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Recent Changes of Level on the Coast of Maine: with Reference to Their Origin and Relation to Other Similar Changes

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RECENT CHANGES OF LEVEL ON THE COAST OF MAINE:
WITH REFERENCE TO THEIR ORIGIN AND RELATION TO OTHER
SIMILAR CHANGES.

BY N. S. SHALER.

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X. Preliminary Report on the Recent Changes of Level on the Coast of Maine: with reference to their origin and relation to other similar changes. 1
By N. S. Shaler.

INTRODUCTION.

For many years there have been frequent reports of changes in the level of rocks and shoals on the coast of Maine. Generally these accounts have been of an untrustworthy nature, inasmuch as they seemed framed in palliation of some blunder of seamanship. A vessel being cast away in some well-known waters, it was natural enough for her captain to claim that the rock was not there before; or that the depth of water had greatly diminished within recent times. Every sailor who had excused his own blunders in this fashion, was naturally inclined to foster the opinion that the rocks were growing nearer the surface year by year, and without any intended deception one can easily imagine that in time a decided conviction might thus be reached. Experience in other regions has shown, however, that a prevailing opinion of this kind is apt to have some foundation. For some centuries the popular belief of the inhabitants of the Scandinavian coast concerning the changes of level of the shore, received no scientific examination; when, however, these questions were approached in a determinate fashion, it soon was made evident that the popular opinion was singularly correct, both as regards the extent and character of the movement. The following considerations, and the facts upon which they are based, result from a tolerably careful study of the record of changes along the New England coast, and from several years of summer labor.

Before giving a detailed account of the facts observable on the coast of Maine, it will be well to consider the general nature of the changes of level which have been observed in neighboring countries. I shall therefore give a brief résumé of the facts concerning elevations and depressions of shore lines in the north Atlantic section of our own continent, and those of the opposite continent of Europe. From the time that geology began to exist as a science, it has been a well-accepted fact that the surface of the dry land has been continually changing its level with reference to the sea. It is, however, among the later investigations that we begin to find anything like a careful study of the last, and therefore the most easily determinable, changes which our continents have undergone. Although by no means complete, these investigations enable us to assert, with a precision which can rarely be obtained in the science, that a great movement of elevation has taken place throughout the whole northern section of the Atlantic coast line, in the most recent times. The quantity of the vertical movement varies greatly in different places; it seems, however, to be quite certain that the elevation is generally greater as we advance towards the north.

1 Published by permission of the Superintendent of the U. S. Coast Survey.
On our own coast it varies from a few feet, in the neighborhood of New York City, to one thousand or more on the coast of Labrador, and two or three times this amount on the Greenland coast. On the European shore this movement has not yet been proved to increase with the same regularity as we pass to the northward. Something of the kind, however, is distinctly traceable, though the local character of the phenomena is much more decided than in America. For instance, there is some proof of a depression of over a thousand feet in Wales, though northern France shows only slight evidences of very recent submergence. It will be necessary to refer to this local character of the movement in Europe, when we come to consider the cause of the submergence which took place about the time of the glacial period; for our present purpose it is only necessary to urge that the whole coast line of the northern Atlantic, with local exceptions, (which we shall see are not difficult to explain), is marked by indications which show that it is just recovering from a period of great depression. At many points the evidence is pretty clear that this movement of elevation is still in progress. It is evident, therefore, that the general character of the changes which have taken place in the immediate past in the northern Atlantic, quite harmonizes with the supposition that there is still some change in progress along the coast of North America. At least it may be worth while to give the subject a careful study. In the following section will be found the results of a journey along the coast of Maine, made with the especial intention of observing the evidence of change which might be found there, while the closing section of this Memoir will be given to the consideration of the physical causes of the changes of level of shore lines, with special reference to the great changes which ushered in the present geological period.

ON THE PHENOMENA OF ELEVATION OF THE COAST OF MAINE.

Of the three possible conditions of any coast line, elevation, stability, and depression, the former gives by far the clearest evidence of its action. Depression can only be shown by level marks observed at long intervals, or by the existence of a contour of surface of determined aerial origin beneath the surface of the water. Stability can be shown only by the obscure indications made by the long continued action of water at its point of contact with the land; extensive submerged tables of rock lying just at the height where the cutting action of the water would have left them, afford the best evidence of this condition. Elevation, however, is shown, whenever the circumstances are favorable, in a very remarkable manner. The following natural indications of this movement may be taken as valuable in the order in which they are named, the most trustworthy being given first.

1. The remains of marine animals lying embedded in stratified deposits above the level of high tide mark.

2. The existence of extensive stratified deposits of sand, gravel or mud, at points where fresh water lakes could have had nothing to do with their formation.

3. The existence of a topography not explicable on any other supposition than marine action above the level of high tides.

The first of these proofs cannot be reasonably expected to occur on all shores which have been recently elevated. Even at the present time a good deal of the shore sand and gravels making along our coast are quite wanting in animal remains; and in the glacial
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period, and the changes which immediately followed it, during which times the great depression of our shores occurred, the physical influences must have been very much against the existence of animal life in any abundance. We shall therefore have to rely, in the main, upon the evidence which can be obtained from the non-fossiliferous gravels and sands of the coast.

The third sort of evidence of elevation which the shore line can give us, though not without its value in the problem before us, we shall find to hold but a subordinate place. We shall see that the duration of the subsidence on the coast of Maine was not great enough to admit of a great amount of marine work, or at least that part of the time of submergence during which the shore was bare of ice, and exposed to the wear of the sea, was not long enough to permit any great amount of erosion. How slight it was may be inferred by the fact that along nearly the whole shore the glacial scratches, which were certainly formed before the gravel beds were laid down in the stratified form which so clearly evinces the action of the seas, are still unworn, down to the water's edge.

This feature of the persistence of the glacial scratches, even to the margin of the sea, is not by any means peculiar to the coast of Maine; it is clearly seen at Newport, Rhode Island, where the scratches, which seem to have had no protection against the action of the weather, retain an admirable clearness, showing, beyond a doubt, that even in portions exposed to the full brunt of the storms, the erosion was not enough to take even a small fraction of an inch from the stone. Along the coast of Massachusetts we have the same feature distinctly shown at various points. On Cape Ann, one of the most exposed promontories of our stormy northern coast, the evidence is very clear.

