BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 14, PP. 207-226, PLS. 19-20 JULY 7, 1903

SUBMARINE VALLEYS OFF THE AMERICAN COAST AND IN THE NORTH ATLANTIC

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(*Read before the Society December 31, 1902*)

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INTRODUCTION

This paper is intended as a sequel to " Reconstruction of the Antillean Continent,"* in which the submarine valleys of the West Indian region

*Bull. Geol. Soc. Am., vol. 6 (1895), pp. 103-140.

are mapped, but its completion has been postponed, while the writer was engaged on other West Indian and Central American investigations, the results of which have appeared from time to time. In these later papers the details of the submarine topography are elaborated, but no additional studies along the Atlantic coast have been completed, though there is a fragmentary notice of some of the valley-like features.* While the key of the subject is among the West Indian islands and off the coast of Florida and Georgia, the features so repeat themselves farther northward, along the great submarine slope, that they are worthy of careful consideration. So also in the north Atlantic, between Greenland and Europe, the region is full of interest. Although the soundings off the European coast are not made along the most satisfactory lines, or carried far enough, yet the studies of Professor Edward Hull † show the general extension of the deep valleys down the continental slope on the eastern side of the Atlantic basin, and Mr Warren Upham made other studies off the American coast.‡ The submarine basins have been widely studied, but the deep incisions of the great continental slopes have been generally overlooked, although several European writers, in various languages, have described special features, and it is these features which form the present theme. Since these pages were in proof, Dr F. Nansen, of Norway, has shown me similar studies in preparation.

Submerged Plains off the eastern Coast of America §

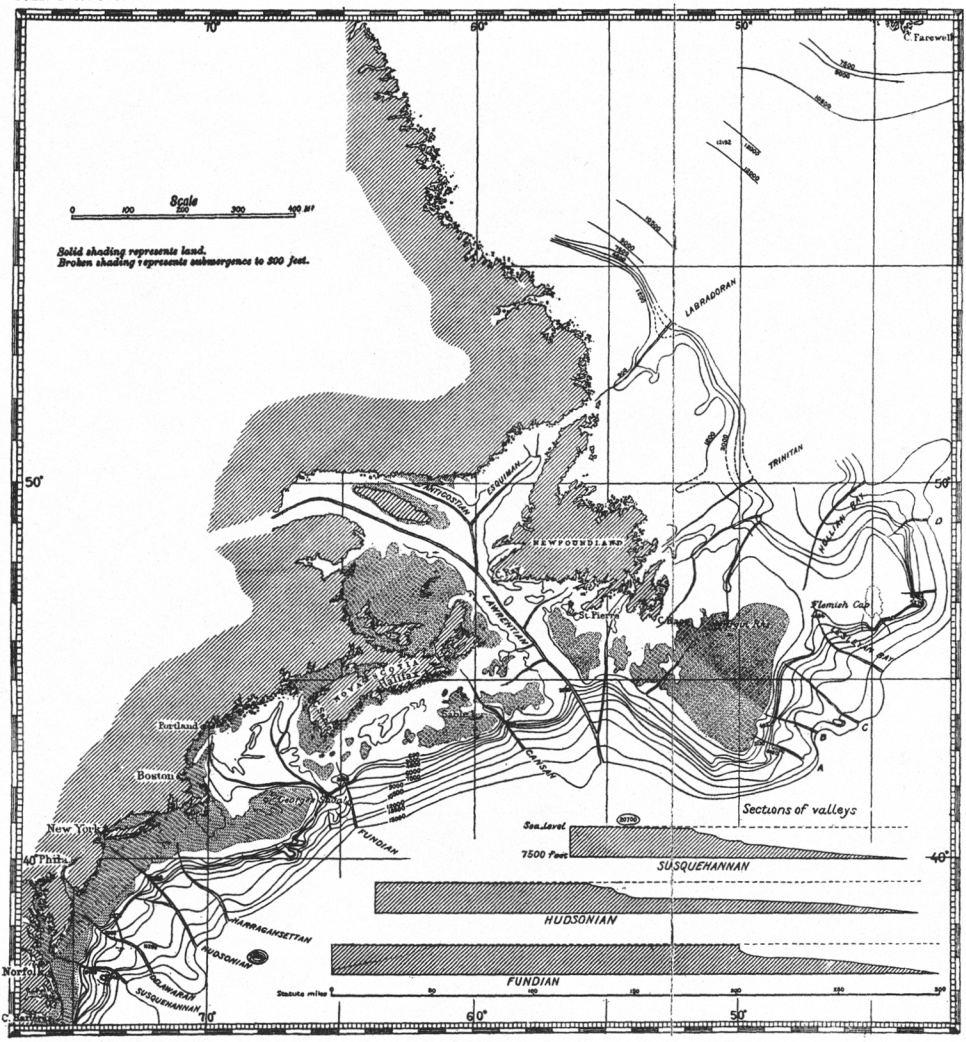
The present topic begins with cape Hatteras and extends to the margin of the Newfoundland banks. Off cape Hatteras the submerged coastal plains are reduced to a breadth of less than 25 miles. They widen to 85 miles off New Jersey, and again south of Rhode Island (Marthas Vineyard), and to considerably more between these localities, especially in front of New York harbor, while they extend 300 miles southeast of Newfoundland. From cape Hatteras to above the latitude off the mouth of Chesapeake bay, the outer edge of the submarine plains is taken to be a line at a depth of 200 to 250 feet below sealevel. Beyond that point it is fringed with a somewhat steeper slope or in places a lower terrace, whose outer margin has a depth of 400 to 450 feet. The chart contour of 600 feet occurs everywhere beyond the margin of the sub-

