siding rocky matter, it might be found in the fact that the traces of extreme crushing, such as corrugation, slaty cleavage, etc., do not occur in volcanic regions—which rarely show signs of much disturbance, but only dykes, *i.e.* narrow fissures filled with lava-rock, cutting through undisturbed, or but slightly disturbed strata, making it probable (as I said in my first notice of Mr. Mallet's theory) that if any heat is, or ever was, generated by the compression of rocks, its effects should be looked for rather in the metamorphosed and plicated rocks of mountain chains than in the lines of volcanic eruption.

I must apologize to the readers of the Geological Magazine for this continued controversy with Mr. Mallet, on the double ground of, 1st, that gentleman's repeated and persevering misrepresentation of my views on volcanic action, and 2ndly, the inherent weakness of the theory he has advanced with so much pretension as "a precise and true theory, in substitution for the current and erroneous notions as to the nature of those forces, from the play of which, within our globe, those grand phenomena of nature (volcanos) are produced." —Phil. Trans. p. 147.

III.—On the Physical Cause of the Submergence and Emergence of the Land during the Glacial Epoch.

By James Croll, of the Geological Survey of Scotland.

(*Continued from page* 314.)

THE greatest extent of the displacement of the earth's centre of gravity, and consequently the greatest rise of the ocean resulting from that displacement, would of course occur at the time of maximum glaciation, when the ice would be all on one hemisphere. But owing to the following circumstance, a still greater rise than that resulting from the displacement of the earth's centre of gravity alone might take place at some considerable time, either before or after the period of maximum glaciation.

It is not at all probable that the ice would melt on the warm hemisphere at exactly the same rate as it would form on the cold hemisphere. It is probable that the ice would melt more rapidly on the warm hemisphere than it would form on the cold. Suppose that during the Glacial epoch, at a time when the cold was gradually increasing on the northern and the warmth on the southern hemisphere, the ice should melt more rapidly off the Antarctic Continent than it was being formed on the Arctic and Sub-arctic regions; suppose also that, by the time a quantity of ice, equal to one-half what exists at present on the Antarctic Continent, had accumulated on the northern hemisphere, the whole of the Antarctic ice had been melted away, the sea would then be fuller than at present by the amount of water resulting from the one mile of melted ice. The height to which this would raise the general level of the sea would be as follows:—

The Antarctic ice-cap is equal in area to $\frac{1}{23\frac{1}{46}}$ of that covered by the ocean. The density of ice to that of water being taken at ·92 to 1, it follows that 25 feet 6 inches of ice melted off the cap would

raise the general level of the ocean one foot, and the one mile of ice melted off would raise the level 200 feet. This 200 feet of rise resulting from the melted ice we must add to the rise resulting from the displacement of the earth's centre of gravity. The removal of the two miles of ice from the Antarctic Continent would displace the centre of gravity 190 feet, and the formation of a mass of ice equal to the one-half of this on the Arctic regions would carry the centre of gravity 95 feet further; giving in all a total displacement of 285 feet, thus producing a rise of sea-level at the North Pole of 285 feet, and in the latitude of Edinburgh of 234 feet. Add to this the rise of 200 feet resulting from the melted ice, and we have then 485 feet of submergence at the Pole, and 434 feet in the latitude of Edinburgh. A rise to a similar extent might probably take place after the period of maximum glaciation, when the ice would be melting on the northern hemisphere more rapidly than it would be forming on the southern.

If we assume the Antarctic ice-cap to be as thick as is represented in the diagram, the extent of the submergence would of course be double the above, and we might have in this case a rise of sea-level in the latitude of Edinburgh to the extent of from 800 to 1000 feet. But be this as it may, it is evident that the quantity of ice on the Antarctic Continent is perfectly sufficient to account for the submergence of the Glacial epoch, for we have little evidence to conclude that the *general* submergence much exceeded 400 or 500 feet.[1] We have evidence in England and other places of submergence to the extent of from 1000 to 2000 feet, but these may be quite local, resulting from subsidence of the land in those particular areas. Elevations and depressions of the land have taken place in all ages, and no doubt during the Glacial epoch also.

