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ART. I.—*Geology of the Island of Bombay; with a Map and Plates.* By H. J. CARTER, Esquire, Assistant Surgeon, Bombay Establishment.

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DIFFICULT as it may appear to unravel the geological history of a tract of country which has been overflowed and ploughed up by successive volcanic effusions, and subsequently elevated, depressed, immersed, or denuded, or all four put together, yet, by patient investigation and search, such a knowledge of its structure and composition may be obtained, as to enable the observer to bring back, in his imagination, to their original state and position, the materials of which it was originally composed, and to place before the reader a satisfactory account of the changes which it has undergone during a given geological period,—changes which to him would otherwise be incomprehensible.

The little island of Bombay, just peeping above the waters of a muddy estuary, would seem to offer little or no novelty in this respect, particularly when compared with the great mountainous masses which surround it; but, when observed carefully, it will be found that what it lacks in size is compensated by amount of excavation, and that the latter has in all probability disclosed the geological type of the whole neighbourhood in its limited space.

Was the island of Bombay, as at first sight appears, composed of one mass of the same kind of dark-looking trappean rock, its geology might be told almost in as many words; but when it is found to present in its thickness the strata of an ancient lake, or river; a coal-deposit in miniature, filled with the fossillized debris of animal and vegetable remains, some, if not most, belonging to species now wholly extinct; and that there have been three or four successive effusions of volcanic matter over and into these strata, forming ten times as many different rocks, it naturally suggests the questions—How far did this lake extend? Was it a lake, or a river, or an estuary? On what kind of rock were its strata deposited? Of what material are its strata composed? To what extent does its coal deposit extend? What was its geological age? When was it destroyed and filled up? What rock first covered it? What kind of rocks subsequently forced their way into it? Has the island undergone any elevation or depression, and have any other strata been deposited on it since the period of active volcanic action ceased? Does the nature of its volcanic effusions, or their relative positions, bear any analogy to similar effusions in the adjoining islands, and on the main land itself?—are all questions which make the little island of Bombay assume a geological importance as interesting as at first it appeared to be unpromising. Let us now see if any of them can be answered.

From the following facts and observations, it will be evident that there have been three distinct periods in the formation of the island of Bombay, viz: 1st, the deposit of the fresh-water strata; 2nd, the volcanic effusions; and, 3rd, the deposit of the marine strata.

Of the Fresh-water Formation, which was of course the oldest, we are unable to come to any conclusions beyond the following, viz., that by the absence of marine fossils in it, and the presence of fresh-water ones, it was deposited in a lake or river; that its upper part is seen entire for 36 feet below the igneous rock which overlies it; and that below this again its strata have been intruded and broken up by other igneous rocks; so that, at present, we can neither tell its whole thickness, nor the nature of the rock on which it was deposited. As to its limits horizontally, it can only be at present stated that it extended all over the island of Bombay, and that portions of it may be seen in the volcanic breccia at Ghora Bunder, a little village on the northern extremity of the island of Salsette, thus giving it an extent north and south of at least twenty miles. We shall see also, by the presence of organic remains in this formation, that it must have been the depository of a large quantity of wood, leaves, fruits, &c., and that these are generally in a fragmental state, and jumbled together, as if they had been brought

from a distance; also that plants, having conical bulbous roots, with stems formed of concentric layers, as if made up of sheathing leaves, like large bulrushes, grew in this lake; that it swarmed with the little entomostraco-crustacean animals called Cypridæ, and that an abundance of small frogs and marsh-tortoises were also present. Moreover, that the material of which its strata are composed seems from its color and composition to be of volcanic origin, but deposited for the most part in a subtle state, though occasionally granular and coarse-grained, but never gravelly, and always argillaceous. This, from the thin layers of which the formation is composed, must have been deposited very gently, and would therefore come nearer to the sediments of a lake than those of a swift stream. At what geological period these strata were formed is not yet known, because there have been no fossils yet found in them which can determine this; but a time arrived when the volcanic material of which they are presumed to have been formed was no longer transported through the agency of water, but came in a molten fluid, and, filling up the lake, dried up or turned off its waters, and changed the then sub-lacustrine plain of Bombay into one of dry black igneous rock. This brings us to the second epoch. It is most probable that this lake was above the level of the sea at the time this occurred, although the general level of its strata is now below it. One other fact connected with the fresh-water formation is here worth mentioning, viz. that within three inches of the igneous rock which overlies it, there is a stratum three inches in thickness, almost entirely composed of the casts of Cypridæ,—not of their valves singly, which they are wont to shed annually, but their entire casts, showing that some sudden alteration of the water in which they were living took place, by which they all as suddenly perished and fell to the bottom. After this occurrence no organic remains are seen, and nothing but the three inches mentioned of a kind of transitionary material between the fresh-water formation and the basalt. The amount of coal in this formation will be seen to be very trifling, and that nearly the whole of the wood and other vegetable remains have been replaced by argillaceous material. At the same time, it will also be seen that it is only at one place that the highly carboniferous part has been exposed, and that, too, over an area only of a few square yards, viz. in the cutting of the sluices, where the main drain of the island empties itself into the sea.