* Read before the Brit. Assoc. Adv. Sci., 1897; Geol. Mag., London, Dec. iv, vol. v. (1898), pp. 35–37.

† "Submerged terraces and river valleys bordering the British isles;" "Suboceanic terraces and river valleys off the coast of western Europe;" "Physical history of the Norwegian fjords," and other papers read before the Victoria Institute and appearing in the Transactions from 1898 till the present year.

‡ Bull. Geol. Soc. Am., vol. 1, 1889, pp. 563–567.

§ See U. S. Hydrographic Charts, no. 1411 and no. 21*a*.



SUBMARINE VALLEYS OF THE ATLANTIC COAST

merged plains, and is not their limit, as is popularly stated; but this line shows frequent cove-like indentations or culs-de-sac. For 250 miles eastward of Cape Cod peninsula the sunken plains maintain their general monotonous characteristics, being submerged from 200 to 250 feet with a fringing border covered by an additional 200 feet of water; but north of this submarine peninsula is the broad valley of the gulf of Maine, traversed by channels from the direction of the Kennebec, Penobscot, and Saint Croix rivers, besides that from the bay of Fundy, showing soundings from 720 to 1,080 feet, without reference to the coves or gulfs into which they enter. This region is one of drift deposits, which may give irregularity to the submarine topography, and probably accounts for the obstruction of 200 feet to the valley. South of Nova Scotia this continental border is broken into hills and valleys, showing the remains of typical coastal plains dissected by deep valleys. Between cape Breton and Newfoundland is the Laurentian valley, which will be noticed later. Beyond are the great banks of Newfoundland, extending 300 miles southeast of that island. Here is a remarkable repetition of the features of the coastal plains of the continent, largely represented by extensive flats submerged only 200 to 250 feet and forming a plateau elevated 150 to 250 feet above a lower plain. It is entirely separated from Newfoundland by a broad channel in depth corresponding to the lower plain. In both cases the soundings indicate channels from 60 to 200, and, in some cases, to 300 feet in depth, incising their surfaces. These banks appear to have had the same relationship to Newfoundland that the plains of New Jersey now have to the mountainous zones behind them.

Evidence of channels similar to those of the Newfoundland banks may be found everywhere on the submerged plains, which are manifestly continuations of the present land surfaces, but they are apt to be obstructed by sands carried by the currents or by drift deposits; but these features will be brought out in studying some of the great river channels.

Hudson River Channel

Its character was recognized by Professor James D. Dana as long ago as 1863,* but the features were not fully known until 1891, when Mr A. Lindenkohl † made use of the accumulated soundings and showed that the drowned channel of the Hudson river is clearly traceable across the submarine shelf of the continent. He says that it is first noticeable 12 miles southeast of Sandy Hook, at a depth of 120 feet below the surface

*Dana's Manual of Geology, 1863.

†Am. Jour. Sci., ser. iii, vol. xli, 1889, pp. 489-499, and Report U. S. Coast Survey for same year

of the sea. Farther on, where the coastal plain is submerged 90 feet, the channel is still 90 feet deeper. At 53 miles the channel reaches the depth of 180 feet, with a breadth of two or three miles between the banks, which are here also covered by 90 feet of water. The coastal plain is more and more submerged, until at 91 miles from the Hook its depth is 234 feet; but the channel of the Hudson here is still deeper than above, although it shows only a depth of 48 feet beneath the banks, probably due to partial filling. At 97 miles it begins to assume the form of a canyon, which continues 23 miles farther, to the apparent edge of the continental shelf. The average breadth of the river channel is one and a quarter miles and of the gorge about three miles, with a depth reaching to 2,844 feet, where the coastal plain is submerged only 420 feet. The bottom of the channel and the canyon is covered by a bluish slate-colored mud, with fine sandy grit. At this point Mr Lindenkohl stopped his inquiries. The continuation of the valley beyond, down the continental slope for 140 miles, will be noticed in its proper place (page 214).