Taking then the beds of stratified drift as the only acceptable and abundant evidence of depression, we must look at the question of the origin of these beds, and the possibility of their being formed by other agents than those which are at work in the sea. Some slight amount of stratification is certainly not inconsistent with the action of ice in the form of extensive sheets, especially when we consider that the plainest mark of the ice work would be that left by the water derived from the melting of the glacial mass, as the conditions changed to those which are now in action. But when the stratified drift is distributed in extensive sheets of approximately horizontal materials along the shore, all doubt of marine action may fairly be put aside.

The following account of an examination of the coast gives only those results which have an important bearing on the question in hand; many of the details which did not seem important to the conclusions have been omitted. In order to reduce the work within the limits of the time at my disposal, the study of the coast was taken up on the west shore of Penobscot Bay, and continued along the main land to the eastward, as far as Machias, Eastport, and Calais. On account of the greater range of height along this part of the coast, the opportunities for tracing the history of a change of level are decidedly better than on the coast from Portland to the Penobscot. In order to acquaint the reader with the general character of the phenomena to the southward of Maine, I shall take up the sketch of the shore at Boston, Mass.

The neighborhood of Boston, like the whole country to the southward as far as New York, is characterized by having a vast accumulation of drift materials disposed in four distinct formations, each indicating a separate stage of the changes of the glacial period, viz.: —
1. Massive drift lying in patches which show themselves to be fragments of a bed of great thickness, left by the old ice sheet as it melted away. This drift is at the base of the detrital accumulation, and is quite without traces of stratification in its most characteristic sections. A large part of the pebbles are scored by glacial scratches.

2. Terrace beds of glacial materials rudely distributed by water; the scratches generally worn away from the surface of the pebbles; the whole indicating one or more pauses in the re-elevation of the country after the passage of the glacial ice.

3. A secondary glacial series indicating a recurrence of local glaciation after the partial re-elevation of the country. These secondary glaciers about Boston occupied only the larger stream beds, being traceable in the Charles, the Mystic, and the Neponset Valleys.

4. The rearranged beds lying within a few feet of the present level, which indicate a long continued rest of the sea at or near its present place. At this level the life-bearing beds come again into prominence.

5. The extensive mud beds and marshes always colored by, and generally in the main composed of, the remains of animals and plants.

There is good reason to believe that the shore line at Boston has stood at a level some feet above its present position. Near Lynn, on the shore inside of Nahant, is a forest bed lying some feet below high-water mark, covered indeed save at the lowest water. In excavations made near Cambridge, coniferous trees have been found with their roots in place, at a foot or more beneath low-tide mark. This recent subsidence is apparently arrested, if it has not been partly overcome, by a movement in the contrary direction. All the evidence derived from the changes of the coast since the beginning of the historical period, clearly point to this conclusion.

As we go northward from Boston, as far as the Merrimac, we find essentially the same features as about Massachusetts Bay. The area of table drift which I take to indicate a period of submergence, increases as we go to the northward. The altitude to which this attains seems to become greater with the increase of area. The depths of the fiord depressions become continually greater; streams of small size occupy larger cuttings than in the country about Boston. Along a part of this stretch of shore extends a narrow island. This strip of land seems entirely composed of drift materials, and appears to be made up of the partly rearranged materials of an ancient moraine laid down during the secondary glacial period, indicated in the neighborhood of Boston by the beds marked No. 3 in the preceding list. The Merrimac would naturally have been the seat of great local glaciation during this time of renewed ice action. Draining a much larger and higher region than the Charles and the Neponset, we should naturally expect the moraine phenomena arising from this secondary ice action to be much greater here than about the mouth of the lesser streams. No evidence has yet been adduced concerning the latest and most limited movements of the shore line at the mouth of the Merrimac. All that can at present be determined is that the depression at the close of the glacial period was greater at this point than near Boston, and that the secondary glaciation which came after the restoration of the shore to very near its present level, was more extensive than at points forty miles further south.

From the mouth of the Merrimac to Portland, the increase of the table drift is a very marked feature in the physiognomy of the shore section. I have seen none of it below fifty feet in height; its stratification remains, however, as indistinct as about Boston. At Port-
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land we have distinct evidence to show that the depression at the close of the glacial period amounted to over one hundred and fifty feet, while at Boston there is good reason to believe that it did not exceed half this amount. Along with the evidences of greater subsidence there are other facts which go to show a longer continuance of the depression. The area of the brick clays and other deposits which show the gradual silting action which must have taken place when the sea was separating the mud from the gravels of the drift is much greater in this section than in Massachusetts. Following up the valley of the river towards Lewiston, these clays and stratified sands are seen in an abundant development. All along the section from Portland northward, sections answering in general character to that shown in Fig. 1, abound. These sections unquestionably indicate something like the following history. The massive drift, the remains of which are still seen in the lower part of the section, retaining the shape in which it was dropped at the melting of the ice sheet, has first been worn away by the action of the marine currents, and afterwards covered by the finer materials torn away from some other part of the drift sheet. The imperfect stratification of the upper part of these sections suggests the idea that the force which swept the materials to their present place was of paroxysmal violence. I have treated the question of the origin of these table drifts in a report on the surface geology of the region about Massachusetts Bay, and shall not therefore repeat the matter here; the conclusion to which we seemed compelled was that the elevation of the land was likely enough of great suddenness, after the fashion of observed changes on the South American coast, and that to the sweep of the receding sea, aided, it may be, by a succession of earthquake ocean waves, we owe the rapid accumulation of these curious table drifts. The materials swept away from the coast of South America by the great waves which have swept against the shore during the last one hundred years must lie in a manner very similar to the masses we have in these rudely stratified drifts.

In crossing from the valley of the Kennebeck to that of the Penobscot, we rise at the level of from two to three hundred feet into the region of the ordinary upland drift, such as covers a large part of Massachusetts. This deposit does not, in any regard, differ from that found further south, unless it may be in the greater size of the fragments which sometimes are found in the mass. I am tempted to believe, from the great variety of the materials found together, that on the whole the transportation from great distances is much more common here than in Massachusetts.