2ND PERIOD.—This period commences with the effusion of the basalto-dioritic tract which caps the main ridges in Bombay, and which, it may be presumed, was at first continuous all over the island. How far this tract of lava extended it is not our present object to inquire; it is

enough for us to know that it extended over the then plain of Bombay: originally it was probably much thicker than it is at present, but the weathering of ages has of course much reduced it, though even now it may be seen to measure 90 feet thick on the eastern, and 51 or more on the western side of the island. Immediately after this effusion, we may conceive the site of Bombay to have been part of a black arid plain: how long this continued geologically we have no proofs to show, but after it had become hard, probably, and fixed, there was a second effusion, which, coming up under the first, and not finding a ready outlet, followed the course of the fresh-water strata below it, intercallating them, and breaking them up into all-sized fragments. This effusion was for the most part scoriaceous or cellular, and gave rise to the amygdaloidal structure which is now its chief characteristic; though in Nowrojee Hill quarry it is compact, which might have arisen from the superincumbent weight of diorite over it at this part. The amygdaloid rock is found invading the fresh-water strata in every part of the island, in one form or another, non-cellular or cellular; the cavities in the latter instance being filled with laumonite, green-earth, quartz, or calc-spar, according to the locality. The part which this effusion took in raising up the longitudinal ridges in the plain of the first effusion, and which ridges, running about N. by E. and S. by W., now border the eastern and western sides of the island, there is no evidence to show; but that this, or the third effusion, to which we now come, or both, were active agents in this matter, there seems to be no reason to doubt, for we find those parts of the ridges most elevated where these effusions are thickest, and in the western ridge either one or the other is seen filling up the internal angle of the roof-like elevation formed by the fresh-water strata there. We have, then, a basalto-dioritic effusion, and an amygdaloid effusion; and now we arrive at another effusion, which we shall term the volcanic breccia. How long an interval elapsed between the amygdaloidal effusion and that which gave rise to the volcanic breccia is as inconceivable as the duration of the interval which existed between the first and second effusions, there being nothing in the island of Bombay to give the slightest idea of either; but, that the volcanic breccia was formed subsequently to the amygdaloid, is proved by the presence of fragments of the latter among the fragments of the other rocks which form the heterogeneous compound of the former. The principal characters of this effusion are that it is composed chiefly of angular fragments of the fresh-water formation, varying in size from particles which are invisible to the naked eye to pieces some tons in weight; also that it contains fragments of various sizes of the two

foregoing effusions; and, lastly, that it is of great extent, forming a continuous tract from Carnac Bunder all long the eastern shore of the island to Sion, and there composing the plain and chain of hills which form the north-eastern part of the island; also, still further, the principal part of the mountains in the island of Salsette. It is this effusion which I think contemporaneous with the Laterite, and in some parts identical with it in every respect; but this will be better understood by a reference to the latter part of the detailed description of this effusion,—we are chiefly concerned with it here as an agent in the changes of form which the first plain of volcanic rock has undergone; and no one can witness the cropping out of this breccia all along the base of the highest parts of the eastern ridge, and its free effusion at the north-east part of the island, with wells extending into it 60 feet deep in Mazagon, and veins and dykes of it bursting through the basalto-dioritic tract in the same neighbourhood, without feeling satisfied, that to make room for such an immense mass, the crusts of the previous rocks must have given way, and have been forced ridge-like upwards, as we now see them, to give vent to the volcanic torrent, which, breaking through the fresh-water formation and igneous rocks that opposed its progress, finally spread their fragments in the manner we have seen them along the eastern shore of the island.