In favour of this view of the cause of the submergence of the Glacial epoch, it is a circumstance of some significance, that in every part of the globe where glaciation has been found, along with it, evidence of the submergence of the land has also been found. The invariable occurrence of submergence along with glaciation points to some physical connexion between the two. It would seem to imply, either that the two were the direct effects of a common cause, or that the one was the cause of the other; that is, the submergence the cause of the glaciation, or the glaciation the cause of the submergence. There is, I presume, no known cause to which the two can be directly related as effects. Nor do I think that there is any one who would suppose that the submergence of the land could have been the cause of its glaciation, even although he attributed all Glacial effects to floating ice. The submergence of our country would, of course, have allowed floating ice to pass over it had there been any to pass over; but submergence would not have produced the ice, neither would it have brought the ice from the Arctic regions where it already existed. But although submergence could not have

[1] In a former paper I considered the effects of another cause, viz. the melting of polar ice resulting from an increase of the Obliquity of the Earth's Orbit.—Trans. Glasgow Geol. Soc. vol. ii. p. 177. Phil. Mag. June, 1867 (Supplement).

been the cause of the Glacial epoch, yet we can, as we have just seen, easily understand how the ice of the Glacial epoch could have been the cause of the submergence. If the Glacial epoch was brought about by an increase in the eccentricity of the earth's orbit, then a submergence of the land as the ice accumulated was a physical necessity.

There is another circumstance connected with Glacial submergence which it is difficult to reconcile with the idea that it resulted from a subsidence of the land. It is well known that during the Glacial epoch the land was not once under water only, but several times; and, besides, there were not merely several periods when the land stood at a lower level in relation to the sea than at present, but there were also several periods when it stood at a much higher level than now. And this holds true, not merely of our own country, but of every country on the northern hemisphere where glaciation has yet been found. All this follows as a necessary consequence from the theory that the oscillations of sea-level resulted from the transference of the ice from the one hemisphere to the other; but it is wholly inconsistent with the idea that they resulted from upheavals and subsidence of the land during a very recent period.

But this is not all, there is more still to be accounted for. It has been the prevailing opinion that at the time when the land was covered with ice, it stood at a much greater elevation than at present. It is, however, not maintained that the facts of geology establish such a conclusion. The greater elevation of the land is simply assumed as an hypothesis to account for the cold (Phil. Mag. for Nov. 1868, p. 376). The facts of geology, however, are fast establishing the opposite conclusion, viz. that when the country was covered with ice, the land stood in relation to the sea at a lower level than at present, and that the continental periods or times when the land stood in relation to the sea at a higher level than now were the warm interglacial periods, when the country was free of snow and ice, and a mild and equable condition of climate prevailed. This is the conclusion towards which we are being led by the more recent revelations of surface geology, and also by certain facts connected with the geographical distribution of plants and animals during the Glacial epoch.

The simple occurrence of a rise and fall of the land in relation to the sea-level in one or in two countries during the Glacial epoch, would not necessarily imply any physical connexion. The coincidence of these movements with the glaciation of the land might have been purely accidental; but when we find that a succession of such movements occurred, not merely in one or in two countries, but in every glaciated country where proper observations have been made, we are forced to the conclusion that the connexion between the two is not accidental, but the result of some fixed cause.

If we admit that an increase in the eccentricity of the earth's orbit was the cause of the Glacial epoch, then we must admit that all those results followed as necessary consequences. For if the Glacial epoch lasted for upwards of one hundred thousand years or so, there

would be a succession of cold and warm periods, and consequently a succession of elevations and depressions of sea-level. And the elevations of the sea-level would take place during the cold periods, and the depressions during the warm periods.

But the agreement between theory and observed facts does not terminate here. It follows from theory that the greatest oscillations of sea-level would take place during the severest part of the Glacial epoch, when the eccentricity of the earth's orbit would be at its highest value, and that the oscillations would gradually diminish in extent as the eccentricity diminished and the climate gradually became less severe. Now it is well known that this is actually what took place; the great submergence, as well as the great elevation or continental period, occurred during the earlier or more severe part of the Glacial epoch, and as the climate grew less severe these changes became of less extent, till we find them terminating in our submerged forests and 25-foot raised beach.

