of Bebec. In this deep gorge we can study, perhaps better than anywhere else, all the phenomena of these local eruptions, which have turned, folded and twisted the stratified rocks of the Bosphorus in such an extraordinary manner, as to make it utterly impossible to discover any regularity in the dip or strike of the strata. At Bebek there is a dike of beautiful dioritic porphyry more than 200 feet wide, which can be traced for at least half a mile, although there are generally stratified rocks above it, which have been modified in texture, twisted and rolled back by this eruption. Smaller dikes appear at other points at Bebek, so that it is not improbable that the whole hill back of the village owes its elevation to this eruption. Arnaoutkuei, Hissar, Koulali and Geukson, indeed all the prominent points on the Bosphorus, furnish equally manifest, though not always equally interesting, examples of these eruptions. In many cases the eruptive rock has decomposed much more rapidly than the stratified rocks about it, and in different localities it may be seen in every stage of decomposition, until in some cases it is distinguishable from sand or clay only by the few crystals of feldspar or amphibole which it contains. At Geukson the great extent of this eruptive rock, which is exposed by a new road, makes it almost certain that it underlies the whole hill, and we have here the curious phenomenon of well-preserved fossils in perpendicular strata lying directly against the porphyry.

It is an interesting fact in this connection that the Paleozoic domain which has been so completely broken up by volcanic

action, has enjoyed since historic times a long immunity from earthquakes. Many earthquakes have been recorded in Constantinople, some very severe, but they have spent their force on the region of the Tertiary formation and on the adjacent southern slope of Stambool, never, so far as we can learn, doing any serious damage on the Bosphorus. The walls and towers of the castles at Hissar remain unshaken, while the old walls of the city have been split and cracked in every direction.

The Mines of the Bosphorus.—These are of iron and copper. There is an iron mine, formerly worked, not far from the village of Beicos on the Asiatic coast, and a copper mine at Sariya on the European shore, now worked by an Englishman, who sends the ore to England to be smelted there. This most interesting mine is situated just at the point where the volcanic rocks of the upper Bosphorus end and the Paleozoic rocks commence. On one side of the valley you have absolute barrenness and desolation, on the other the luxuriant and picturesque scenery which has made the Bosphorus so famous. The locality of the mines is marked by groups of hills—white, red, and yellow—which are perhaps mostly the refuse of old mining operations, and are composed of disintegrating quartz, conglomerates, and variously-colored clays and earths. The metalliferous rocks are sometimes quartz, sometimes limestone or shales, and sometimes of a peculiar gray argillaceous stone, the character of which is difficult to determine. Those rocks all furnish pyrites of iron, copper and arsenic, and are decidedly richer than the average of English copper mines. Their extent is unknown. Thus far they have been worked only in a primitive way by running galleries into the sides of the hills, following the veins of metalliferous rock. There seems to be little doubt that these deposits are connected with the volcanic rocks, as we find traces of copper on the Asiatic shore, not opposite Sariya, but higher up in the eruptive rocks, or where these meet the Paleozoic. We find *iron* pyrite sand nodules everywhere, but there is no trace of copper below Sariya until we come to the Prince's Islands in the Sea of Marmora.

The origin of the Bosphorus.—It is evident, from the facts already stated, that what now constitutes the Paleozoic zone of the Bosphorus, a territory of about 700 square miles, rose above the seas at the commencement of the Devonian period as a single island. For ages it continued to be so. It was not until the close of the Tertiary period that it was united to the continent of Europe, although it was probably during the Cretaceous epoch that it became a part of Asia. Until its union with Europe, the Mediterranean, the Black Sea, and the Caspian were all one body of water. The Caspian was separated from the Black Sea, and its surface is now variously estimated

at from 80 to 300 feet below the level of the latter. The formation of the Thracian peninsula cut off the Black Sea from the Mediterranean, and it had to seek some outlet. Before this time the succession of local eruptions mentioned above had broken up the strata of the old Paleozoic island so as to form deep valleys in all directions. As the waters of the Black Sea rose, they found their way into one after another of these valleys until they reached the Marmora, which was then probably a lake. The rise in the Marmora cut through the channel of the Dardanelles. There is no evidence whatever of the Bosphorus having been opened by a single eruption or earthquake, or of any raising and breaking of the rocks on a continuous line. The only thing which makes the problem a difficult one is the existence of the great volcanic domain at the northern extremity of the straits. The channel of the Bosphorus passes through this a distance of more than four miles. How was this part of the channel formed? If we knew the age to which this domain belongs, we might answer this question. As it is, it must remain a matter of speculation.