On the Penobscot Bay the quantity of drift material, and its disposition, differs somewhat from what we find on the Kennebeck. The mass of the detrital matter seems greater, and the amount of silt beds much less than near Portland. At Belfast, where the drift is seen to considerable advantage, the following points are observed. The principal channel of the bay, and the minor streams which fall into it, are both quite free from evidences of the local secondary glaciation, such as we found in the valleys of the streams near Boston. The reason for this is easily found without supposing that the secondary glaciers were want-
ing here. In the neighborhood of Boston these local glaciers left their moraines at a few feet above the sea level. When they retreated from this position they wasted rapidly, leaving no distinct moraines in the upper part of the river basins. It is true that about Mount Wachusett, at heights of over seven hundred feet above the sea, these ice marks are found again, but the changes required to carry the ice in the valleys back from the sea to heights of near one thousand feet must have taken place with great rapidity, so that no moraines were left. During the return of the ice the glaciers would have pushed their moraines far beyond the shore line on this part of our coast, so that they would have soon been wasted away by the sea. None of the elevations near here give favorable points for observation concerning the later stages of the ice retreat. Among the Camden Hills, however, I found several traces of local glaciation, going to show that the ice lingered there as it did on the flanks of Wachusett, only at a somewhat lower level; the point of arrest in the former locality seeming to be about two hundred feet lower than in the Massachusetts Hills. This is explained by the more northerly position of this region.

The drift at Belfast lies in a nearly unbroken slope, extending from a point about two hundred and fifty feet above the water down to near the tide mark. There can be little doubt that the sheet of drift was once of quite uniform thickness over the floor of the Bay and surrounding country. The action of the sea during the time of depression at the close of the glacial period, leveled off the surface and partially stratified the materials. The work of rearrangement of a glacial mass by water action, can only go on at the period of contact of sea and land. Under the influence of the strong tides which sweep the shore, pebbles as large as walnuts can be carried for great distances down descending slopes, but larger masses cannot be moved except by the agency of the waves. The work began at the point of greatest depression, when the sea line was about two hundred and fifty feet higher than at present, and has been continued step by step as the sea retreated down the long slope. Naturally the action of the weather has done something to obliterate the successive stages of this great movement of the sea, but enough remains to enable us to make some important general conclusions concerning the way in which the change came about. In the first place it is to be noticed that there are nothing like distinct terraces on this drift slope, which would justify us in supposing that the elevation took place very steadily and rapidly without the long pauses which would be required to make terrace marks strong enough to endure. The amount of aerial erosion which has acted upon this partly arranged drift, is seemingly about equal at all levels from the base to the summit of the slope. Without attaching very much importance to this sort of evidence, it may fairly entitle us to suspect that the time occupied in the change which carried the sea through a vertical movement of two hundred and fifty feet was relatively very short indeed. It is quite clear that the time required to cut the scarp which marks the present shore has never been given to the work of terrace making at any point between the point of greatest depression and the present shore line.

As I shall discuss the general relations between the glacial action and the hydrography of the State of Maine in another part of this report, it will not be necessary at this point to give any study to the form of the great basin of Penobscot Bay. I therefore pass at once to the east side of the Bay.

In the neighborhood of Castine, and along the shore to the southward, the deposit of drift is much thinner than in the neighborhood of Belfast. This is clearly due to the dif-
ference in the character of the underlying rock which is much less easily riven by the ice action than the rock on the east side of the Bay. This shore therefore wants the distinct inclined plane of detritus, which we have described as occurring on the western side.

The Megobben Reach offers us a curious case of a continuous valley lying in a position where its formation cannot well be accounted for by the excavating character of ice action. From certain indications derived from the form of the “roches moutonées” in this reach of water, I was somewhat inclined to think that a part of the great stream which poured from the Penobscot Bay during the glacial period, was turned from its more southern course to pass through this valley. From the general character of the valley, however, I am now inclined to consider it as marking the place of a great east and west fault line, which has been developed by the ice action. Along its whole shore the drift lies in thin masses, being much less developed than in the country to the west of the Penobscot. The reason for this is likely to be found in the hard nature of the rock lying to the north. Moreover, the transporting power as affecting the distance whence the detritus could have been derived would have been greater in the valley region of the Penobscot than on this shore where the gathering together of ice streams did not occur.

At Sedgwick there occurs a considerable indentation in the shore to the northward, marking the point where the harder syenitic is replaced by a soft serpentinous rock, in which the pebble-armed ice managed to make a deeper cut. The barren hills at this point and to the eastward as far as the village of Brookline, are denuded of all the small drift, nothing of the glacial debris being left except the larger boulders. This stripping, which I am compelled to refer to the action of the sea during the period of depression, extends from near the water line to at least two hundred and fifty feet above the sea. Many of the heaps of boulders are wedged together as if they had been strongly beaten by wave action. A part of the deep waters which surround Mount Desert lie between Brookline and that Island; the small islands which dot its surface have but little drift upon them, and this in no way characteristic. The insular masses which lie to the southward of Megobben Reach were not visited by me on account of severe weather, which rendered it difficult to pass the intervening waters. So far as seen they had the same character as the rocks to the eastward, there being comparatively little drift on their faces. Report has recently come to me of the discovery on Deer Isle, at the height of about two hundred feet above the sea, of a mass of marine shells of the same age as the beds at Portland.

On the Island of Mount Desert the evidences of great subsidence during the glacial period are few and inconspicuous. The reason for this is probably to be found in the fact that owing to the great height of the hills the secondary glaciation was quite strong and lasted long continued, and resulted in sweeping away to the seaward the product of the erosion during the principal ice time. The re-elevation of the island was probably complete, or nearly so, before the ice ceased to pour from the hills into the sea. It is only close to high water mark, say within twenty or thirty feet or so, that there are any distinct signs of stratification in the glacial material. The evidence of the existence of extensive local glaciers is very perfect. The numerous valleys leading from the hills have all more or less distinct moraine heaps along their course. The valley of Great Pond is dammed to the southward by a moraine mass, having a height of about one hundred feet above the water. I have industriously searched the flanks of the Mount Desert hills for any trace of terraces, but have failed to find them even in their most obscure form.
East of Mount Desert the shore, as seen from the sea, presents essentially the same conditions of erratic phenomena. The coating of drift is quite thin, and seems to be altogether of the secondary glacial time. At Milbridge the detrital sheet is again rather thicker, but in character and origin does not differ particularly from that at Mt. Desert, except that there are some signs of a table of detritus at the height of about one hundred feet above the water. Most of the small rocky isles which make up the outer fringe of the fiord zone, between Milbridge and Machiasport, are bare of drift, or nearly so, showing the action of ocean waves for at least one hundred feet above the present level of the sea. The character of the drift remains unchanged along this part of the coast. The remains of the original glacial action, or that produced by the first stage of the glacial period, are rare, if indeed they exist at all. Most of the drift material seems to have been reworked during the second coming of the ice, when the glaciation, though insufficient to produce a great wear upon the rocks, or to accumulate much detritus, yet served to efface or render illegible the record made by the far greater ice time which preceded it. Between Machiasport and Eastport the drift materials were narrowly examined; they seem to belong altogether to the second stage of the ice action. The only peculiar features observable are connected with some thin beds of brick clays, which seem to mark the persistence of the subsidence after the passage of the ice from the coast in its retreat. The country back of this section of the coast has comparatively little height, so it is not improbable that the ice was less strongly urged to the seaward at this point than in the region to the westward. This may have caused the ice to disappear here sometime before it did on the other parts of the coast.

