THE GLACIAL PERIOD

AND

OSCILLATION OF THE LAND.

BY

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THE CONNECTION OF THE GLACIAL PERIOD WITH OSCILLATION OF THE LAND, ESPECIALLY IN SCANDINAVIA.

By Dr. NILS OLOF HOLST. Translated by F. A. BATHER, D.Sc.

[In a recently published paper[1] Dr. N. O. Holst, of the Geological Survey of Sweden, has given a detailed description of the Post-Glacial deposits of the Baltic Sea and the Gulf of Bothnia. The paper is accompanied by a map showing the chief points of observation. The determination of the different horizons depends on (1) the stratigraphy; (2) the sub-fossil diatomaceous flora; (3) the sub-fossil higher flora. The stratigraphical evidence is in the form of numerous sections, taken all along the coast. The diatoms are used chiefly, but not solely, to distinguish the marine from the fresh-water deposits; their determinations, nearly 3,000 in number, are due to Professor P. T. Cleve and his daughter, Dr. Astrid Cleve. The remains of the higher plants have been determined by Dr. Gunnar Andersson.

The fresh-water (*Ancylus*) epoch and the salt-water (*Litorina*) epoch are divided by the author as follows:—

1. The oldest *Ancylus* epoch, the deposits of which age in southern Sweden partly are barren, partly contain Arctic plants.

2. The middle *Ancylus* epoch, of which the deposits contain the remains of fir and birch. During this epoch the land-ice melted away from the lower parts of central Sweden, and the sea came into the Baltic, making the water temporarily salt.

3. The youngest *Ancylus* epoch, or the older half of the oak epoch.

4. The *Litorina* epoch, or the younger half of the oak epoch, when the present communication with the sea was opened, and the water of the inland sea, which during the *Ancylus* epochs had been fresh as a rule, now became salt.

The fact that the climate became temporarily colder in the middle of the *Litorina* epoch is established by finds of boreal diatoms: *Navicula semen*, *N. amphibola*, *Pinnularia streptoraphe*, etc.

Wider interest attaches to the concluding pages (113 et sqq.), in which the author deals with the question of oscillation of the land in Scandinavia and with the explanation of the Glacial Period, on which matters he expresses some new views. We therefore offer a full translation of this part of Dr. Holst's memoir.]

I HAVE elsewhere[2] shown that the events immediately connected with the melting of the Scandinavian land-ice occurred in rapid succession. The same was the case with the oldest Post-Glacial events. Thus it has been demonstrated in the present paper that the Glacial marine clay and sand, deposited along the present coast

[1] "Bidrag till kännedomen om Östersjöns och Bottniska Vikens postglaciala geologi": Sveriges Geologiska Undersökning, Afhandl., ser. C, No. 180. 8vo; 128 pp., 1 map; 1899 (published March, 1901).

[2] N. O. Holst, "Har det funnits mer än en istid i Sverige?": Sver. Geol. Unders., 1895, ser. C, No. 151, see pp. 36–39. German translation by W. Wolff, "Hat es in Schweden mehr als eine Eiszeit gegeben?" pp. 38–42; Berlin, 1899.

of Blekinge and of the Kalmar district, were exposed by elevation of the land and were weathered before the deposition of Post-Glacial beds upon them had begun. It was this elevation of the land that connected Scania with Denmark and permitted the immigration of the larger land animals.[1] It appears as though not only this elevation, but also the succeeding depression, during which the oldest *Ancylus* beds were deposited in the government districts of Blekinge and Kalmar, took place in the former district before the Arctic plants had found time to immigrate thither. But when this depression reached the neighbourhood of Kalmar, the Arctic plants were already there. In Blekinge and the Kalmar district there followed an elevation, probably of less importance, and it was not until the succeeding depression, which marks the beginning of the middle *Ancylus* epoch, that southern Sweden saw the deposition of beds that can be paralleled with the oldest Post-Glacial beds of central Sweden. But these latter lie without break conformably on the Glacial beds. This implies that southern Sweden incurred two elevations and their succeeding depressions, in which central Sweden had no share. No explanation of these facts is more natural than that *southern Sweden, relieved of its ice-load, rose*[2] *and began to oscillate, while the land-ice continued to keep central Sweden depressed.* In other words, this means that there was a clear and definite connection on the one hand between the weight of the land-ice and the depression of the land, on the other hand between the removal of the weight and the elevation of the land. But this is a result pregnant with the most important consequences for the whole of glacial geology.