Susquehanna and Delaware Channels

The surface of the submerged plain in this region has been so leveled by the shifting sands that Mr Lindenkohl was unable to trace the channels across it, as in the case of the Hudson, but inside of the bays he found them. Thus in the Chesapeake the channel was observed for 35 miles and found to be from one to two miles wide, with a depth from 42 to 108 feet at points where the adjacent banks were submerged to a depth of 48 feet. Below it is filled by sand bars. So also he found the drowned channel of the Delaware from 54 to 108 feet below sealevel, or from 30 to 84 feet deeper than the shoals. The obstruction of the channels by the sands appears to have been due rather to the action of currents in shallow water during epochs of slight changes of level than to their filling in deeper water at a greater distance from the shore. Further evidence of the existence of channels deeply incising the coastal plains, whether above the sealevel or below it, is found by borings which reveal them and show that the modern streams in their lower reaches are flowing over channels, now silted up to depths of 250 feet or more, the most notable being not in this region, but near the mouth of the Mississippi, whose original bed is a thousand feet below sealevel at New Orleans, though for some distance beyond the coastline it is obscured like the channels of the Chesapeake and Delaware. The former courses of these great river valleys again become apparent in the deep coves or canyons incising the edge of the continental slope, which is the principal

subject of this paper to be more fully elaborated. The channel of Narragansett bay is also traceable across the sub-coastal plain.

Laurentian and other Channels

South of Long island and New England evidence of similar channels passing into coves or canyons and gulfs frequently recurs. The gulf of Maine is a broad valley in the submerged plain, with several channels converging toward it, as has been mentioned; but by far the grandest of all the valleys traversing the drowned plains of the continent is that of the Laurentian.

The Laurentian channel from the mouth of the Saguenay extends for 900 statute miles before reaching the edge of the continental shelf. Soundings in the Saguenay fiord reach to a depth of 882 feet, but below this point the Saint Lawrence is filled so as to have a depth of scarcely more than a hundred feet; however, 35 miles farther down it reaches to 702 feet, beyond which the soundings so far taken show a somewhat less depth. A short distance still farther on a depth of 1,128 feet is shown. In the gulf of Saint Lawrence, below the mouth of the river, the depth is 1,368 feet. Even 500 miles beyond this point the incomplete soundings do not reveal a greater depth (1,350 feet), but there are intermediate measurements reaching to 1,878 feet, which show the need of fuller soundings or suggest that the lower part of the course is obstructed probably in part by drift. For the last 140 miles before reaching the edge of the continental shelf the soundings do not touch the bottom, and consequently are insufficient for knowledge of the full depth. Eventually they show that the valley enters a deep amphitheater or gulf indenting the border of the continental mass. The floor of the gulf of Saint Lawrence is generally submerged from 200 to 250 feet, or where it has been dissected the depth may be 200 feet greater, as on the margins of the coastal plains or banks. Through this floor the course of the Laurentian valley is strongly marked, and has a general breadth from 50 to 70 miles, or somewhat greater where the tributaries enter it, the most important being the twin valleys from the north of Anticosti (Anticostian) and that from the straits of Belle isle (Esquiman), north of Newfoundland. This valley has already been previously described by the writer,* being the first of his papers on submarine valleys.

Another class of channels incising the submerged plains should be noted. These are the fiords extending from the bays of Newfoundland. Thus that of Placentia bay has a depth of 846 feet and that of Trinity

*J. W. Spencer: High elevations preceding the Pleistocene period [in America]. Bull. Geol. Soc. Am., vol. 1, 1889.

bay 1,494 feet, with their courses apparently obstructed to the amount of 300 and 600 feet, supposedly by drift deposits, in a manner not seen among the channels in more southern latitudes. But fuller soundings may reveal the course of the valleys without so much apparent obstruction. Evidence also appears of the existence of several fiords extending from Newfoundland across the banks, but the soundings are not full enough to work out the old hydrography. A valley (the Labradoran) trending northward from the straits of Belle isle, between Newfoundland and Labrador, is shown to a depth of 1,500 feet, and Hamilton inlet, in Labrador, reaches to 1,800 feet, with its lower portion seemingly blocked in part. These apparent obstructions by drift deposits are of much value as showing that the valleys were formed before the epoch of glacial drift. This inference as to the age of the buried valleys may be carried farther south.

Among the shallower soundings of the Laurentian valley, already explained by either insufficient exploration or to drift filling, those reaching to about 1,800 feet sufficiently establish that the general depth of the valley throughout the greater portion of its length is equal to this amount, while the channels through the gulf of Maine are not known to have exceeded 1,100 feet. Such valleys continue to within a few miles of the edge of the continental margin, where they are abruptly precipitated into coves, ampitheaters, or gulfs.

The submarine valleys mentioned are continuations of those of existing rivers. Others are not traceable to the modern rivers, because submergence even to their sources, as the Cansoan valley, which heads in the straits of Canso, and the Esquiman and Labradoran, which approach each other in common in the col, now sunken to form the straits of Belle isle, between Newfoundland and the continent. So also the banks of Newfoundland are nearly dissected by the Lesleyan and Hullian bays, all of which are now beneath the Atlantic waters.