The intensity of the ice action, which had evidently suffered some abatement in the section between Machiasport and Eastport, as is shown by the disappearance of the fiord character in this part of the shore, is again augmented in the immediate vicinity of the latter point. The harbor of Eastport, though a typical specimen of fiord structure, is almost destitute of glacial waste. Area for area it has not the tenth part of the detritus we find in Boston Harbor, though the proportionate erosion has been more than as great. The channels between the islands are far deeper than those found in Massachusetts Bay, indicating a cutting agent much more active. Here, too, the ice, having kept its place upon the rocks for some time after the re-elevation of the shore, there is little evidence of recent elevation. Some few faintly indicated terraces lying at a height of ten or fifteen feet above the sea, seem to show that the last ten feet of the lift may have been effected after the re-elevation of the shore. All the drift material appears to have been derived from the immediate neighborhood of the shore line; there is none which we are required to refer to points far in the interior. Here, as elsewhere, it must not be hastily inferred that the glacial period did not effect the transportation of materials from great distances. We must reconcile the facts as we find them, with what we may observe at other points where distant transportation is most unequivocally proven.\footnote{In the Ohio Valley, as far south as 38° N. L., we have dredged miles north of that point by the agency of ice, materials which have come from a region at least six hun-}

From Eastport northward, there is a gradual change in the character of the drift material which is hard to explain. The beds of gravel nearly disappear, and in their place come
considerable deposits of clay, extending to rather over one hundred feet above the low water mark. The stratification of the clay is quite evident, and affords the most unquestionable proof of subsidence. It is obviously difficult to reconcile the ideas of a coast covered with ice about Eastport, but becoming more and more freed as we pass to the northward towards Calais. Such irregularities seem, however, to exist in the region where similar conditions continue to the present day, as upon the shores of Greenland and Spitzbergen; the ice attaining the sea at parts of the shore, and leaving great stretches quite uncovered. There is something in the arrangement of the interior country along this shore which may have affected the peculiar distribution of the ice. The considerable chain of lakes lying to the north of Eastport marks a valley which develops on that part of the shore, and may have guided a great mass of ice from the interior to the coast, in such a fashion as to sweep the shore from Machias to Eastport, while leaving the west coast of Passamaquoddy Bay quite uncovered, and free to receive the sediment of the sea during the time of depression.

Near Calais there are some, though rather faint, traces of local moraines. It is highly probable that during the closing stages of the ice time this valley, from Calais north, had its local glacier. For some miles above Calais the clays keep their place in the river valley, but of their development in this direction I have no information. From Calais to McAdam Junction, and thence to Bangor, the view of the drift phenomena was hastily gained from the railway train. The following observations on the distribution of the erratic materials along this route may not be without value.

The underlying rock in the section between Calais and McAdam, has been planed down until there are only slight reliefs derived from the bed rock. The amount of ice action indicated in this section seems greater than that of any part of the coast of Maine, and is owing to the fact that the materials composing the bed rock are of far more uniform hardness. It is probable that the vast accumulations of the St. Lawrence basin, which have forced their way in part to the east and southeast, forming with their debris the great masses of the Banks of Newfoundland, did not give complete relief to this ice sheet; a part found its way over the low barrier at the head of the Bay of Fundy, and swept its shores with a stronger ice stream than that which worked on the coast of Maine. The secondary ice period was sufficiently strong in this section to give us moraine matter almost as abundant as the great ice time in Massachusetts. For the first ten miles from the sea there are extensive clay beds. After that we come upon ordinary boulder drift. The distribution of this debris is quite unlike that in the regions to the southward. Over the whole surface is a rather thin sheet of pebbles, somewhat affected by water action at various points; strongly marked moraines, extending in an east and west direction, show the action of the retreating ice. This structure is best seen near Barlow's Mills, where the ridges seem quite continuous, having a height of about fifty feet, a horizontal section of three hundred feet or more. The intervals between several of these ridges was not over some hundreds of yards.

From McAdam to the Saint Croix, the surface slopes gently downward, with only slight indications of local moraines. The valley of the St. Croix has a singular want of boundaries. At the point where the railroad crosses there is scarcely a trace of containing walls. The stream evidently has a fair amount of cutting power, and has been at work since an early geological time, so that we must suppose that it has been able to excavate the usual amount of material in forming its valley. We can best account for the present want of
relief by supposing that the glacial erosion has destroyed the relief which the flowing water had made. From the St. Croix to the Penobscot, there is little variety in the drift marks; at Mattawamkeag the country is level, with a rather thin coating of drift, most confusedly arranged, there being nothing like distinct moraines at the head of the last named stream. The valley is scarcely better defined than that of the St. Croix. In the table country of Kentucky or Tennessee, where the rivers have about the same cutting power as here, the channel section would be several times as deep. This feature of excavation increases as we follow the Penobscot to the southward, and with the deepened valley comes a greater distinctness in the order of the glacial debris. Near Mattawamkeag it is difficult to recognize anything like distinct moraines, but when we get within thirty miles of Bangor these remains become more and more distinct. Close to the latter town these terminal heaps are very well marked. The fact seems to be that the retreating glacier had no local organization in the upper part of the valley, while its independence was marked about Bangor. As seen at a glance, the section north of Bangor presents no evidences of having been below the level of the sea at the close of the glacial period. As in the localities previously discussed, this is to be accounted for on the supposition that the ice retained its place in sufficient thickness to bar the access of the sea during the period of great submergence.

In recapitulation of the evidence afforded by the detrital beds of this section of the Atlantic sea board, we have the following points which are worthy of notice.