It is clear that the depression, if dependent on the weight of the land-ice, should yield evidence of having been greater the nearer one comes to the centre of the ice; in other words, the nearer one comes to those regions where the ice-load was greatest. A glance at a map indicating the extent of the depression shows at once that such was the case.[3] While in the south the curve of depression

[1] That the aurochs already existed in the province of Kalmar at the beginning of the fir period, i.e. at the beginning of the middle *Ancylus* epoch, has been proved on a preceding page. But the only Post-Glacial elevation of importance that occurred in southern Sweden before that period was the very one that immediately followed the deposition of the Glacial marine beds.

[2] It is quite probable that this elevation during the oldest Post-Glacial Period also reached northern Germany. If such was the case, may it not in part have been the reason why the Vistula and Oder during that period did not flow into the Baltic but had their outlet through the Elbe? Cf. F. Wahnschaffe, "Die Ursachen der Oberflächengestaltung des norddeutschen Flachlandes"; Stuttgart, 1891.

It is also very probable that the same upward pressure of the land outside the periphery of the land-ice took place in North America, and that this affords the correct explanation of many phenomena which otherwise appear inexplicable.

[3] See Gerard De Geer, "Om Skandinaviens geografiska utveckling," 2. Kartor, pls. 2, 3, 4; Stockholm, 1896. The criticism must, however, be passed on these plates that they do not, as they profess, give the depression-curves for different epochs of the melting of the ice, but that all three show only the same thing, namely, the extent of the depression at the time of the final melting of the ice. According to the plates, the depression during the melting of the ice remained the same for a long period, while, on the contrary, all the facts tend to prove that throughout that time the extent of the depression altered very rapidly.

that crosses the southern Baltic, and in the east that which passes by the southern end of Lake Ladoga, both mark zero, as one proceeds from south to north or from east to west the curves mark higher and higher numbers, until the greatest depression known, so far as established by tracing the highest Glacial marine coastline, attains in northern Sweden no less than 280 metres.[1] Lately, indeed, it has been said that in Norrland the Glacial marine coastline is at a lower level in the interior than near the present coast. But if that is the case, we may recall the fact that the highest Glacial coastline was formed at different times in different places. It is therefore quite possible that the apparently abnormal conditions in Norrland spring from nothing else than the formation of the Glacial coastline, first at the coast and afterwards at the interior, for the simple reason that "the ice did not melt from the interior of Norrland until the elevation had been in progress for some time."[2] The conditions in Norrland are therefore in no way opposed to the rule that increased depression and increased ice-load point in the same direction.

Scandinavia under its load of land-ice may be compared to a depressed spring. When the load is removed the land tends to resume its original position. This explains the great rapidity with which the land rose at the close of the Ice Age, a rapidity for which in my above-quoted paper of 1895 I gave conclusive evidence, although I then did not fully understand what caused the rapid rise of the land. But although this demands a certain elasticity in the crust of the earth, yet it cannot be supposed that this elasticity was so great as to permit the land, pressed down as it was during a large part of the Ice Age, to regain the state of equilibrium in which it was at the beginning of the Ice Age; some of the upward tension must in the meantime have been neutralized. The highest Glacial marine coastline therefore marks only the final result of the depression at the moment when the ice melted. Now the position of this line no less than 280 metres above sea-level is alone enough to show that the depression was considerable. But for the reason just mentioned this height indicates *only a part* of the Glacial depression. This line of argument has already led us to the conclusion that at the beginning of the Ice Age Scandinavia lay much higher than now. But that this elevation was in itself enough to afford a simple and natural explanation of the Glacial Period will be proved in the sequel by more conclusive evidence.