The protean forms assumed by this effusion and its decompositions, passing through so many different rocks, may easily be conceived; it is therefore white at one part, blue at another, yellow at a third, brown at a fourth, red at a fifth, and black at a sixth, with all the intermediate shades; composed, as before stated, of fragments of rocks in the immediate vicinity, changed into all kinds of consistences, and more than that indeed, fragments of large-grained diorite, which have come up from a region much below any we are acquainted with in Bombay. As to structure and hardness, it presents every stage, from the coarsest and softest argillaceous breccia, which may be cut with a knife, to the blackest and hardest homogeneous jasper, seen at the hills of Antop and Sewree. Such a destructive agent, then, as this effusion must have been, might be safely allowed to have been the one most active in the upheaval of the longitudinal ridges in the island of Bombay, if not the mountains in the island of Salsette also. Lastly, we have a fourth effusion, and this is proved by the existence of dykes of volcanic breccia through the last mentioned. Of their contents, little can be made out, and they prove nothing further, than that the third was not the last effusion. In the detailed descriptions of the three latter effusions, I may have mentioned some little tracts as pertaining to one which

may pertain to another; but it is almost impossible to expect accuracy in this respect with effusions which are all more or less alike, and errors of such kind, after all, are of little importance, as they cannot affect the grand facts, and, moreover, the observer may correct them as he best likes himself. That there have been four successive effusions there can be no doubt; and that the three latter, pursuing a course in the first instance under the basalto-dioritic tract, have all contributed to destroy its horizontality, by raising up the ridges which now exist upon it, is equally obvious. With the dykes, which have been last mentioned, the period of active volcanic action in the island of Bombay seems to have ended; how far passively the island has since been affected there is nothing to determine.

3RD PERIOD.—*Deposition of the Marine Formation.*—There is nothing in this to make us think that it is of very ancient date geologically: it would seem to belong to the Post and Newer Pliocene Formations. The clay and lower part of the beach, as no remains of human bones or artificial structures have I think been found in either, perhaps belong to the former, while the shells consist of the same species as those which are found on the shore at the present time. That the island has undergone elevation since the period of volcanic action ceased would seem to be proved by the remains of a portion of sea-beach called Phipps' Oart, in the centre of the island, near which no sea now comes; but this elevation must be very trifling, for the ridge of a beach is always higher than the sea, even at the highest tides, and the summit of this is only eight or nine feet above high-water mark, while the accumulation of detritus poured into the estuary of Bombay from the neighbouring hills is as likely to have produced this, and to have filled up the lagoonal depression in the centre of the island to the level of the sea, as anything else.

At the same time, Bombay could never have been very deep, or long under water, or the deposits on it would have been much thicker than they are, and of more ancient date: as it is, the beaches hardly exceed 20, and the clay 10 feet in thickness. Where there is no clay, as close to the shore, the beaches are thickest, and *vice versâ*.

The analogy which the basalto-dioritic tract and amygdaloid effusions bear to those on the main land are most striking, and may be seen by a reference to Colonel Sykes' valuable paper on the Trappean Region of the Dekkan and Konkan, immediately opposite,*—that of the adjoining islands I hope at some future period to show myself.

* Trans. Geol. Soc., 4to, second series, vol. iv. p. 409.

Such is a short summary of the geology of the island of Bombay, and I have premised instead of appended it, in hopes that the reader may be induced to peruse the following descriptions in detail from which these inferences have been deduced; let us begin with a brief outline of its geography.

The island of Bombay is trapezoidal in figure, having its long axis nearly N. by E., and S. by W., its short parallel side towards the sea, and its long one towards the land. The outer side is six miles long, and the inner one eleven miles; both are bordered by ridges of hills, scarped towards the east, while they slope gradually towards the west. Between these ridges, which are about two miles apart, there is a level plain, called the "Flats." The greatest width of the island is a little more than three miles.