1. The depression of the land at the close of the first division of the glacial period, a depression which seemed to increase in amount as we went from the southern to the more northern regions.

2. The return of the ice in the shape of a set of local glaciers which covered the shore at Mt. Desert, and along most of the territory, at least as far as New Brunswick, persisting until the final re-elevation of the land to near its present level.

From the inspection of the coast of Maine alone it is not possible for us to form any satisfactory judgment as to the time which has elapsed since the passage of this secondary ice sheet. The evidence obtained on other parts of the coast of the North Atlantic, and among the mountains of Europe, points to the conclusion, which is very general in its way, that a period of at least ten thousand years must have elapsed since this great change took place. This point will be seen to have an important bearing on the matter of the re-elevation of the shore, when this comes to be considered in the final section of this report.

THE EXCAVATION OF THE ICE TIME.

In reports on the glacial history of Narragansett and Massachusetts Bays, I have considered somewhat in detail the action of an ice sheet working over a surface of irregular hardness. I shall not repeat here the matter discussed in those papers, but only recapitulate briefly the general conclusions which are necessary for our present inquiry. The following propositions I regard as established.

1. That the fiord zone results from the irregular wearing of the rock surface traversed by the glacial sheet; the whole of the surface within the glacial tract wherever the differ-

\[1\] The report on Massachusetts Bay is not yet published.
ences in hardness are great, has been marked by the peculiar corrugation which, when made apparent by the level of the sea, as on the coast line, comes into peculiar prominence.

2. The wearing has been determined by the following additional circumstances. (A.) The velocity of the stream. (B.) Its depth. (C.) The angle of declivity, and (D.) the arming of the ice sheet at its bottom with pebbles of sufficient hardness to have a strong cutting power.

3. As an adjunct to the ice action,— the subglacial streams; these doubtless existed then, as they now exist in Greenland, and must have cooperated in many cases with considerable effect in the formation of the deeper cuts of the ice.

4. There is an important conclusion, a corollary to the preceding propositions, that the deeper any cut becomes through the action of glacial movement the more rapid the wear. The accumulation of the ice in the valleys tends to relieve the weight acting upon the hill tops, and thus magnifies the erosion on the low grounds at the expense of the wear of the higher surfaces. Thus it is seen that while ice in some of its conditions of action is indeed a planing agent, it is not strictly correct to regard it as necessarily or even generally an agent which acts against existing reliefs.

So far as I have been able to see, the excavations which cut up the shore of Maine present no difficulties which demand especial explanation. All the great fiord-cut shores of the world are excavated in highly metamorphosed materials. It is a fact, that metamorphosed rocks, especially the series which is affiliated with granite, vary far more in composition than any of the unchanged sedimentary beds. In most cases this great variety of structure depends upon the action of the penetrated waters charged under varied conditions of heat and pressure with the chemical agents of change. Fissures which gave passage to these streams have naturally had their borders far more completely changed than the other parts of the mass. Other agents have cooperated to localize the characters of our metamorphosed rocks, making them as unlike in their horizontal sections as our unchanged rocks are uniform in this direction. Chief among these is the contorting action to which they have been subjected, which by bringing different beds to the surface in their narrow areas, has powerfully contributed to the diversification of the hardness of the surface.

The evidences of great excavation along the coast of Maine are invariably associated with either of the two following circumstances, the previous existence of great drainage channels, obviously determined as regards position and direction by running water, or the presence of great obstacles which have, by partly diverting the ice stream, concentrated its wear in narrower limits. The truth of the first of these propositions is evident to any one who will take the principal rivers of Maine, examine their drainage basins, and observe their dependence on features which could only have had a value with reference to the action of fluid water. If the direction of the river systems had been in any way determined by the ice action, they would have been very differently arranged from what they are now. It is evident that they are the work of water acting in its fluid form, and that the action of ice has been limited to a certain amount of broadening and deepening the channels it already found in existence.

The exceptions to this general rule are found in those cases where the presence of an obstacle of great height has interfered with, or where the difference in hardness of the materials flowed over has greatly modified, the cutting action of the ice. At Mount Desert, for example, we have a great mass of high land extending in a general northeast and
southwest direction, opposing the trend of the ice current which came from the north by west in a very direct fashion. It will be seen, however, that the tendency has been to deflect the lower part of the ice stream to the southwest, a part, however, passing around to the east of the chain of hills, and a part pouring through the deep valleys of Somes' Sound and Great Pond. The result of this deflecting action has been to deepen the channel on the west of Mount Desert until it is by far the most profound of all the fiords on the coast of Maine. By the less considerable ice stream which was turned into Frenchman Bay, that great though relatively shallower excavation was formed.

Wherever the ice moving over a plane surface is arrested by any such partially surmountable obstacle as the hills of Mount Desert, the result of the effort to mount the barrier is an increase of wear at the base, at the point where the change of direction is brought about. To this action we doubtless owe the fact that all the elevated points along this coast are separated from the main land by strips of deep water. It may also be noticed on the main land that mountain masses, which have interposed as barriers to the movement of the ice, have had the region to the north of their bases much more cut away than the southern segment. Many of these barriers have extensive lakes to the immediate north. This is conspicuously the case in Wachusett, Mass., and is seen in many other points in New England. Even in those cases where the map shows no lake basin, it will often be found that extensive swamp areas mark the position of lake basins which have been filled up since the glacial period. By this filling up more than two-thirds of the area of lake surface existing in southern New England at the close of the glacial period has been destroyed.

The peninsula of Nova Scotia probably turned the ice current which came down the St. Lawrence, so that it sent a good part of its stream over the low col at the head of the Bay of Fundy. This stream would have tended greatly to increase the excavation of that singular arm of the sea, and may perhaps, in part at least, account for the prodigious depth of the central abyss recently discovered there by the explorers of the United States Coast Survey.

This is hardly the place in which to undertake any inquiry into the physical history of the Gulf of St. Lawrence. We may, however, call attention to the fact that this great basin is in all essential aspects comparable to the Great Lakes which lie at the upper part of the valley, and must be explained in the same manner. Being at once at the end of a great river system and on the sea board, it must have been swept by a far stronger ice stream than the upper and more interior basins. If, as it seems most reasonable to believe, the great lakes, from Superior to Ontario, have been dug out by ice action, then we must regard the Gulf of St. Lawrence as the product of the same forces, more gigantic in proportion to the greater mass of the wearing agent.