From what has been said it is clear that the Glacial and Post-Glacial changes of level in Scandinavia (and the same applies to North America) are due to a special cause, and therefore cannot be compared with volcanic or continent-building oscillations. All attempts to generalize from such comparisons are foredoomed to failure.

[1] A. G. Högbom, "Till frågan om den senglaciala hafsgränsen i Norrland": Geol. Fören. Stockholm Förhandl., 1899, xxi, p. 595.

[2] A. G. Högbom, "Om högsta marina gränsen i norra Sverige": Geol. Fören. Stockholm Förhandl., 1896, xviii, p. 488.

No better success has attended the attempts to discover the cause of the Glacial Period in directions other than that here indicated. Especially is this true of the struggles after some far-fetched astronomical explanation of this terrestrial phenomenon. The geologist who perambulates the universe in search of such explanations may be likened to an erudite bookworm who turns his study upside down in search of his pencil, which all the time is behind his ear.

To the view here stated as to the cause of changes of level in Glacial and Post-Glacial times, I have been led by my own researches, and my ideas already tended in this direction before I realized that T. F. Jamieson, and other geologists after him, had expressed views almost identical with my own. Subsequently I have perused Jamieson's writings on this subject more closely, and, with sincere admiration for his acumen, have found that so early as 1865,[1] supported by comparatively few observations, he put forward the leading idea which in 1882[2] he developed in more detail, and which, confirmed as it now is by more numerous observations, can without hesitation be accepted as the only correct one.

From the papers by Jamieson I think it right to make the following instructive extracts :—

"It has occurred to me [Jamieson] that the enormous weight of ice thrown upon the land may have had something to do with this depression [the great glacial depression]. . . . . We don't know what is the state of the matter on which the solid crust of the earth reposes. If it is in a state of fusion, a depression might take place from a cause of this kind, and then the melting of the ice would account for the rising of the land, which seems to have followed upon the decrease of the glaciers." (Q.J.G.S., loc. cit.)

"Assuming the specific gravity of the ice to have been 875, compared with water as 1,000, or in other words to have been seven-eighths of the weight of water, then the weight of a mass of ice 1,000 feet thick would be 378 pounds to the square inch, or equal to fully 25 atmospheres, and would amount to 678,675,690 tons on every square mile. If the ice was 3,000 feet thick, it would at this rate amount to over 2,000 million tons on the square mile." (GEOL. MAG., t.c., p. 403; Jamieson here quotes some geologists who have supposed that the thickness of the ice has been much greater, and then he continues as follows :—) "It is evident that a thickness of even 3,000 feet of ice will give us a weight by no means despicable, a weight which would require a marvellous rigidity indeed in the earth beneath it to sustain such a load without yielding in some degree" (p. 404).

"That the crust of the earth is flexible and elastic the phenomena of earthquakes sufficiently demonstrate. The surface heaves like the billows of the sea, sometimes causing trees to bend so as to

[1] T. F. Jamieson, "On the History of the last Geological Changes in Scotland": Quart. Journ. Geol. Soc., 1865, xxi, p. 178.

[2] "On the Cause of the Depression and Re-elevation of the Land during the Glacial Period": GEOL. MAG., 1882, Dec. II, Vol. IX, pp. 400 and 457.

touch the ground with their tops, or tossing up flagstones into the air so as to make them come down bottom upwards," etc. (p. 404.)

"If upheavals and depressions of the land have not been caused by changes of pressure, it may be asked, what is it they have been caused by?" (p. 405.)

"If beneath that part of the surface which was affected by the heavy pressure of the ice, there happened to be a quantity of lava in a fluid state, the result might be to cause an outburst of the lava to take place at some more distant point. This would relieve the tension and lead to a permanent depression of the ice-covered area. For example, in North America the great fields of ice that lay on certain portions of that continent by their downward pressure may have occasioned some of those extensive eruptions which seem to have taken place in the region of California after the commencement of the Glacial period. The volcanic phenomena of Iceland in like manner may have been affected by similar causes. That there has been a considerable permanent depression of some of the most heavily glaciated regions since the commencement of the Glacial period, I think there is much reason to believe. The features of the fjord districts of Norway and the West Highlands of Scotland, and of British Columbia, for example, seem to show this; for these coasts have all the appearance of depressed mountain lands, which have been cut and carved by streams and glaciers far beneath the present level of the sea." (p. 405.)