It follows therefore, according to the theory advanced, that the mere fact of an area having been under sea does not imply that there has been any subsidence or elevation of the land, and that consequently the inference which has been drawn from these submerged areas as to changes in physical geography may be in many cases not well founded.

Sir Charles Lyell, in his "Principles," publishes a map showing the extent of surface in Europe which has been covered by the sea since the earlier part of the Tertiary period. This map is intended to show the extraordinary amount of subsidence and elevation of the land which has taken place during that period. It is necessary for Sir Charles's theory of the cause of the Glacial epoch that changes in the physical geography of the globe to an enormous extent should have taken place during a very recent period, in order to account for the great change of climate which occurred at that epoch. But if the foregoing results be anything like correct, it does not necessarily follow that there must have been great changes in the physical geography of Europe, simply because the sea covered those areas marked in the map, for this may have been produced by oscillations of sea-level, and not by changes in the land. In fact, the areas marked in Sir Charles's map as having been covered by the sea, are just those which would be covered were the sea-level raised a few hundred feet. No doubt there were elevations and subsidences in many of the areas marked in the map during the Tertiary period, and to this cause a considerable amount of the submergence might be due; but I have little doubt that by far the greater part must be attributed to oscillations of sea-level. It is no objection that the greater part of the shells and other organic remains found in the marine deposits of those areas are not indicative of a cold or glacial condition of climate, for, as we have seen, the greatest submergence would probably have taken place either before the more severe cold had set in or after it had to a great extent passed away. That the submergence of those areas probably resulted from elevations of sea-level rather than depressions of the land, is further evident from

the following considerations. If we suppose that the climate of the Glacial epoch was brought about mainly by changes in the physical geography of the globe, we must assume that these great changes took place, geologically speaking, at a very recent date. Then when we ask what ground is there for assuming that any such change in the relations of sea and land as is required actually took place, the submergence of those areas is adduced as the proof. Did it follow as a physical necessity that all submergence must be the result of subsidence of the land, and not of elevations of the sea, there would be some force in the reasons adduced. But such a conclusion by no means follows, and, *à priori*, it is just as likely that the appearance of the ice was the cause of the submergence as that the submergence was the cause of the appearance of the ice. Again, a subsidence of the land to the extent required would to a great extent have altered the configuration of the country, and the main river-systems of Europe; but there is no evidence that any such change has taken place. All the main valleys are well known to have existed prior to the Glacial epoch, and our rivers to have occupied the same channels then as they do now. In the case of some of the smaller streams, it is true, a slight deviation has resulted at some points from the filling up of their channels with drift during the Glacial epoch; but as a general rule all the principal valleys and river-systems are older than the Glacial epoch. This, of course, could not be the case if a subsidence of the land sufficiently great to account for the submergence of the areas in question, or changes in the physical geography of Europe necessary to produce a Glacial epoch, had actually taken place. The total absence of any geological evidence for the existence of any change which could explain either the submergence of the areas in question or the climate of the Glacial epoch, is strong evidence that the submergence of the Glacial epoch, as well as of the areas in question, was the result of a simple oscillation of sea-level resulting from the displacement of the earth's centre of gravity by the transference of the ice-cap from the southern to the northern hemisphere.

