ART. L.—*Examination of Mr. Alfred R. Wallace's Modification of the Physical Theory of Secular Changes of Climate*; by
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PART II.—*Geological and Paleontological Facts in relation to Mr. Wallace's Modification of the Theory.*

MR. WALLACE'S chief, and indeed only real modification of my theory, is to the effect, as I have pointed out, that the alternate phases of precession causing the winter of each hemisphere to be in aphelion and perihelion each 10,500 years would produce a complete change of climate only when a country was partially snow-clad. According to his view, when the greater part of Northwestern Europe was almost wholly buried under snow and ice, those glacial conditions must have continued, and perhaps have even become intensified, when the winter solstice moved round to perihelion, instead of being replaced, as I have maintained, by an almost perpetual spring. In short, Mr. Wallace's conclusion is that, during the Glacial Epoch proper, a warm and equable Interglacial Period could not have occurred.

In the preceding part of this paper I have endeavored to show that physical principles do not warrant such a conclusion. I shall now proceed to consider what the direct testimony of Geology and Paleontology is on the subject; and I believe we shall find that the facts of Geology and Paleontology are as much opposed to the conclusion as are the principles of Physics.

On this point I may quote the evidence of a geologist who, more than any other, has devoted special attention to all points relating to Glacial and Interglacial periods. Prof. J. Geikie, after devoting upwards of 500 pages of his 'Prehistoric Europe'

to the consideration and accumulation of facts from all parts of this country and the continent relating to Glacial and Interglacial periods, gives the following as the result of his investigations:—

“We note,” he says, “as we advance from Pliocene times, how the climatic conditions of the colder epochs of the Glacial Period increase in severity until they culminate with the appearance of that great northern *mer de glace* which overwhelmed all Northern Europe, and reached as far south as the 50th parallel of latitude in Saxony. Thereafter the glacial epochs decline in importance until in the Postglacial Period they cease to return. The genial climate of Interglacial ages probably *also attained a maximum* toward the *middle* of the Pleistocene Period, and afterwards became less genial at successive stages, the temperate and equable conditions of early Postglacial times being probably the latest manifestation of the Interglacial phase.” (‘Prehistoric Europe,’ p. 561.)

I shall now quote the same author’s description of an Interglacial Period as demonstrated by its flora and fauna. The reader must, however, observe that by Pleistocene Period, Professor Geikie means the so-called Glacial Period with its alternations of severe arctic climate and mild and genial conditions. See p. 544, ‘Prehistoric Europe.’

“An examination,” he says, “of Pleistocene organic remains leads us to conclude that strongly contrasted climatic conditions alternated during the Period. At one time an extremely equable and genial climate prevailed, allowing animals, which are now relegated to widely-separated zones, to live throughout the year in one and the same latitude. Hippopotamuses, elephants and rhinoceroses, Irish deer, horses, oxen and bisons then ranged from the borders of the Mediterranean as far north at least as Middle England and Northern Germany. In like manner, plants which no longer occur together—some being banished to hilly regions, while others are restricted to low grounds, and yet others have retreated to the extreme south of the Continent or to warmer regions beyond the limits of Europe—lived side by side. The fig-tree, the judas-tree, and the Canary laurel flourished in Northern France along with the sycamore, the hazel, and the willow. And we encounter in the Pleistocene deposits of various countries in Europe the same remarkable commingling of northern and southern forms—of forms that demand a humid climate and are capable of enduring considerable cold, together with species which, while seeking moist conditions, yet could not survive the cold of our present winters. The testimony of the mammals and plants is confirmed by that of the land and freshwater mollusca—all the evidence thus conspiring to demonstrate that the climate of

Pleistocene Europe was, for some time at all events, remarkably equable and somewhat humid. The summers may not indeed have been warmer than they are now; the winters, however, were certainly much more genial." ('Prehistoric Europe,' p. 540.)