"It seems likely that there might be a tendency to bulge up in the region which lay immediately beyond this area of depression; just as we sometimes see in the advance of a railway embankment, which not only depresses the soil beneath it, but also causes the ground to swell up further off." (p. 461.)

So far Jamieson. His ideas have, before me, been shared by Whittlesey, N. S. Shaler,[1] and Warren Upham,[2] the last-mentioned having developed them further. Upham calls our special attention to the indisputable glacial formations that date from the Carboniferous or Permian periods, as that in South Africa at 30° S. lat.,[3] in India at only 20° N.,[4] as well as in Australia,[5] and he correlates these phenomena with the mountain-building that took place during that time. Of the glaciated areas here mentioned I have myself visited that in Australia, in the neighbourhood of Bacchus Marsh, just west of Melbourne (37°–38° S.), and can confirm the correctness of the descriptions given. Here occurs a typical boulder-clay, of blue

[1] "Fluviatile Swamps of New England": Amer. Journ. Sci., 1887, ser. III, vol. xxxiii. See pp. 220, 221.

[2] "Probable Causes of Glaciation," Appendix A to G. F. Wright's "The Ice Age in North America"; New York, 1891. See also Amer. Geol., 1890, pp. 327 et sqq.; and Amer. Journ. Sci., 1891, vol. xli, p. 33.

[3] A. Schenck, "Ueber Glacialerscheinungen in Südafrika": Verhandl. des VIII deutschen Geographentages in Berlin, 1889.

[4] R. D. Oldham, "A Manual of the Geology of India," Calcutta, 1893. See pp. 157 and 198.

[5] T. W. E. David, "Evidences of Glacial Action in Australia in Permo-Carboniferous Time": Quart. Journ. Geol. Soc., 1896, lii, p. 289.

colour, containing glacially striated stones of many kinds of foreign rocks. This boulder-clay is overlaid by sandstone with *Gangamopteris*, belonging to the Carboniferous or the Permian system. What cast suspicion on the glacial deposits of Australia was the great thickness ascribed to them, namely, as much as 5,000 feet. But this estimate, which sounds so fantastic, is really founded on a mistake that arose in the following way:—In the valley where this thickness was calculated the morainic beds are obliquely inclined one above the other. By measuring each of these beds and adding the apparent thicknesses together a total was obtained which naturally was not the true vertical thickness. That this in reality is not so extraordinarily great is clear from the fact that the solid Silurian rock crops out both at the bottom and on the side of the valley in question. For a 5,000 foot thick moraine to find room between these outcrops, it must lie in a very deep hollow of most unusual and inexplicable shape.

For my part I think Upham must be accounted right in his contention that the glacial phenomena of South Africa, India, and Australia can be explained only on the supposition that these districts formerly lay much higher than now. Especially does this apply to the Indian glacial district, situate only 20° from the equator. There is no place here for the interglacialist hypothesis, and if a former elevation be not admitted for this district we may justly ask what else can have produced glacial phenomena so near the equator. On the other hand, we may adduce the fact that Kilima Ndjaro in East Africa, said to be about 6,000 metres high, exhibits glaciation although only 3° from the equator.

But if an elevation of the land in equatorial regions can produce glaciers, what glacial results may we not expect from an elevation in the latitude of Scandinavia, Greenland, and North America? The question is reduced to this: Can we show that during Quaternary times such an elevation really did take place in the three great glacial districts? It is as a rule difficult to prove former elevation of the land if the region once raised now lies sunk below sea-level; but in proportion as the oceans that bound North America and Scandinavia have been more closely investigated this proof has been forthcoming, and a considerable elevation of Quaternary age is now fully established both for North America and Scandinavia.