Oscillations of sea-level in relation to Distribution.—The oscillations of sea-level resulting from the displacement of the earth's centre of gravity help to throw new light on some obscure points connected with the subject of the geographical distribution of plants and animals. At the time when the ice would be on the southern hemisphere during the Glacial epoch, and the northern hemisphere enjoying a warm and equable climate, the sea-level would be several hundred feet lower than at present, the North Sea would probably be dry land, and Great Britain and Ireland joined to the continent, thus opening up a pathway from the continent to our island. As has been shown in former papers (*Phil. Mag.* November, 1868; August, 1864; June, 1867, *Supplement*), during the inter-glacial periods the climate would be much warmer and more equable than now, so that animals from the south, such as the hippopotamus, hyæna, lion, *Elephas antiquus* and *Rhinoceros megarhinus*, would migrate into this country, where at present they could

not live in consequence of the cold. We have therefore an explanation, as was suggested on a former occasion (*Phil. Mag.* Nov. 1868), of the fact that the bones of these animals are found mingled in the same grave with those of the musk ox, mammoth, reindeer, and other animals which lived in this country during the cold periods of the Glacial epoch; the animals from the north would cross over into this country upon the frozen sea during the cold periods, while those from the south would find the English Channel dry land during the warm periods.

The same reasoning will hold equally true in reference to the old and new world. The depth of Behring Straits is under thirty fathoms; consequently a lowering of the sea-level of less than 200 feet would connect Asia with America, and thus allow plants and animals, as Mr. Darwin believes, to pass from the one continent to the other.[1] During this period, when Behring Straits would be dry land, Greenland would be comparatively free from ice, and the Arctic regions enjoying a comparatively mild climate. In this case plants and animals belonging to temperate regions could avail themselves of this passage, and thus we can explain how plants belonging to temperate regions may have, during the Miocene period, passed from the old to the new continent, and *vice versâ*.

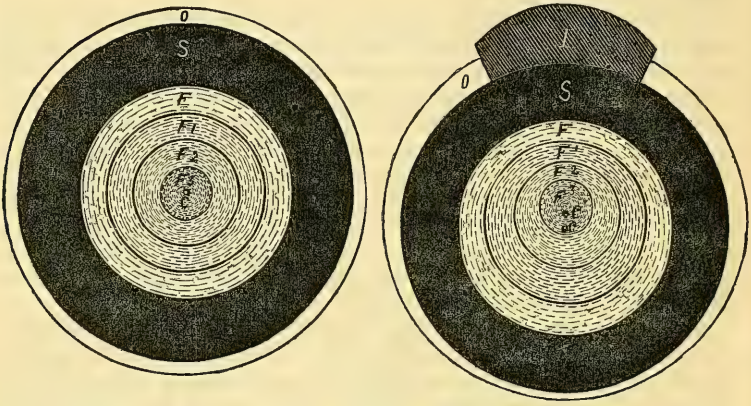
As has already been noticed, during the time of the greatest extension of the ice, the quantity of ice on the southern hemisphere might be considerably greater than what exists on the entire globe at present. In that case there might, in addition to the lowering of the sea-level resulting from the displacement of the earth's centre of gravity, be a considerable lowering resulting from the draining of the ocean to form the additional ice. This decrease and increase in the total quantity of ice which we have considered would affect the level of the ocean as much at the equator as at the poles; consequently during the Glacial epoch there might have been at the equator elevations and depressions of sea-level to the extent of a few hundred feet.

Extent of submergence on the hypothesis that the earth is fluid in the interior.—But we have been proceeding upon the supposition that the earth is solid to its centre. If we assume, however, what is the general opinion among geologists, that it consists of a fluid interior surrounded by a thick and rigid crust or shell, then the extent of the submergence resulting from the displacement of the centre of gravity for a given thickness of ice must be much greater than I have estimated it to be. This is evident, because, if the interior of the globe be in a fluid state, it, in all probability, consists of materials differing in density. The densest materials will be at the centre, and the least dense at the outside or surface. Now the transference of an ice-cap from the one pole to the other will not merely displace the ocean—the fluid mass on the outside of the shell—but it will also displace the heavier fluid materials in the interior of the shell. In other words, the heavier materials will be attracted by the ice-cap more forcibly than the lighter, consequently

[1] Origin of Species, chap. xi. (fifth edition).

they will approach towards the cap to a certain extent, sinking, as it were, into the lighter materials, and displacing them towards the opposite pole. This displacement will of course tend to shift the earth's centre of gravity in the direction of the ice-cap, because the heavier materials are shifted in this direction, and the lighter materials in the opposite direction. This process will perhaps be better understood from the following figures.