This, be it observed, is a description of a condition of things which existed during an interglacial period belonging, not to the close, but to the very climax of the Glacial Epoch. For immediately preceding and succeeding this Period almost the whole of Northern Europe was enveloped in one continuous sheet of ice. "But if," continues Professor J. Geikie, "the evidence of such a climate having formerly obtained be very weighty, not less convincing are the proofs, supplied by the Pleistocene deposits, of extreme conditions. Think what must have been the state of middle and Northern Europe when Paleolithic man hunted the reindeer in Southern France, and when the arctic willow and its congeners grew at low levels in Central Europe. Reflect upon the fact that in the very same latitude in France, where at one time the Canary laurel and the fig-tree flourished, the pine, the spruce, and northern and high-alpine mosses at another time found a congenial habitat. Bear in view, also, that the land and freshwater mollusks testify in like manner to the same strongly contrasted climate. Besides those that tell of more equable and genial conditions than the present, there are species now restricted to the higher Alps and northern latitudes that formerly abounded in middle Europe, and their shells occur commingled in the same deposits with the remains of lemmings, marmots, reindeer, and other northern and mountain-loving animals." (p. 541.)

But more convincing still is another range of facts, some of which have been adduced by Mr. Wallace himself. In a section on alternations of warm and cold periods during the Glacial Epoch ('Island Life,' p. 114), he says:—

"The evidence that such was the case" (alternate warm and cold periods) "is very remarkable. The 'Till,' as we have seen, could only have been formed when the country was entirely buried under a large ice-sheet of enormous thickness, and when it must therefore have been, in all the parts so covered, almost entirely destitute of animal and vegetable life. But in several places in Scotland fine layers of sand and gravel, with beds of peaty matter, have been found resting on 'till' and again covered by 'till.' Sometimes these intercalated beds are very thin, but in other cases they are twenty or thirty feet thick, and in them have been found remains of the extinct ox, the Irish elk, the horse, reindeer and mammoth. Here we have evidence of two distinct periods of intense cold, and an intervening milder period sufficiently prolonged for the country

to become covered with vegetation and stocked with animal life."

Let us now see to what all this leads. It has been proved beyond the possibility of a doubt that, at the time the till was being formed which *overlies* the Scottish interglacial beds, the whole of Scotland, Scandinavia, the bed of the North Sea, and a great part of the north of England was covered with one continuous sheet of ice upwards of 2000 feet in thickness. This sheet overwhelmed the Hebrides, the Orkney and Shetland islands, extended into Russia, filled the basin of the Baltic, overflowed Denmark and Holstein, and advanced into North Germany as far at least as Berlin. It has also been demonstrated that, at the time the Lower Till was being formed which *underlies* these interglacial beds, northwestern Europe was under a still more severe state of glaciation. The ice-sheet at this time advanced farther south into England, and extended into North Germany as far as Saxony. It is perfectly obvious that this sheet must have destroyed all plant and animal life in Scotland; and before the country could have become covered with vegetation and stocked with those interglacial animals, to which Mr. Wallace refers, the ice must have disappeared and the climate become mild.

Equally conclusive are the facts adduced by Mr. Wallace in reference to the interglacial beds of England. "In the east of England, Mr. Skertchly," he says, "enumerates four distinct boulder clays with intervening deposits of gravels and sands. Mr. Searles V. Wood, Jr., classes the most recent (Hessle) boulder-clay as 'post-glacial,' but he admits an intervening warmer period, characterized by southern forms of mollusca and insects, after which glacial conditions again prevailed with northern types of mollusca. Elsewhere Mr. Wood says: 'Looking at the presence of such fluviatile mollusca as *Cyrena fluminalis* and *Unio littoralis* and of such mammalia as the hippopotamus and other great pachyderms, and of such a littoral Lusitanian fauna as that of the Selsea bed, where it is mixed up with the remains of some of those pachyderms, as well as of some other features, it has seemed to me that the climate of the earlier part of the Post-glacial Period in England was possibly even warmer than our present climate; and that it was succeeded by a refrigeration sufficiently severe to cause ice to form all round our coasts, and glaciers to accumulate in the valleys of the mountain districts.'" That these faunæ indicate a warm and equable condition of climate is further evident from Mr. Wallace's remarks: "The fact," he says, "of the hippopotamus having lived at 54° north latitude in England, quite close to the time of the Glacial Epoch, is absolutely inconsistent with a mere gradual amelioration of climate

from that time to the present day. The immense quantity of vegetable food which this creature requires, implies a mild and uniform climate with hardly any severe winter; and no theory that has yet been suggested renders this possible except that of alternate cold and warm periods during the Glacial Epoch itself. . . . Thus the very existence of the hippopotamus in Yorkshire as well as in the south of England in close association with glacial conditions must be held to be a strong corroborative argument in favor of the reality of an interglacial warm period."