As regards North America, many geologists, of whom I shall cite only J. W. Spencer,[1] have demonstrated that the larger rivers on the eastern side of the continent, from the Mississippi up to the St. Lawrence, have channels clearly excavated beyond the coast to a depth below the sea of "3,000 feet or more"; and this naturally indicates that formerly the land was elevated to a corresponding height. Similar observations have been made on the Pacific coast of North America. That this elevation took place at a relatively recent period follows from the fact that the submarine channels are not filled up as they would otherwise have been.

[1] "The High Continental Elevation preceding the Pleistocene Period": Bull. Geol. Soc. Amer., 1890, i, p. 65.

Like observations have been made on the coast of Norway, where the deep fjords continue as submarine valleys beyond the present coast to a great depth. For these to have been carved out by the rivers of a past age, the land must of course have lain much higher than now. The so-called 'Norwegian Channel,' if, as is probable, it represents an ancient river-bed, proves the same thing.

The Scandinavian Pre-Glacial elevation, however, was not confined to the coast of Scandinavia, but evidently affected a large part of the bottom of the present North Atlantic, both westwards to the east[1] coast of Greenland and southwards to the south part of England. So far as Great Britain is concerned this elevation is undeniable. The mere existence in this country of a Pre-Glacial mammalian fauna, obviously exterminated by the Ice Age[2] and partly reminiscent of more southern regions (elephants of various species, mammoth, mastodon, lion, hyæna, etc.), is enough to presuppose a land-connection between the continent and England and Ireland, so that the animals could cross to these islands.[3] But these mammals did not merely *wander across* the English Channel and the southern parts of the North Sea; they also *inhabited* the districts now sunk beneath the waters, as may be inferred from the "almost incredible" "quantity of teeth and bones belonging to the mammoth, woolly rhinoceros, horse, reindeer, and spotted hyæna, and other animals, dredged up by the fishermen in the German Ocean" (op. cit., p. 365). That the animals lived here at no distant date follows from the fact that their bones are found on the very surface of the sea-floor, as well as from the mixture of remains of Pre-Glacial animals with those of the reindeer, as to whose contemporaneity with the Ice Age there can be no doubt. Finds of this boreal species on the floor of the North Sea show further that the elevation still existed when the Glacial Period was setting in.

Furthermore, submarine peat-bogs along the coast of England, as well as the discovery of the fresh-water bivalve, *Unio pictorum*, and *shore* shells at a greater depth than 200 feet in the English Channel (op. cit., p. 364), bear clear witness to an elevation of the land in Quaternary times.

But the depth of the English Channel and of the southern part of the North Sea is not very great—at the southern end of the Dogger Bank not more than 13–16 metres—and a raising of the sea-bottom from 30 to 50 metres would be enough to bring a large

[1] 'Västra' (west) in original; correction by the author.

[2] H. H. Howorth, "Did the Mammoth live before, during, or after the Deposition of the Drift?": GEOL. MAG., 1892, Dec. III, Vol. IX, pp. 250 and 395.

In England the so-called interglacial occurrences of the larger mammals seem to rest only on mistakes or on the estimation of secondary occurrences as primary. Of course they disappear at the same time as the so-called 'interglacial' deposits cease to be interpreted as interglacial, and this is already the case with the majority. Thus the 'middle sand,' formerly the most important of the interglacial formations, is now very generally regarded as glacial. And, so far as I could discover from conversation with English geologists, the idea of a true 'interglacial' period is now almost abandoned by them.

[3] W. Boyd Dawkins: "Cave Hunting, etc."; London, 1874. See p. 362.

part of it above the surface. It may therefore be objected that, even though the land-connection in question may really have existed, still it is in itself no proof of any considerable elevation, certainly not of one great enough to explain the severe climate of the Glacial Period. And this, no doubt, is perfectly true.