Characteristics of the submerged Continental Slope

In general

From the narrowed continental shelf off cape Hatteras there is a rapid descent to 3,096 feet in 7 miles, and then to 9,582 feet in the next 6 miles, without the revelation of any intermediate ledges. This is the most abrupt descent shown in the continental slope. North of this point both the submerged coastal plain and the great continental slope widen rapidly, as they do southward. Off Nova Scotia the zone of descent is somewhat reduced in breadth, and at some points off the Newfoundland banks

it becomes precipitous, which is like that near Flemish cap, off cape Hatteras. At various points are suggestions of submarine plateaus in the slope, owing to the occurrence of somewhat extensive plains with only slight gradients—for example, southeast of New Jersey, between the contours of 9,000 and 10,500 feet, which are here some 60 miles apart.

SUSQUEHANNAN VALLEY

In the margin of the continental shelf in front of Chesapeake bay there is a strongly marked indentation corresponding to it. Here at some distance within the 600 line connecting the promontories on its two sides the depression or valley reaches depths of 4,686 and 5,154 feet, enclosing a cul-de-sac or gulf, having a still farther descent to 6,420 feet below sealevel. Some 15 miles farther outward the valley reaches to more than 9,846 feet, thus making known another abrupt step in it. From this point the valley descends only about 900 feet in the next 30 or 40 miles, but it has a depth of 1,500 feet below the floor of the adjacent continental slope. In this locality an outlying fragment of a submarine plateau appears at about 5,000 feet below sealevel, and overhangs by nearly 5,000 feet the adjacent valley to the north; but the valley bends round to the east of this promontory, where it has descended to the great depth of 8,000 feet below this fragment of a submarine tableland, and has a depth of 12,840 feet below sealevel at a distance of 60 miles from the head of the cul-de-sac or cove, indenting the edge of the continental shelf. About 30 miles farther it enters an embayment shown by the 15,000-foot line. This embayment has a length of 150 miles and a breadth of 70 miles, with a depth from 1,200 to 2,400 feet below the floor of the lower plains of the continental slope. Thus the Susquehannan valley occurs all the way down to oceanic depths.

THE DELAWAREAN VALLEY

Mr Lindenkohl first called attention to a cul-de-sac of 2,376 feet inside the 600-foot contour in front of Delaware bay. At a point about 95 miles from cape May, in the same direction, incomplete soundings show the valley reaches to 3,000 feet below sealevel, where the adjacent continental slope is only 1,200 feet below the surface, and 10 miles farther the depth of the channel is 6,066 feet, or about 1,200 feet deeper than the neighboring sea bottom. For the next 90 miles the valley is shown in the contours, and at this distance its depth is 11,256 feet below sealevel, or more than 1,000 feet deeper than the adjacent continental slope. Some 50 miles farther it enters the Susquehannan embayment, as already mentioned. A little farther north than that of the Delaware, Mr Lindenkohl

found another cove or gulf at 2,334 feet, which is probably a tributary of the Delawarean valley from Great Egg harbor.

The contoured chart brings out prominently the submarine peninsula extending far seaward and separating the Susquehannan embayment from that of the Hudson.

THE HUDSONIAN VALLEY

Mr Lindenkohl gives the head of the Hudson canyon at 97 miles from Sandy Hook, and in the next 23 miles shows that it descends from 234 to 2,844 feet (see page 210). The soundings in the line of the Hudson channel beyond this point are unfortunately scanty, but from those on either side, when connected by the intermediate contours drawn in the usual way, parallel with the inner lines, the continuation of the valley may be inferred by the evidence of an embayment between 11,400 and 15,000 feet below sealevel, and in a distance of about 110 miles the descent is found to be 8,500 feet from the bottom of the cul-de-sac above mentioned, which is already nearly 3,000 feet below sealevel.

In front of Narragansett bay there is a strong embayment in the 9,000-foot contour, and here are several closely located soundings showing the indentation of the continental slope. This valley seems to be a tributary to the Hudsonian embayment.

THE FUNDIAN VALLEY

Some distance eastward of the Cape Cod peninsula the continental slope is narrowed to a zone of 50 miles, and here south off the Georges shoals the edge of the submerged coastal plain is indented by two great gulfs, one of which has a depth of 2,520 feet below the adjacent promontory (which is 5,580 feet below sealevel, while the great cove is 8,100 feet). The other cul-de-sac shows 1,860 feet inside the 600-foot line and farther on descends to 6,702 feet, while the bounding promontory, even 10 miles or more beyond, is covered by a reduced depth of 5,802 feet of water. Eastward of this point we reach the canyon of the Fundian valley, which across the submarine coastal plain has already been described. Its well marked channel at this point descends abruptly into the canyon, which heads in an amphitheater having a depth of 4,080* feet, 10 miles within the 600-foot line. In the next 15 miles the descent reaches to 6,984 feet. In another 30 miles its depth is 9,000 feet, and at least 1,200 feet deeper than the adjacent sea floor. An indentation in the lower zone of the continental slope corresponding with the valley is plainly shown at 15,000 feet.