At the two short sides of the figure there are sandy beaches, which, being above the level of the "Flats," prevent the sea from overflowing them, but on the outer side of the island there is no beach, because the whole is black basalt, probably extending a long distance into the sea; while on the inner side, which borders the harbour, there is an accumulation of silt, deposited from the back-waters, and the rivers which empty themselves into the estuary, in which the island of Bombay is situated.

The southern extremity of the outer side of the island is called Malabar Point, and the northern Worlee; while the southern extremity of the inner side is marked by the Light House, which stands on the extreme end of a thin prolongation called Colaba; and at the northern extremity is a tower called Riva Fort. Between Malabar Hill and the extremity of Colaba is a deep bay, called Back Bay, in which there is a sandy beach, and on the opposite or corresponding side of the trapezoid is a similar excavation, in which there is also a beach, called Mahim Sands. Both of these beaches are a few feet above high-water mark, and they chiefly prevent the sea from overflowing the centre of the island.

The highest point in the lateral ridges (which are interrupted more or less by breaks here and there) does not exceed 180 feet, which is the height of Malabar Hill just above the eastern corner of Back Bay. The southern part of the eastern ridge, called Nowrojee Hill, is 117 feet; Mazagon Hill, next to it, 162 feet; Chinchpoogly Hill, 153 feet; Parell Flag-staff or Colongee Hill 163 feet, above high-water mark; and Antop Hill, which is in the centre of the little range bordering the north-eastern part of the island, is 85 feet; while another hill in the

same range, a little to the north of it, is about 127 feet above high-water mark,—the latter has been measured by comparison.

The Flats are but just above the level of the sea, which overflows a small portion of them at the "springs," and the ridges of the beaches average about six feet above high-water mark.

From this description, it must be evident that a section of the island of Bombay, either longitudinally or transversely, if proportionally given, will have a very insignificant appearance. (See Map.)

With respect to its relations with the main land, Bombay is separated to the northward from the mountainous island of Salsette, which is six or seven times larger, by a channel, narrowing to a point not more than 125 yards wide; while Salsette, again, in like manner, is separated from the main land by a similar channel. To the south and east of Bombay is its harbour, in which are also several mountainous islands and islets, which lie scattered between it and the main land. The harbour, or estuary, is about six miles across in its widest part.

This short geographical introduction will be sufficient to explain the map of the island of Bombay hereto annexed; let us now proceed to its geology.

Insignificant as the elevation of Bombay is from its low hills and general flatness, yet it is by no means so in geological composition, for although its structure is not known for more than 60 feet here and there below high-water mark, which, added to its highest point, gives only a total thickness of 240 feet, yet in this thickness we have from 30 to 50 feet or more of fresh-water strata, covered by volcanic rock, which has been thrown out over them, in some parts 90 feet thick, and pierced by various subsequent effusions even still thicker; together with a marine formation, filling up the lagoonal depression of the island, and consisting of mud, in some parts 10 feet, and in other parts sandy beaches, 20 feet thick. Thus we have abundance in a geological point of view to occupy our attention, although we have little geographically.

But, before proceeding further, it would be as well to consider the general composition of the ridges of the island, and then their mineralogical characters in detail, in order that we may arrive at a right understanding of the relative position of the rocks which compose them, and the names by which we intend to designate their various forms.

The rocks of Bombay, which chiefly form its ridges, come under the class volcanic, and all belong to the trappean system: there are no hypogene rocks, that is igneous rocks which have been formed below the surface, and afterwards raised above it. Besides these, there

is a series of aqueous strata, which comes under the head of fresh-water formations, from the character of its fossils; and this, as before stated, is overlaid, and intruded by, both the volcanic rocks.

The whole of the upper part of the eastern ridge, from Riva Fort to the end of Colaba, is composed of fine-grained diorite, more or less basaltic towards the summit, while the whole of the upper part of the outer or western ridge is composed of fine compact black basalt. Both of these rocks rest conformably on the fresh-water formation, which is composed of argillaceous and bituminous shale, broken up by subsequent volcanic effusions, assuming the forms of trappite, aphanite, spilite, amygdaloid, &c.