But there are other evidences for a much greater elevation in the north-west of Europe. That the agreement between the floras of Scandinavia, Scotland, the Faeroes, Iceland, and Greenland necessarily presupposes a land-connection in Quaternary times, has been long understood. Such a connection involves an elevation of the sea-floor between Scotland and Greenland of about 3,000 feet (891 metres).[1] But did such an elevation really take place during the Quaternary Period? Conclusive proof of it was given by A. S. Jensen,[2] when he demonstrated the logical consequences of the discoveries made by the Ingolf expedition in 1896 during the investigation of the sea-floor between Jan Mayen and Iceland. Here the expedition found at a great depth, reaching as much as 1,309 Danish fathoms,[3] such *shallow*-water bivalves as *Astarte Banksii, A. borealis, A. compressa, Cardium ciliatum, C. groenlandicum, Cyrtodaria siliqua, Macoma calcaria, Saxicava arctica,* and *Yoldia arctica.* These marine molluscs, which can live only at small depths, according to Jensen in not more than 100 fathoms of water, occur in great numbers, and it is quite clear that they have lived where their shells now are met with. These discoveries therefore prove that the sea-bottom between Scandinavia and Greenland once lay more than 1,200 fathoms (2,138 metres) higher than now. As for the date of the elevation, Jensen justly observes that the occurrence of *Yoldia arctica* is enough to show that it took place during the Glacial Period. During which part of that period the elevation existed is not discussed by Jensen, but it is most reasonable to refer it to the beginning of the period, when an elevation is established both for England and Scandinavia.[4] If this elevation started from the Archæan district of Scandinavia and of Greenland, as there is good reason for supposing, then the elevation of Scandinavia must have been greater than that demonstrated by Jensen for the sea-floor between Scandinavia and Greenland. But if the elevation was only of the same, or even approximately the same magnitude, it was still quite enough to afford an explanation of the Glacial Period itself.

But this elevation of the sea-floor between Scandinavia and Greenland carried with it another important consequence, in that it changed this part of the ocean into an inland sea, comparable with the Mediterranean, and united with the body of the Atlantic only by the deep channel between the Shetlands and Faeroes.[5]

[1] See the map to W. H. Hudleston's paper "On the Eastern Margin of the North Atlantic Basin": Geol. Mag., 1899, Dec. IV, Vol. VI, p. 97.

[2] "Om Levninger af Grundtvandsdyr paa store Havdyb mellem Jan Mayen og Island": Vidensk. Meddel. Naturhist. Foren. Köbenhavn, 1900, p. 229.

[3] 8,087 English feet; 2,465 metres.—Translator.

[4] The same elevation also reached Iceland. See Th. Thoroddsen in Geol. Fören. Stockholm Förhandl., 1900, xxii, p. 546.

[5] Cf. Hudleston's map cited above.

From this in turn it followed that the Gulf Stream was completely shut off from the Arctic Ocean and forced to turn south and west of the British Isles, and thus to concentrate its heat-giving energy on central Europe. This explains the mild climate found in a portion of Europe during a stage of Pre-Glacial time.

As shown above, it may be considered as a fact confirmed by known phenomena, that at the beginning of the Quaternary Period portions of the North American continent lay at least 1,000 metres, and Scandinavia still more, perhaps 2,000 metres, higher than now. As for the intervening Greenland, it seems probable that it could not be unaffected by these changes of level, but that it took part in them.[1]

We meet here the legitimate question: What is it that produced such a great elevation in these particular parts of our earth? The answer is that North America, Greenland, and Scandinavia, not merely taken together, but each separately, are the largest areas of Archæan rocks in the world.[2] The remarkable coincidence of the great glaciated districts with the Archæan districts has long since been commented on as peculiar. No explanation, however, has been given of this fact. What it really means I shall here show.

During the Silurian Period Scandinavia was partly covered by the sea, as clearly proved by the numerous patches of Silurian rock. Possibly the same was the case during a part of the Devonian Period. But before the close of that period Scandinavia rose above the water, and probably went on rising right up to the Quaternary Period. At all events the Archæan area of Scandinavia never again sank beneath the sea, as clearly demonstrated by the absence of younger marine formations from within its boundaries. Examination of a geological map of Europe shows that the shore of the later Palæozoic, and still more that of the Mesozoic, sea moved eastwards further and further away from Scandinavia, which seems to imply that, during the long ages that elapsed after the Silurian (or Devonian) Period, Scandinavia continually rose, and involved in its rise a part of the surrounding area.