While we find ourselves forced to attribute so much work to the action of ice upon this part of our shore, it must necessarily be asked how far the erosion and transportation has been accomplished by the ice-time which has just passed away. All the indications of glacial action being essentially superficial, its marks are in a peculiar degree liable to the destruction which in a greater or less degree awaits all geological records. We have seen how the secondary period of the last glacial time, though it brought but a thin sheet of ice over the shore on the eastern coast of Maine, still swept away from that section all the great evidences of previous ice work which, in the more southern district of Massachusetts
form such prominent features. So it is evident that the marks of glacial work coming from a time anterior to the last ice period, however conspicuous in their day, would have been in the main destroyed by the succeeding period. I cannot undertake to give a final answer in the matter of the time at which the excavating work along the coast of Maine was accomplished. Certain circumstances incline me, however, to the opinion that the ice work was in a great degree done by glacial action anterior to the last glacial period. Of these the most important is the following.

If we examine closely the shore line where it is drawn along the rocky part of our coast, say from Massachusetts Bay to Eastport, we find that everywhere there is a steep escarpment bounding the land, which shows in every feature the work of the sea. The general relation of this escarpment to the adjoining country is shown in Fig. 2. There can be no doubt that this cut represents the wearing of the sea acting continuously, and for great periods, at the same, or near the same, level. But it is evident that the last glacial period found the shore in much the same form as at present, for, except when the rock is very crumblly, or exposed to the severest beat of the waves, it is covered with the scoring of the ice sheet. Now if the wearing brought about during the glacial period did not exceed the few feet which would have been required to erase the old shore line, it is evident it could not have sufficed to dig out the great fiords along which that shore is traced. Yet the valleys of the fiord section are as clear and sufficient evidence of ice work as the glacial scratches themselves, and must be explained by the same agent. Thus it is seen, beyond reasonable doubt, that between the time when the shore was formed and the present day, the ice action which has occurred was relatively only slight, and could not have accomplished the greatest part of the ice work indicated by the topography of the region. At first sight it would seem as if we might find an explanation by supposing that the shore had been excavated between the first disappearance of the ice and the return of the glaciers at the second stage of the period. But besides the evident difficulty of the length of time between the two phases of the ice period which this hypothesis requires—a time which, measured by the rate of cutting of the waves, must have been several times as great as that which can be called post-glacial—there is the fact that in Massachusetts the secondary glacial period did not make any continuous sheet of ice whatever, but only local streams leading from the high land toward the shore in the principal river valleys. Even in nearly the southernmost country where the ice came in a sheet to the shore, in the valley of Narragansett Bay, we have the same glaciated coast, and the same sea beach scored and grooved by the ice. It thus becomes evident that the topography of this country is due to antecedent glacial periods having an effect far exceeding in aggregate amount the work of the last of the series. Having proven more than one glacial period, it is easily seen that it becomes probable that this work has been done by a number of successive ice-times rather than by any one great period of this character. This view of the duration and severity of the ice-time is in perfect accordance with what is known from other sources concerning the condition of that time. Many students of the question of the origin and antiquity of man
are now convinced that he antedated the last or generally accepted glacial period. Many of our existing land animals seem to have survived that great change. It is difficult to see how these things would be possible if the ice action had continued long enough to mould the whole topography of the circumpolar regions down to the parallel of 40°.

I have elsewhere discussed the question of the origin of glacial action, and shall not repeat the matter here, except to indicate summarily the opinions to which its consideration seemed to lead. These were briefly as follows:—

Glacial action, such as is indicated by the records of the last ice period, requires us to suppose an intensification of evaporation over all the oceanic areas between 40° north and south of the Equator. This increased evaporation could only be brought about by an increase in the heat of the surface of the earth causing an enhancement of the supply of vapor for condensation. Of all the possible sources of increased heat the following are the only ones which have been suggested which deserve consideration. 1. Change in the attitude of the land and sea to each other. 2. Change in the temperature of celestial space through which our solar system is moving. 3. Change in the eccentricity of the earth's orbit in connection with the precession of the equinoxes. Each of these hypotheses has proved in the end unsatisfactory. We therefore were driven to the hypothesis, which is borne out by many considerations, that the sun is a source of varying heat; that it is in fact a variable star. The sudden increment of its heat by one-half would make the intertropical region the seat of intense evaporation, and the cloud-wrapped polar regions the seat of excessive precipitation, while the counter-trades, or return upper currents of air, would have their carrying power much enhanced by the greater activity of the trade wind system, consequent on the increase in the difference between the temperature of the equatorial and polar regions.

Looking upon our sun as a variable star, we get a basis for recurrent change, and can conceive the physical and vital phenomena of our planet moving in accord with the changes in that source of nearly all the physical and vital energy of the earth's surface. Some evidence has already been obtained of the following glacial periods:—

1. In the Cambrian, about the zone of *Paradoxides Harlani*.
2. At the close of the horizon of the Cincinnati group.
3. In the time immediately antecedent to the heavier coal measures of the carboniferous period.
4. In the trias. Evidence of the occurrence of glaciers in this period has been found in South Africa as well as Europe.
5. In the tertiary (probably three periods).

When we consider the extreme liability of such action as glaciation to be destroyed by subsequent agents, it becomes clear that these few periods, determined at the very outset of the research into the history of this agent, must be only a small part of the successive periods of similar change. It is also evident that the recurrence of successive glacial periods must have a most important influence upon the course of life; forcing great migrations, and effecting great changes in the whole character of the conditions of existence. It is not my purpose at this time to consider the evidence which can be brought from other regions to show the immediate value of these changes; and I can only indicate that the horizons of all our conglomerates are horizons where great changes have been effected even in the marine life, which is likely to have been less influenced by the change than the life of
ON THE COAST OF MAINE.

the land areas. Moreover, we may hope to get, through the study of these relics of the past glacial action, a means of determining the identity of formations at points remote from each other. If there should, for example, be evidence that at various points on the earth’s surface rocks of supposed triassic age, as determined by their fossil contents, are associated with distinct evidences of glacial action, we may feel that the identification of age is more exact by far than it can be made on the evidence derived from fossils alone. That similar organic forms can continue to exist in one region long after they have been extinguished in another, is a fact so well recognized as to need no proof; but a glacial period, we are entitled to believe, must have been simultaneous, at least throughout one hemisphere, probably over both, and may therefore give with certain lessened risks of error, a means of determining identity of time in regions remote from each other.