Such is a brief outline of the general composition of the ridges, and the relative position of the rocks which compose them; the following are the mineralogical characters of the latter. I should here premise, also, that in nomenclature I shall chiefly follow Alexandre Brongniart's classification and mineral characters of rocks, as given under the article "*Roches,*" in the Dictionnaire des Sciences Naturelles.

Diorite, (syn. greenstone,) is essentially composed of felspar and hornblende, and is either coarse-grained or fine-grained—the former is generally the oldest: that of Bombay is fine-grained, and hardly admits of being recognized by the naked eye; but, when magnified, the dark green hornblende is easily distinguished from the less colored felspar. It is this compound which forms the upper part of the eastern ridge, and varies in color from green and blue to sometimes black. When it is very compact, sparkling, and sub-granular, its binary compound and crystallization almost undistinguishable, and its homogeneity almost complete, then we shall call it *basalt;* and in this state, possessed of a blue black, or deep purple color, it forms the upper part of the western ridge. Diorite, when forming part of a trappean effusion, may pass into basalt; hence we have the upper part of the eastern ridge in some places very basaltic. When the binary compound of diorite has an intermixture of blue earthy matter, it becomes a semi-crystalline rock, and this we shall call *trappite;* while, when there is no longer any appearance of the crystalline compound, viz. felspar and hornblende, and the whole is an earthy substance, it is called *aphanite,* from ἀφᾰνίζω, to make unseen, in allusion to the felspar. I shall not make use of the term "trap" as a specific appellation here, as it confuses, and trappite and aphanite will, I think, be found sufficient. In this way, then, the distinguishable binary compound of diorite may pass into the undistin-

guishable one called basalt,* or into the semi-crystalline one, trappite, or earthy one, termed aphanite, in which all traces of both the felspar and hornblende in a crystalline state have disappeared. Now, when aphanite is cellular, its cavities being filled with calc-spar in particular, chlorite, zeolites, quartz, amethyst, or calcedony, it is called *spilite*, and the other rocks, too, when cellular, and filled with such substances, are termed amygdaloid, or variolitic. Under the foregoing generic names, then, we have all the trappean rocks in Bombay included. We next come to the fresh-water formation, in which we have argillaceous shale, argillo-calcareous shale, and argillo-bitumenous shale, with small quantities of coal; also chert and jasper, arising from the exposure of the argillaceous strata to great heat. Add to the foregoing a volcanic breccia, composed of fragments of the other formations, bound together by a base of aphanite, more or less fine, more or less coarse; harder or softer, and sometimes passing into a black jasper, as at Sewree, and Antop Hill. Lastly, we have the blue and brown clay of the Flats, containing the calcareous concretions called *kunkur;* and the consolidated sand and sea-shells of the beaches.

Having thus premised sufficient to prevent a misunderstanding in the terms which will be used, and the kind of rocks they designate, let us now trace the different formations mentioned throughout the island, beginning with the diorite, which is the most prevalent, the most prominent, and the most widely-spread of all.

Diorite.—This rock forms the summit of all the eastern ridges, except that bordering the north-east part of the island, and will be found to extend continuously from the extremity of Colaba to Riva Fort, that is the whole length of the island. It is interrupted by breaks or breaches here and there, and diminishes in height towards both extremities; but between the fort and the village of Nagaum, a distance of five miles, it presents points of variable heights, rising to 163 feet above the level of high-water mark. In some of the breaks it appears to be so expended that its continuity is hardly traceable, as at Nagaum, while in other places, as at Nowrojee Hill, where it has been quarried, it is 90 feet thick. Again, the width of this tract varies, so far as it is observed superficially: it forms the whole of Colaba, and the eastern part of the Esplanade and Fort, and, of course, it extends into the harbour on one side, and, obscured by the beach which forms the

* Some basalts may of course be composed of felspar and angite, and, when this is the case, the rock is called "dolerite."