Fig. 2. Fig. 3.



O. The Ocean. S. Solid Crust or Shell.
F, F^1, F^2, F^3. The various concentric layers of the fluid interior. The layers increase in density towards the centre.
I. The Ice-cap. C. Centre of gravity.
C^1. The displaced centre of gravity.

In Figure 2, where there is no ice-cap, the centre of gravity of the earth coincides with the centre of the concentric layers of the fluid interior. In Figure 3, where there is an ice-cap placed on one pole, the concentric layer F^1 being denser than layer F, is attracted towards the cap more forcibly than F, and consequently sinks to a certain depth in F. Again, F^2 being denser than F^1, it also sinks to a certain extent in F^1. And again, F^3, the mass at the centre, being denser than F^2, it also sinks in F^2. All this being combined with the effects of the ice-cap, and the displaced ocean outside the shell, the centre of gravity of the entire globe will no longer be at C, but at C^1, a considerable distance nearer to the side of the shell on which the cap rests than C, and also a considerable distance nearer than it would have been had the interior of the globe been solid. There are here three causes tending to shift the centre of gravity, (1) the ice-cap, (2) the displaced ocean, and (3) the displaced materials in the interior. Two of the three causes mutually re-act on each other in such a way as to increase each other's effect. Thus the more the ocean is drawn in the direction of the ice-cap, the more effect it has in drawing the heavier materials in the interior in the same direction, and in turn the more the heavier materials, in the interior, are drawn towards the cap, the greater is the displacement of the earth's

centre of gravity, and of course, as a consequence, the greater is the displacement of the ocean. It may be observed also that, other things being equal, the thinner the solid crust or shell is, and the greater the difference in the density of the fluid materials in the interior, the greater will be the extent of the displacement of the ocean, because the greater will be the displacement of the centre of gravity.

It follows that if we knew (1) the extent of the general submergence of the Glacial epoch, and (2) the present amount of ice on the southern hemisphere, we could determine whether or not the earth is fluid in the interior.

IV.—Geological Notes from the Neighbourhood of Cairo.

By John Milne, F.G.S.

THIS neighbourhood has already been described by several authors, —the most complete account of the Tertiary beds being by Dr. Fraas, Aus dem Orient, 1867. Dr. Figari Bey, in vol. i. of Studi Scientifici sull' Egitto; H. Bauerman, Esq., and Dr. C. Le Nêve Foster, in the Quart. Journ. Geol. Soc. 1869, vol. xxv. p. 40, have also written on the district, the latter observers referring especially to the occurrence of Celestine in the Moccattam quarries.

The surroundings, of Cairo, being by no means a geological *terra incognita*, there will perhaps be but little to be gleaned in the way of additional particulars respecting this district from the following brief communication; it is therefore hoped it will be accepted rather as a note to accompany the few specimens collected[1] than as an independent paper.

Middens or Rubbish Heaps.—Outside Cairo, and noticeably so between its N.E. and S.W. sides, there are a number of dark-coloured low hills, forming a range about four or five miles in length, with an undulating surface,—in contour not unlike the Downs of our southern counties. In places these approach so closely to the city as partially to bury the walls with which it is surrounded, above which they rise rather steeply, at an angle of 25° to 28°, to a height of from 100 to 125 feet. On the opposite side, that is, towards the S.E., they slope more gradually, descending by a series of undulations and small valleys of the same depth as the hills are in height. The summit of these hills, which may be averaged at a quarter of a mile in width, and which, with the lateral ridges, is sufficient for the accommodation of numerous windmills, affords an extensive view towards the S.W. across Cairo to the Pyramids of Gizeh, and towards the E. over the plain in which are situated the Tombs of the Caliphs to the range of Moccattam. This view is represented as a diagram, in order to show the relation of the Red Hills to the Limestones of Moccattam, and also the dip of the strata. (See Woodcut, Fig. 1.)

It is not until these hills are approached and closely examined that their nature can be determined, after which one contemplates them

[1] The specimens referred to, have been presented by the author to the British Museum.