I trust that Mr. Wallace has not been misled by Mr. Wood's unfortunate use of the term "Post-glacial" as applied to the Hessle boulder-clay. The Hessle boulder-clay as surely belongs to the Glacial Period proper as does the true Till of Scotland, which covers the lowlands and overlies the interglacial beds of that country. It is the *moraine profonde* of the last *mer de glace* which covered the greater part of northwestern Europe. The Upper Till of Scotland and the Hessle boulder-clay of England belong to the same period. This has been clearly shown by Professor J. Geikie in his 'Great Ice-Age,' chapter xxx (2d edition), and in 'Prehistoric Europe,' chapter xii, and elsewhere. The Hessle boulder-clay is, in short, a continuation of the Upper Till of Scotland.

The position of these Hessle beds to which Mr. Wallace refers, like that of the interglacial beds of Scotland, is between two boulder-clays—the Hessle and the Purple boulder-clays, both of which indicate a period of extreme glaciation; only the Purple boulder-clay period was somewhat the more severe of the two. At both periods the greater part of northwestern Europe was buried under ice. We know that during the last great ice-period, which was undoubtedly the period of the Hessle boulder-clay, the ice-sheet reached in North Germany as far as Berlin; while during the period of the Purple boulder-clay it advanced to about Saxony.

The observations of Professor Torrell, Dr. A. Penck, Professor Credner, Professor Berendt, Dr. Jentzsch, A. Helland, F. Wohnschaffe, H. Habenicht, and other geologists have shown that there are in North Germany three distinct boulder-clays—an Upper, Middle, and Lower, with two series of interglacial beds. In these interglacial beds have been found organic remains which evidently indicate a mild and genial condition of climate. The younger interglacial period (the one prior to the last great extension of the ice) in all probability corresponds to the last interglacial period of Scotland, England and Ireland. Interglacial beds belonging to the same period have been found in Switzerland, Italy, Denmark, North America, and other places, all indicating a mild and equable condition of climate.

There is another class of facts, almost entirely overlooked, which prove even more conclusively the warm character of interglacial periods. These facts will, however, be more appropriately discussed when we come to consider the question of warm polar climates.

It would be impossible within the limits of the present paper to give even the briefest outline of the recent discoveries in regard to interglacial periods. But though this were possible it would be wholly unnecessary, as the facts which have already been adduced by Mr. Wallace himself are perfectly sufficient for our present purpose.

If now it be true, as it undoubtedly is, that the Hesse boulder-clay of England belongs to the same age as the Upper Till of Scotland, and that the last warm interglacial period, when the *Cyrena fluminalis* and *Unio littoralis*, the hippopotamus, the *Elephas antiquus*, and other animals of a southern type lived in England, occurred between two glacial periods so severe as to envelop the greater part of northwestern Europe in a continuous sheet of ice, then this particular interglacial period must have intervened during a high state of eccentricity, and not, as Mr. Wallace assumes, at a period subsequent to the Glacial Epoch proper, when the eccentricity had greatly diminished. This is obvious; for if the last great ice-sheet could have been produced without a high state of eccentricity, then there seems no reason why the one preceding it should not also have been produced without high eccentricity. If so, then all the previous ice-sheets may in like manner have been so produced. For the difference in magnitude between the last and penultimate ice-sheets was not so great as to warrant the supposition of any considerable difference in the amount of eccentricity at the two periods when these ice-sheets were respectively developed. In short, if the last great ice-sheet can be explained without the supposition of a high state of eccentricity, then there does not appear to be any real necessity for any theory of eccentricity in accounting for the Glacial Epoch.