Esplanade, appears in Back Bay again on the other; but at present it will only confuse us to trace it where it is concealed, and, therefore, we will confine our observations to where it is exposed. It forms also the eastern part of the Native Town, at the northern extremity of which is the quarry of Nowrojee Hill, where, as before stated, it is seen to be 90 feet thick; here, also, its superficial area is greatly expanded, and extends continuously across the island from Mazagon Hill due west to the Flats, a distance of one mile. This breadth is greater than at any other part, and is prolonged from Nowrojee Hill due north to the Mount, a distance of one mile and a quarter. At this part, also, it has been intersected and pierced in all directions by a subsequent effusion, which we shall come to hereafter. At the Mount, it narrows again, and spreads out on Chinchpoogly Hill, and thence is continued on over Colongee or Parell Flag-staff Hill to the village of Nagaum; here it sinks to within a few feet of the level of the Flats, and is continued on in the form of a few boulders for half a mile, and then, rising again a few feet more or less, ends at Riva Fort, the northern extremity of the island. The principal feature of this ridge is, that it is more or less scarped towards the east, while it slopes more or less suddenly towards the west; a feature which, however, it should be remembered, is common to every hill in Bombay, without exception. Its summits and sides are also covered with naked rocks and boulders, from the mode of desintegration of the diorite, which follows the veins with which it is intersected; hence they are in cuboidal or polyhedral masses, and, when more minutely divided, end in becoming spheroids, throwing off concentric crusts.

The mineralogical composition and structure of this rock varies. Generally, its crystalline structure may be distinguished with a good magnifying glass, but sometimes it becomes so minute, and compact, and tough, that it almost takes on the form of basalt; still we may infer its composition by seeking out its structure in larger-grained specimens. In these we shall find tabular crystals of white felspar; amorphous crystals of green hornblende; a small quantity of green or blue earth, ("green-earth,") with more or less olivine; also small particles of peroxide of iron, or, probably, titanitic iron, or rutile, from its rich brown red color in some parts; all of which are caught up by the magnetized needle in their natural state when the mass is pulverized,—this, of course, can only be seen by manipulation under a high magnifying power. The presence of the iron accounts for the decomposition of the rock into greenish blue, then yellow, and lastly red earth, these being the usual colors which iron assumes in passing from its protoxide to its peroxidized state.

Further, it may be observed of this rock, *en masse*, that the upper part is tougher and more difficult to break than the lower part, while the latter, on the contrary, is more cleavable. Cavities are sparsely scattered in it, which contain varieties of scolezite or needlestone, the latter name being derived from its spicular crystallization. In some parts it is blacker than in others, while frequently it presents a spotted appearance, on account of the black portions being circumscribed instead of generally spread throughout the rock. I am unable to explain the latter appearance, except that the hornblende is blacker in these places than in others, probably from the greater quantity of protoxide of iron which it contains; in other words, that the distribution of the iron throughout the rock has been unequal, or has become aggregated in some parts of it more than in others during its crystallization or *ab origine*. In the next ridge I am about to mention, this mottled state prevails very much, and on weathering, the dark portions remain, while the lighter parts wear away, giving the surface a botryodal appearance, in which the spheroids are about the size of bullets. This form seems to answer to that called "*orbicular diorite*" (Bt.)

The next ridge we have to trace, and which is composed of the same rock, is very low, scarcely rising at one or two points more than 50 feet above the sea. It lies on the east side of the latter, and commences close upon the sea opposite Mazagon Hill, from the base of which it is separated by subsequent effusions of volcanic matter. Its rocks, which appear just above the sea at its commencement at Mazagon, rise gradually to Tank Bunder, where there is a high mound of it, after which it sinks below the mud, and subsequently makes its appearance again at Kandlee Battery: there, as at Tank Bunder, it rises to about 50 feet above the sea, and again sinks gradually, as it pursues a direct line northwards to within a hundred yards of the base of Colongee or Parell Flag-staff Hill, where it ends; being separated the whole way from the first ridge by the subsequent effusion to which I have alluded. It does not differ in composition or structure from the diorite of the first ridge, except that its surface in many places weathers into the botryodal form mentioned, particularly a little south of Tank Bunder; this is its great peculiarity. It is very insignificant in height, when compared with the first ridge; but is, in like manner, tilted up and scarped towards the east.

Lastly, we have a third ridge of diorite on the east side of the island, which begins at a point 400 yards N. E. of Kandlee Battery, called Jackaryah's Bunder, and 600 yards east of the first ridge. It pursues a course a little to the eastward of north, and, about a mile from its