ON THE CAUSE OF DEPRESSION IN THE GLACIAL PERIOD.

That there is a necessary connection between the accumulation of great masses of ice, such as the glacial periods brought upon the surface of the circumpolar regions, and the depression of those regions, is a point most easily demonstrated. Over the whole of the shore of the North Atlantic the evidence is complete; at the southernmost point where the glacial action has been observed, we find slight evidences of subsidence. This increases steadily, though irregularly, as we go northward, until we come to the highest latitudes where civilized man has penetrated, where we have evidences of subsidence amounting to two thousand feet or more. The only hypothesis as yet advanced to account for this irregular movement, is that of which Adhémar was the originator.

The accumulation of a great weight of ice at either pole in succession, would result in the displacement of the centre of gravity of the earth, which would be drawn the nearer to the pole where the accumulation took place. The result of this change upon the altitude of the sea would be very great. The water being free to obey the changed conditions would rearrange itself with reference to the new centre of attraction. The result would be the deepening of the sea by the amount of the displacement of the centre of gravity about the pole where the ice accumulated. That such a result is in good degree a necessary consequence of the accumulation of masses of ice about either one or the other pole, is easily believed. But there is every reason to suspect that the conditions were not fulfilled during the last glacial period. The observations of Darwin, and more recently, and more especially, of Agassiz, have shown that the southern extremity of South America bears marks of as recent and extensive glaciation as the Northern Hemisphere. Until it is proven to the contrary by evidence which has not been seen, we must suppose that the glaciation in the two hemispheres was simultaneous. If this be the case, the idea of a displacement of the centre of gravity is no longer so available as an explanation; for although the tendency to accumulate the seas about the poles would exist in a very diminished way under this condition, its amount would not be sufficient to account for the phenomena of depression. Moreover, any result of this kind would probably be more than compensated by the substrata of material from the sea, and the consequent reduction of its depth. If we suppose both hemispheres laden with ice down to the parallel of 45°, then the thickness to be on the average one mile, we shall have subtracted from the ocean water enough to lower its depth by over half a mile of altitude. Something of this would be compensated
by the attraction of the mass of ice about either pole; but it is clear that inasmuch as the seas do not rise under the influence of the masses of the continents against which they rest, at least more than a trifling amount, so the water could not rise against the polar ice caps to any great height. The double polar ice cap, even were it a mile thick, could not affect the gravitation of the sea more than the high lands of Western South America. Moreover, the fact that in high northern countries some time elapsed after the disappearance of the ice cap before the re-emergence of the land took place, while on the theory of disturbed gravitation it should have disappeared pari passu with the waning of the ice, is a strong argument against the sufficiency of this explanation. Probably the most insuperable objection which can be made against this hypothesis of depression through a change of the centre of gravity arising from the magnitude of the ice sheet, is found in the fact that the depression does not increase with regularity throughout the whole of the Northern Hemisphere, which it should have done if this view be correct. The increase from a few feet (not exceeding fifty) along Long Island Sound to three hundred on the coast of Maine, is excessive. This rate, if kept up, as it must have been if this hypothesis be true, would have made the depression at the poles many miles of depth.

In view of these arguments I find myself compelled to abandon this view concerning the origin of the glacial depression. In seeking another explanation of the phenomenon, I have endeavored to arrive at something which should be easily connected with the general facts of continental and other mass movements of the earth's crust. In pursuing this object the following opinions have been forced upon me.

The constant movements of sea and land show clearly that the surface of the earth and the solid matter, for a considerable depth, are subject to movements which vary much in direction and intensity. At first sight, however, it would seem as if this variety of movement was far more considerable than it is in fact. The following considerations will serve to limit the phenomena in the range of its action in an important way.

As the sea is the region of constant deposition, and the land of constant erosion, there must be in the long run quite constant upward movement of the land areas and depression of the floors of earth beneath the seas. For instance, the region of the Ohio valley was near the sea level in the silurian and carboniferous times, and is a few hundred feet above it at the present day, notwithstanding the constant erosion which has affected it nearly ever since. We cannot reasonably reckon the time which has elapsed since the coal period at less than twenty million years. Now the rate of wear on this region, as shown by the discharge through the Mississippi River, will carry away about one foot in seven thousand years. This may be reduced to one foot in ten thousand years, if we would keep within bounds. But even this slow rate will require a steady rise of at least twenty-five hundred feet since the close of the carboniferous period, relatively a very modern period. Further to the northward, the Laurentian Hills, judged by their age, must have lost several times as much height, even supposing they waste only at the rate of the plain, which is far below the south. This class of facts entitles us to suppose that the lands are, on the whole, constantly rising. On the other hand, all the known facts, such as the continuous deposition of strata to the amount of thousands of feet in waters always shallow, the increasing evidence of ancient zoological barriers in the sea, under circumstances which require us to suppose that depth of water was the obstacle to the exchange of life; and other facts which cannot be
succinctly stated, give us evidence of the truth of the natural supposition that concurrent with the rise of the land there has been a constant increase in the depth of the sea.

If we try, however, to reduce all great changes of level to the two movements, sinking of the sea and rising of the land, we are met by the difficulty, which will suggest itself to all geologists, that the sea and land have in many regions changed places in alternation. It seems to me, however, that this difficulty is in a great measure overcome by the careful study of the necessary conditions of the movement. In diagrams Nos. 3, 4 and 5, we have represented the line from the centre of any sea to the interior of any continental area. Assuming that the constant tendency of the movements is to depress the seaward part of this section and lift the landward part, we have to notice that there must be a fulcrum point, or point of rotation of the movement. This point may occupy either of three relations in reference to the sea. It may be to the seaward of the shore; it may fall at the shore line, or it may lie to the landward of the shore. Supposing the sea floor to be constantly sinking, and the land constantly rising, it is evident that in the first of these suppositions the land would continually gain on the sea; in the second case, great changes might take place without any effect on the position of the shore; while in the third case the sea would seem to gain on the land. The fact that in most of the land areas where we knew the geology well enough to form an opinion on the matter, there are centres of ancient upheaval about which the oscillations of level have taken place,

In the diagrams 3 and 4, similar letters denote corresponding points. In figures 3 and 4, the straight lines A B, A' B', are diagrammatic expressions for sections extending across the shore. For convenience of delineation, the action of the movement of the small segments of the crust represented is supposed to be like that of a rigid bar.