If we adopt the Physical theory of the cause of the Glacial Epoch, we are compelled to maintain that the last two great Ice-periods were the indirect results of a high state of eccentricity, and in this case we can hardly avoid the conclusion that the mild intervening period was due to the same cause. The occurrence of a mild interglacial period between the two ice-periods is directly in opposition to Mr. Wallace's view that during a high state of eccentricity the ice would not disappear but be continued. It is in perfect harmony, however, with that which I advocate; for during high eccentricity a mild and equable condition of climate, when the winters occur in

perihelion, is as much a necessary result as a cold and glacial condition when they occur in aphelion.

The facts of Geology thus to me appear so far to be as much opposed to Mr. Wallace's modifications as are the principles of Physics.

Difficulty in detecting the Climatic Character of the earlier Interglacial Periods.—It follows according to theory that, other things being equal, the greater the amount of eccentricity the more equable and mild will the interglacial periods be. It is probable therefore that some of the earlier interglacial periods were milder and more equable than the last. It may be difficult in the present state of our knowledge to prove this conclusion by direct geological and paleontological evidence; but, on the other hand, it is certainly impossible to disprove it by that means. The absence of deposits containing organic remains indicative of a superior mildness of climate having obtained during early interglacial periods cannot certainly be regarded as satisfactory evidence against the conclusion just referred to. When we consider the enormous pressure and destructive power of an ice-sheet some 2000 or 3000 feet in thickness grinding down the face of a country, our surprise is that so much evidence remains of even the last interglacial period. That so few relics of the flora and fauna of preceding interglacial periods have been preserved is a conclusion which we might *a priori* anticipate. This fact has been clearly pointed out by Mr. Wallace himself, who says:—"If there have been, not two only, but a series of such alternations of climate, we could not possibly expect to find more than the most slender indications of them, because each succeeding ice-sheet would necessarily grind down or otherwise destroy much of the superficial deposits left by its predecessors, while the torrents that must always have accompanied the melting of these huge masses of ice would wash away even such fragments as might have escaped the ice itself" (p. 118).

When we pass beyond the limits reached by the ice-sheets of the Glacial Epoch we may expect, of course, to find the remains of many of the plants and animals which lived during the earlier interglacial periods. But here, again, we encounter another difficulty; for we have in this case seldom any means of determining the age to which these remains belong. Unless in relation to overlying and underlying bowlder-clays, there seems in many cases no way of knowing to what interglacial period they ought to be assigned; or, in fact, whether they are really interglacial or not. If the remains in question indicated a condition of climate much milder than the present, the probability is that they would be classified as preglacial. I fully agree with Prof. J. Geikie, that many of those plants

and animals of a southern type which have been regarded as Preglacial are in reality of Interglacial age.

Objection as to the number of Interglacial Periods.—It has been urged as an objection to the Physical theory of the Glacial Epoch, that according to it there ought to have been more interglacial periods than we have direct evidence of having actually occurred. I am doubtful as to the force of this objection. I do not think that there could have been more than about five well-marked interglacial periods during the entire Glacial Epoch; three probably during the former half of the epoch, and certainly not more than two during the latter half. There would be a large interval between the two maxima of eccentricity of 100,000 and 200,000 years ago, when the alternations of climate would be comparatively moderate in extent. Besides it is not correct to assume, as is generally done, that the interval between two consecutive interglacial periods is only 21,000 years; for the mean rate of motion of the perihelion during the Glacial Epoch was considerably less than has been assumed. It will be seen from the table of the Longitude of the Perihelion, given in 'Climate and Time,' p. 320, that it has taken the perihelion 231,000 years to make one complete revolution.

If, therefore we assume, what of course is not certain, that mean rate of precession during the Glacial Epoch to have been the same as the present, then the rate of precession to that of the perihelion's motion would, in this case, be as 9 to 1. The equinoxial point will take 25,811 years to make one revolution; but as the perihelion moves in the opposite direction, it will reduce the time taken by the point in passing from perihelion round to perihelion to 23,230 years, which will represent the mean interval between two consecutive interglacial periods. But as the motion of the perihelion was very irregular, the length of the interval between the periods would of course differ considerably.