* This is a recent sounding, here used in place of 3,510 shown on map.

A short distance east of the Fundian canyon there is a fine cove deeply indenting the edge of the submerged coastal plain at 600 feet, with a depth of 3,648 feet.

THE CANSOAN VALLEY

The Cansoan valley, though interrupted by apparent drift deposits, has a depth of 1,080 to 1,200 feet across the coastal plain, after which it rapidly descends to 7,020 feet into a cove more than 2,000 feet deeper than the adjacent floor to the southwest of it.

THE LAURENTIAN VALLEY

On reaching the edge of the continentel shelf, like the other valleys it descends into an amphitheater 3,666 feet deep. This may be found to be not the deepest part of a canyon-like valley when closer soundings are taken, as was the case with the Fundian valley. Unfortunately the soundings are few, and the continuation can not be located, but there are several soundings which show a strong indentation in the continental slope to a depth of 15,000 feet. From Placentia bay, Newfoundland, a valley also passes over the margin of the banks by way of an amphitheater or cove.

VALLEYS OFF THE NEWFOUNDLAND BANKS

Southeast of the Great bank the descending valley is seen within the 600-foot line at 3,120, at 11,100 (where it is 2,520 feet below the adjacent submerged cliff), and again it appears at 12,738 feet, indenting the 12,000-foot line. Another similar valley occurs just north of this one, where the cove reaches to 4,944 feet, while the adjacent shelf is only 690 feet below sealevel. This valley is also traceable down the slope. Flemish cap is the highest flat of the submerged bank of the most eastern extension of the continental mass. In this locality the great slope descends very rapidly to oceanic depths; but even here we find evidence of a cul-de-sac of 5,000 to 6,000 feet deep. Between Flemish cap and the Great bank the submerged plateau is deeply indented on both sides by large valleys or embayments, which are here named Lesleyan bay (after Professor J. P. Lesley, one of the originators of geomorphy), and Hullian bay (after Professor Edward Hull, who has made similar studies on the eastern side of the Atlantic). Northeast of Newfoundland banks other valleys appear even among the scanty soundings, though there seems to be more refilling by drift accumulations than on the other side of the plateau. Thus while the fiord of Trinity bay attains a depth of 1,488 feet, it is not seen across the banks, while an adjacent one reaches to

2,430 feet, where the lateral bank is only 1,020 feet below sealevel. While the drowned col in the straits of Belle Isle is 240 feet below sealevel and the Labradoran channel (here so named) trends northeastward and is seen to become a valley at a depth of 1,500 feet, the soundings are too few to mark its further course. From the same col, but extending southeastward, is the Esquiman channel, joining the Laurentian valley.

SOME FEATURES OF THE CONTINENTAL SLOPE

It is notable that the embayments into the continental slope in front of the great valleys mentioned are much deeper than would be suggested by the outline of the present shores. The approximation of the Lesleyan and Hullian bays indenting the opposite sides of the last stretch of the submarine continuation of the American continent is such a feature as characterizes the atmospheric erosion of tablelands with their ultimate dissection into separated plateaus. The cul-de-sac, coves, or gulfs are found to indent the border of the continental mass for distances of 8 to 20 miles or more, and even the incomplete soundings show that their width is reduced to even 3 miles, but they enter lower embayments, widening to 5, 10, or even 20 miles or more when far seaward, but yet no wider than the lower reaches of valleys of existing rivers.

The declivities of some of the greater valleys observed do not show a greater slope than about 100 feet per mile. Except for short tributaries from plateau regions, this is too large an amount for normal valleys. The data are insufficient to work out the gradients, as has been done in the case of the Floridian channel, where it is often about a foot per mile for long distances, succeeded by rapid descents from one step to another. However, we find everywhere in the coves or gulfs, indenting the margin of the drowned continental shelves, the evidence of abrupt or rapid descent from step to step, although we do not know the gradients between them or of the further descent of the valleys. Such submarine features are repetitions of what may be seen on the tablelands of Mexico and Central America, with the slopes between the steps greatly reduced.

Geological Characteristics of the Region traversed by the Valleys

From the occurrence of the geological formations of the adjacent coastal plains some inferences of the character of the submerged plains may be formed, which to some extent are sustained by the direct evidence of the materials brought up by the dredges. Thus we can form an idea of the age of the valleys.