The course of events on the North American continent was precisely the same. Here the shore of the later Palæozoic and Mesozoic sea moved southwards ever further and further from the rising Archæan area of the north.

On what can this harmony of events have depended?

If so late as the Quaternary Period the crust of the earth was found to yield to the pressure of the land-ice, still more must it have yielded to burdens during the earlier stages of the earth's development. That this was actually the case is shown in Scandinavia itself by numerous instances from Cambro-Silurian times. For some years it has been well known that faults, often accompanied

[1] During my journey to Greenland in 1880 I saw from the sea south of Ivigtut supposed beaches in a situation exposed to the sea at a great height on the mountain slopes. Time, however, did not permit me to examine them. Numerous similar observations are mentioned in "Meddelelser om Grönland."

[2] See Berghaus' "Physikalischer Atlas," Maps 7/8, 9, and 13; Gotha, 1892.

by breccia-formation, may be observed in Scandinavia at many points on the boundary-line between the Archæan and Cambro-Silurian deposits, as on Bornholm, in Scania, on Lake Vetter, in Ostrogothia, Nerike, Dalecarlia, Gestrikland, Jemtland, on the Christiania fjord, on the Kola peninsula, and other places.[1] Even the quite insignificant occurrence of Silurian at Humlenäs in the province of Kalmar can show a similar fault with accompanying breccia-formation. For my part I do not think that any explanation of these phenomena will ever be found more satisfactory than that the earth's crust, which during the Cambro-Silurian periods was much thinner than now, yielded beneath the weight of the Cambro-Silurian sediments. If such were the conditions, we can also understand the immense thickness which the Palæozoic rocks occasionally attain, and which may have arisen by the gradual sinking of the sea-floor in proportion as the formation of sediment proceeded.[2]

But if sedimentation tends to depress the earth's crust, and actually has depressed it in certain places, then to such a sinking there must have corresponded elevation in another place[3]; and it is precisely this elevation above all that has affected the Archæan areas, and particularly the greater ones — those that could, so to speak, move independently—because these areas have not merely formed the thinnest parts of the crust, but have lacked the strengthening influence of the stratified deposits.

This, then, seems to have been the way in which elevation of the Scandinavian and North American Archæan areas was brought about and carried on, until at the beginning of the Glacial Period they had reached such a height that each formed the centre for an ice-sheet.

If the conception put forward in the preceding pages is the right one, it follows that the phenomena which accompany the appearance of an ice-sheet involve such radical and manifold changes within the glaciated area that an Ice Age cannot, so to say, come and go unmarked, but must leave the most obvious traces behind it. Therefore it is that the idea here propounded is utterly opposed to the interglacialist view, and therefore it has been attacked by champions of the latter.[4] The chief objection raised by them to the present explanation of the Ice Age is the following.

Granted, they say, that this might be quite a satisfactory explanation of the Scandinavian, Greenland, and North American ice-sheets, still it is not enough to explain the former small glaciated areas in the Pyrenees, the Alps, the Caucasus, and so forth. To

[1] See "Generalregister" to vols. vi–x of Geol. Fören. Stockholm Förhandl., p. 34.
A fault in Jemtland is described by A. Högbom in his paper, "Om förkastningsbreccior vid den Jemtländska silurformationens östra gräns": Geol. Fören. Stockholm Förhandl., 1886, viii, p. 352.
The Palæozoic faults on the Kola peninsula have been described by W. Ramsay, Fennia xvi, No. 1, pp. 2 and xv; No. 4, pp. 7 and 11.

[2] The same views were expressed by James Hall in the "Palæontology of New York," iii, pp. 69 et sqq.; Albany, 1859.

[3] Cf. J. Hall, op. cit., p. 95.