When we consider how difficult it must be to detect in the drift covering glaciated countries even a relic of early interglacial deposits, and when moreover we remember that it is only within the past few years that geologists have begun to bestow any attention on the subject, it is certainly not surprising that direct geological evidence of so few interglacial periods has as yet been discovered. In England, geologists have, however, already detected evidence of three interglacial periods with four or five ice-periods. In Germany, quite recently, two interglacial periods and three or more ice-periods have been recognized by competent observers. In Denmark there are four boulder-clays separated by intercalated beds of sand and clay. In severely glaciated Scotland, where traces of former interglacial

periods can hardly be expected, there have nevertheless been found in old preglacial buried channels and other sheltered hollows three, four, and in some places five, boulder-clays, separated from one another by immense beds of sand, gravel and clay. Some of these beds are found to be continuous for long distances. It is true that these intercalated beds have yielded few or no organic remains, but it may well be that further research will yet result in the discovery of more abundant fossils; for frequently the beds in question are too thick and too extensive to allow us to infer their subglacial origin. They do not in such respects resemble the deposits which have been accumulated by aqueous action under ice, but have all the characteristics of deposits which have been laid down in lakes and lacustrine hollows. As some have already yielded organic remains, a more extended scrutiny will probably lead to the discovery of similar fossils in those beds which are at present believed to be unfossiliferous.

Interglacial Periods less strongly marked in Temperate Regions than Glacial.—I quite agree with Mr. Wallace that the interglacial deposits never exhibit any indication of a climate whose warmth corresponded to the severity of the preceding cold. This, however, cannot be urged as an objection, for it is a result which follows as a necessary consequence from theory. It theoretically follows that the cold of the glacial periods will not only exceed in severity the heat of the interglacial, but will also be of longer duration. During the glacial periods extreme cold is the characteristic of the winters, which, owing to the presence of snow and ice, only becomes moderated, although, of course considerably, during the summers. But, on the other hand, during interglacial periods mildness and equability of temperature rather than heat are the characteristics both of summer and winter.

That the cold of the glacial periods must have continued longer than the warmth of the interglacial will, I think, be apparent from the following considerations. As long as a country remains permanently covered with snow and ice, the climate, as has been repeatedly shown, must continue cold, no matter what the direct heat of the sun may be. Astronomically considered the interglacial periods are, of course, of the same length as the glacial,—the mean length of which, during the Glacial Epoch, was about 11,600 years; but the cold of a glacial period would not, as we shall presently see, actually terminate at the end of the period, but would be continued on probably for centuries into the succeeding interglacial period. Suppose that during a glacial period the country is covered with a sheet of ice, which during the continuance of the period had accumulated to the thickness of 2000 or 3000 feet. All this enormous quantity of

ice would have to be melted off the ground before the warmth of the interglacial period would commence. So long as a single inch of ice covered the surface of the country, the cold would continue. Ice, as we have seen, by chilling the air induces fresh snow to fall; and of course it is only when the amount of ice annually melted exceeds that being formed from the falling snow, that a diminution in the thickness of the sheet would begin to take place. A real melting of the ice, and consequent decrease in the thickness of the sheet, would probably not commence till the astronomical and physical agencies in operation during the glacial period began to act in an opposite direction. In short, it would be the favorable conditions of the interglacial period that would effectually remove the ice; and it would be then, and only then, that the warmth would begin. While, again, at the close of the period, when the first inch of ice made its appearance on the surface of the country, the interglacial condition of climate would come to an end. The time required to remove the ice does not prevent an interglacial condition of climate; it only somewhat shortens its duration.

There is another circumstance worthy of notice here. It is this: as the mild and equable character of the climate during interglacial periods resulted to a large extent from the enormous transference of equatorial heat, and its distribution over temperate and polar regions, the difference of climatic conditions between the subtropical and the temperate and polar regions would be less marked than at present; in other words, the temperature would not differ so much with latitude as it does at present. This, as we have seen, is a conclusion which is fully borne out by geological and paleontological facts.

The question as to the probable cause of warm polar climates will next be considered.