In Fig. 3, the pivot, P, is to the landward of the shore, S, the line A B indicating the surface of the continent near the coast. Let the depression of the sea floor and the elevation of the land go on until the continental surface is in the position indicated by the lines A' B', and the shore will be removed to the point S', and the sea gains. S L, indicates the sea level. If we suppose, however, that the dotted line P L', denotes the sea level, then the pivot point will fall just at the shore line, and all the changes in the position of the line A B will not affect the position of the water lines.

In Fig. 4, the pivot point is the seaward of the shore line A B, indicating the original position of the continental surface, and A' B', the position of the change. Inspection will show that in this diagram the change has caused the shore to move seaward, and the land gains.

Fig. 5 represents a shore line with an axis of rotation, A B, cutting it in such a manner that the points P and P' may be taken for the pivot points of the diagrams 3 and 4, respectively. All that portion of the shore line above the straight line would be sinking; all below, rising.
is much in favor of this theory of the changes of sea and land. For our present purpose it is not necessary to argue this question in all its phases, it is enough that it enables us to coordinate the changes of the sea and land, and so far to aid us in the conception of the instability of the equilibrium of the crust which is one of the most important facts brought to light by the study of the geological record. The constant changes in the position of the fulcrum point of the movement of sea and land, show that the position of this point, with reference to the whole line, is a matter liable to constant change. In the determination of the position of this fulcrum we may be reasonably certain that whatever the source of the force which brings about the upheaval and subsidence, the matter of weight must have a certain value. Physicists who have attentively considered the question of the origin of the continental folds and ocean furrows, are quite in accord in considering them as folds of the earth's crust, or, to keep clear of assumptions, let us say the outermost part of the earth, which has been compelled to adapt itself to a diminished interior. Without pretending to claim this conclusion to be so well founded as to put an end to controversy, we may use it to complete our conception of the relation of forces to the section from the interior of the continent to the centre of the sea. It will be evident that this section must have its present place determined by two main factors, the energy of the uplifting force and that of the restraining weight. If the amount of this weight at particular points can be made to vary considerably, the whole effect of the movement may be materially changed. A careful consideration of the accompanying diagram will show that a change in the position of the point of rotation or fulcrum of the section will completely alter the result of the movement. When the pivot point is just at the shore line, a great deal of sinking of the sea floor and elevation of the centre of the continent may take place without affecting the relations of sea and land. When the pivot point is to the land side of the shore, then the movement will make the sea appear to gain on the land; when the pivot is to the seaward of the shore, then the land will gain. Elsewhere I have followed these considerations in a more detailed fashion with special reference to the question of the origin of continents. The conclusion is, however, so evident that it is hardly necessary to trace the whole matter here.

![Diagram](image)

**Fig. 6.**

The dotted line, \(a, a, a, a\), indicates the change of position of the surface after the ice caps have been formed.

\(c\), Continents. \(i\), Ice sheet. \(a\), Sea level.

It is very important to notice, however, that in the case of a rigid mass, such as we suppose the crust to be, supported on material having sufficient mobility to give way under strain, much as a fluid would do, then the imposition of any weight upon one extremity of a given section, such as is shown in Fig. 6, would necessarily produce a change in the position of the pivot point. Now in the ice accumulation of the glacial period we have just such a change of weight as would be likely to bring about considerable effects of this kind. A great mass of water is taken from the sea and heaped to the depth of a mile or more
upon the land. A mile in depth of ice weighs about as much as half a mile of ordinary rock, so that by covering the continent of North America with a deposit of this kind we more than double its altitude above the sea. Now if the weight of the mass uplifted be an element in determining the height to which the continents are raised, then we must allow this ice mass a decided influence in depressing the continental areas.

The reader may help himself to form a conception of the nature of these effects if he will float a rigid substance, such as a bar of wood, upon some semifluid, such as tar or treacle, weighting one end so that by its depression it may sink beneath the surface, thus elevating the other end. Now if he will add weight to the elevated end, subtracting it, if he please, from the other end, he will see the change in altitude which I conceive to have occurred by the accumulation of glacial matter. Another illustration, more satisfactory on the whole, is afforded by a little study of any of our frozen lakes. Let a weight be accumulated at any point on ice of moderate strength. The result is the depression of the ice at that point, and its elevation around the sunken point. In this condition the ridge and depression may well represent the state of the tensions which give its continent and sea basin. Now if we take a part of the weight from the depression and place it on the elevated part of the ice, we will thereby change the altitude of the elevation. If the hollow of the ice were filled with water this change would bring about an extension of the area covered with water, representing the invasion of the land by the sea during the glacial period. The fact that in a substance as rigid as ice these movements can take place without fracture, shows us that there is nothing in the solidity of the earth to prevent such movements.

It must not be thought that this view requires us to suppose the interior of the earth is a fluid mass, although it is quite reconcilable with that theory. I am inclined to cling to an opinion set forth by me some years ago that the central region of the earth is quite rigid, while between the outer fifty miles of strata and basement rocks, and the inner core of solid matter, there may remain a section which has not yet been completely solidified, and still admits of sufficient movement to give us the rise of the continental folds and the sinking of the sea floors. Nor am I satisfied that the condition of the mass on which the so-called crust rests, is such as can be called fluid, judged by the tests we apply to objects on the earth's surface. A rigidity such as belongs to the metals of average resistance to compression might permit such movements as we find to occur in masses urged by the enormous tensions to which our continents are subjected.

There can be hardly any question that the conclusion that the continents are kept in their attitude by constant tensions, is necessary and indisputable. As a factor in determining the position which any point occupies with reference to the centre of the earth, the weight of the mass supported must be of importance. Unfortunately the data for determining the value of this element are quite wanting; it seems evident enough, however, that we may more reasonably look to the weight of the ice accumulated on the continents during the glacial period for the depression of the land areas it occupied, than to any other cause. Only in this way can we account for the local character of the depression in many places, or for the coexistence of extensive subsidences in the southern as well as the northern hemisphere.
If this theory of the glacial depression be accepted we may obtain thereby a basis on which to compute the rigidity of the earth's crust as well as other important features connected with those parts of the earth, which though quite close to the surface, are beyond direct observation.\footnote{This report is meant to be preliminary to a more special and exhaustive study on the glacial and other dynamic phenomena of the coast of Maine.}
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