[4] J. Geikie: "The Great Ice Age," 3rd ed., p. 792; London, 1894.

this, however, it may be replied that these smaller peripheral glacial areas were perhaps directly due to the general sinking of temperature produced by the North European ice-sheet during its maximum extension.

That such a fall in temperature really took place may be considered as proved by the fact that so boreal an animal as the reindeer, during a part of the Glacial Period, had a wide distribution in southern Europe. And, as regards the cause of the smaller peripheral glaciated districts, it may once more be recalled that if a mountain chain be sufficiently raised, no matter by what cause, a glaciated area may be produced when and where you please.

But there is another objection, which, at first glance, seems more weighty. Besides the oscillations of Glacial age, there have in Sweden also been some of Post-Glacial age, partly during the *Ancylus* period, partly during that of *Litorina*. Now, if the pressure of the land-ice and the removal of that pressure afford a valid explanation of the former—and it can hardly be denied that such is the case—still it seems quite impossible that they can explain the latter. Surely the ice-sheet cannot produce oscillations of level some ten thousands of years after its disappearance. So no doubt it seems; and yet this is exactly what the ice has done.

Nowadays it is well known that the Glacial and Post-Glacial areas of depression almost entirely coincide. Not only do the zero curves on the periphery of these areas follow the same course, but the maxima or centres themselves are on the whole the same.[1] It is only the amount of the depression that was different, the Glacial sinking reaching 280 metres, the *Ancylus* sinking exceeding 200 metres (?), and that of the *Litorina* period being about 100 metres.[2]

The conformity now demonstrated between the Glacial and Post-Glacial changes of level points to a common cause. This has long since been perceived, and A. G. Högbom, who remarked the fact, expressed it as follows: "The same factors have governed the oscillations of the land continuously from the Ice Age to the present day."[3] But what can the common cause or common factor have been? To this I reply: Nothing else than the removal of the ice-pressure. When this ceased the Scandinavian area of depression was set in a swinging motion, like a pendulum set free. This area, depressed somewhat lower than the highest Glacial coastline, rises for the first time as the land-ice disappears. This is the late Glacial elevation. It sinks afresh in the *Ancylus* period, and during this depression the highest *Ancylus* beach is formed.[4] But again the area rises, and finally sinks for the third time to the level marked

[1] Gerard De Geer: "Om Skandinaviens geografiska utveckling," 2. Kartor, pls. 4, 5, and 6; Stockholm, 1896.

[2] The arithmetical progression from 100 to 200 and 280 is not regular. May not this indicate that the last figure is too low, and that the Glacial depression was greater than is shown by the highest Glacial marine coastline?

[3] "Om högsta marina gränsen i norra Sverige": Geol. Fören. Stockholm Förhandl., 1896, xviii. See p. 487.

[4] There is no reference here to the undulatory motion of the land-oscillations, but only to their final result.

by the highest *Litorina* beach. The elevation consequent on that is still going on.[1] And it is not too rash to predict that these oscillations will continue until the ever-weakening effect of the impulse given by the land-ice is neutralized by the other terrestrial factors that produce land-oscillations.[2]

From the foregoing pages it appears that "the *Post-Glacial* geology of the Baltic Sea and the Gulf of Bothnia" stand in the closest relation to their Glacial geology. Therefore I have been unable to make the former clear without at the same time throwing some light on the latter.

[1] Each successive swing was naturally not only less extensive but shorter than the preceding. From this it may be inferred that the *Litorina* depression prevailed a shorter time than the *Ancylus* depression.

[2] Here, of course, it is only Scandinavia that is alluded to. But the same remarks are largely applicable also to North America, although it is not unlikely that the North American ice-sheet, being much larger than that of Scandinavia, melted later than it. In that case the Post-Glacial epoch must have been shorter in North America than in Europe. Herein may lie the reason why many North American geologists, in their estimates of Post-Glacial time, have arrived in harmony at such low figures as 7,000 to 10,000 years—a far shorter time than that in which the Post-Glacial deposits of Scandinavia were formed.

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