From New Jersey onward to Newfoundland, surface deposits of drift

are to a greater or less extent developed, and these partially obstruct the valleys (pages 211, 214, 215). Off cape Hatteras, dredgings bring up quantities of old Miocene water-worn shells mixed with modern species. Miocene beds occur in Maryland and New Jersey, while they have been removed from Long island, which is surmounted by drift; but fragments of Miocene beds recur in Marthas Vineyard, and have been recovered by dredgings from depths of 35 to 70 fathoms, off the Georges shoals, south of the gulf of Maine. The same have been found on the Banquereau, southeast of cape Breton, adjacent to the Laurentian channel. Again Tertiary fossils have been obtained from the great bank of Newfoundland (latitude 44 degrees 30 minutes, longitude 50 degrees 15 minutes). While the drowned plains off Maryland and New Jersey are covered by sands, these do not appear in the Hudson channel, as it incises the continental shelf, for here is found a fine blue clay. It thus appears that the completion of the valleys of the submarine coastal plain has been since the old Miocene period, and their origin, due to atmospheric erosion during a period of land elevation, may not be questioned. The great Laurentian valley doubtless owes part of its origin to a much earlier date, but while it is excavated out of all the formations represented since Archæan times, it cuts through Carboniferous and Triassic rocks, and consequently is of later date. As has been shown by Professor W J McGee,* the great period of erosion was after the accumulation of Lafayette formation, and these deposits, as the writer has seen, underlie the drift of New Jersey. The Lafayette was accumulated after a long period of Tertiary erosion of this region, and is provisionally regarded as of late Pliocene age. Doctor Dall has shown that some fossiliferous beds beneath the Dismal swamp of Virginia are referable to the Pliocene period. The pre-Lafayette erosion gave rise to flattened topography of the old Miocene surface. The formation of the channels of the Coastal plain, or their reopening, was after the Lafayette period, or early Pleistocene epoch, when the fiords of Newfoundland and Nova Scotia were fashioned, but prior to the accumulation of the drift or the Columbia formation, both of which kinds of deposits rest on the post-Lafayette topographic surfaces.

From the continuity of the continental shelf with the coastal plain and the occurrence of similar formations on the outlying banks, one is led to conclude that the plains, whether now above or below sealevel, form one feature, and that the sands, more or less filling the valleys, is only such a feature as would be produced by the slight changes of level that have occurred since the mid-Pleistocene epoch. It is also interesting to note that the banks of Newfoundland, which show the same character of submarine plains as in the region south of the drift, are not so

* The Lafayette.

covered with it as to prevent the recovery of Tertiary deposits and establish the common origin of these plains with those existing in New Jersey.

Some Valleys of the North Atlantic and adjacent Arctic Basins*

VALLEYS BETWEEN GREENLAND AND AMERICA

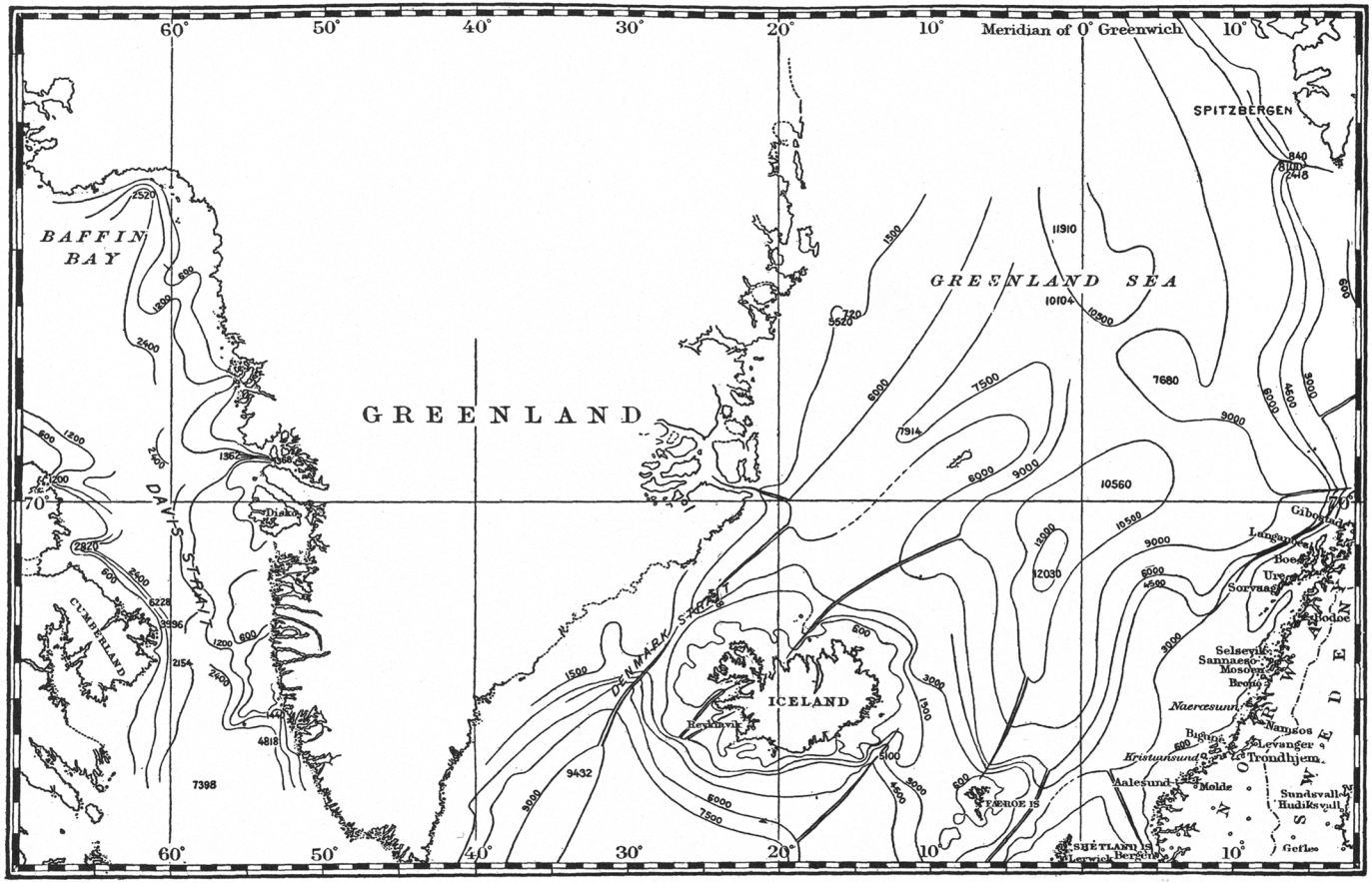
The soundings beyond the Newfoundland banks are insufficient for study. One line between Labrador and Greenland shows a rapid descent from the continental shelf (here less than a thousand feet below sealevel) to 5,220, and farther on to 9,732 feet, beyond which the descent is more gradual to the depth of 12,196 feet, which is in the center of the arm of the Atlantic basin between Greenland and the continent. Between Greenland and the southern point of Baffins Land the depth is reduced to 8,100 feet, and a little farther northward to 6,600 feet, though there may be a deeper channel not made known. In latitute 66 degrees the soundings are numerous and show fragments of the Greenland coastal plain, even to a breadth of 70 miles, with a submergence of less than 300 feet, while the trough in Davis straits, except in narrow channels, is reduced to 2,160 or 2,270 feet. Here is the col between the arm of the Atlantic basin and Baffin bay, in which, nearby, are culs-de-sac, one reaching to 3,996 feet, with the bay beyond, having a depth of 6,000 feet, and another 5,580 feet within the 1,700-foot contour line. The soundings are moderately numerous and show magnificent fiords to depths of 4,000 feet. While at first sight the soundings here suggest that Baffin bay is a distinct basin, yet upon second consideration, owing to a considerable part of the bay having only a moderate depth, this apparent form may be due to partial obstruction of the straits by glacial or iceberg deposits or to the soundings being insufficient to reveal a restricted valley beneath this narrowed arm of the sea. Some of the deep tributary fiords, however, are not refilled with drift to the point of distinction, as off Newfoundland and Norway.

The maximum depth of the lower part of Hudson straits is unknown, except that it is more than 1,800 feet deep at several points, while several hundred miles westward it is 1,200 feet, and Hudson bay, even near its outlet, much less. The upper part of Hamilton inlet has a depth of 600 feet, but the coastal plain in front, much of which is shallow, is not known to be covered by more than 200 feet of water.

VALLEYS BETWEEN GREENLAND AND SCOTLAND

The soundings in this belt are numerous and full of interest. While there are many illustrations of the oceanic basin wherein the submarine

*See the U. S. Hydrographic Charts, nos. 21*a*, 21*b*, 318, 1531.



SUBMARINE VALLEYS OF THE NORTH ATLANTIC AND ARCTIC BASINS

Soundings and contours in feet

plateau of this region is shown, the writers have given no attention to the relatively small valleys, in size and characters like those of rivers, too small to be represented on the ordinary maps, except by undue exaggeration. . It is these valleys and their enlargement into submarine bays which are the principal source of interest to the writer. In this region the North Atlantic plateau (the Wyville-Thomson ridge) rises to separate its basin from that of the Arctic.

Iceland is bordered by a subcoastal plain, on the west reaching to a breadth of 70 miles; but it is deeply indented by submerged valleys, one of which is 648 feet near its head, where the adjacent floor is submerged only 84 feet. This canyon is traceable for 60 miles, with a depth of 600 feet below the coastal shelf itself, and then widens into an embayment. Similar features are repeated round the whole island, some of which are shown on the map (plate 20). From recently made Danish soundings it would seem that the great fiord traced (see map) north of Iceland should enter the Arctic embayment west of that shown on map as the one with which it connects. Doctor Nansen is now extending these studies.

Between Greenland and Iceland the submarine plateau rises to within about 1,500 feet of sealevel, except in a channel where the depth attains 1,968 feet. The submarine plateau is here incised by amphitheaters, coves, or gulfs to the depth of 600 to 1,200 feet, and these widen out and become very deep valleys. Thus one can be traced from the col for 150 miles, where its depth becomes 3,000 or 4,000 feet below the submarine plateau. The fiord of Scoresby sound has a depth of 1,800 feet far within the landlocked mouth. Its lower part does not show so great a depth, supposedly on account of glacial or iceberg drift. In latitude 74 degrees north is a finely shown cove attaining a depth of 5,520 feet, where the adjacent plateau is submerged 720 feet.

VALLEYS BETWEEN ICELAND AND THE FAROE ISLANDS

Between Iceland and the Faroe islands the plateau reaches to within 1,500 to 1,662 feet of sealevel. Near Iceland it is incised by a fine cul-de-sac, obtaining a depth of 4,092 feet, where the floor at its head is 960 feet below the surface, and beside it 2,100 feet; thus the submarine valley itself has a depth of 1,992 feet. North of Faroe islands is an embayment reaching to a depth of 7,290 feet, while an extension of the plateau toward the east is covered by 1,224 feet of water. Near Iceland the southern side of this ridge is marked by another cul-de-sac at a depth of 4,092 feet below the surface, or some 2,000 feet deep in the plateau itself.

VALLEYS BETWEEN THE FAROE AND SHETLAND ISLANDS

Between Faroe islands and the Shetlands the North Atlantic plateau is more deeply incised than in the stretches to the westward. Here is an

incision in the so named Lightning channel with a breadth of 30 miles, where the col is submerged to a depth of 3,180 feet. From this trough a valley descends northward to the Arctic basin, and one with more rapid gradient to the deep Atlantic arm between the Rockall banks and Scotland, which has been mentioned by Professor Hull and others, as has also the Sognefjord (over 4,000 feet deep), a tributary of the Arctic basin.*

The troughs of the Arctic basin expand and deepen west of Spitzbergen, where a depth of 15,900 feet is reached (latitude, 78 degrees 30 minutes), and beyond this Nansen did the greatest Arctic work in finding the continental slope bordering the Eurasian continent, and thereby establishing almost with certainty the absence of polar lands. Even the occasional soundings show finely the occurrence of a great cove southwest of Spitzbergen, which obtains a depth of 8,100 feet, where the plateau beside it is only 2,418 feet below sealevel, and at the head of it, 10 miles landward, the depth is reduced to 800 feet. An amphitheater in the continental shelf off Tromsoe, Norway, attains a depth of 5,100 feet where the adjacent sounding is only 1,494 feet. This northern basin is most interesting and suggestive. It is modified by islands and sunken plateaus, like the Caribbean and gulf of Mexico basins, and its features as far as known are in harmony with the tropical ones between the two Americas.

VALLEYS BETWEEN AMERICA AND BRITISH ISLES

Between America and the British isles the North Atlantic plateau rises to the summit described. There are a few troughs which show arms of the Atlantic basin deeply indenting it, enough to suggest that when fuller soundings are made south of the Icelandic ridge valleys trending from that ridge may be traceable to the indentations of valley form at depths of 12,000 feet in about latitude 52 degrees, made known by cable soundings. Similar suggestions of deep valleys or embayments appear northwestward of the ridge of the Azores.

On the Origin of the Submarine Valleys

The origin of submarine valleys attaining a depth of even 1,000 or 2,000 feet in the continental shelf, and whose outer edge is submerged 300 or 400 feet, although implying a recent elevation of 2,000 or 3,000 feet, need scarcely be called into question. While these channels pass through canyons and descend abruptly into the deeper valleys which open out into embayments in the great continental slope to depths of

*See Professor Hull's papers cited before.

12,000 or 15,000 feet, it may seem difficult to explain these lower reaches by the hypothesis of atmospheric action during a period of emergence on account of the stupendous changes of level of land and sea required; yet the writer has ventured to adopt this hypothesis, in which he has been confirmed by many years of research. But from the broad standpoint the complex conditions doubtless qualify the simple hypothesis of the former elevation of the land with its consequent sculpturing by atmospheric agents. While some of the valleys may be attributed to tectonic or orogenic, or occasional ones to volcanic causes, no explanation based on these causes has been worked out in detail; consequently the author has been led, after presenting the facts given in this and other papers, to emphasize particularly the resemblances between these submarine valleys and land features, with the conclusion that the former were sculptured on the great continental slopes by atmospheric agents, which implies a greater change of level of land and sea than the 2,000 or 3,000 feet above mentioned. If it were a question of simple elevation, it would amount to 12,000 or 15,000 feet higher than at present along the border of the continent. This great elevation, however, may have been much reduced by an unequal bending down of the continental slope, or indeed to some extent by a shifting of the oceanic waters. Then also arises the question, What became of the waters, and also what were the causes of these great continental movements, about which we know nothing? The problem thus becomes so complex that the writer has to confine himself to the study of the resemblances above mentioned. While the features along the Atlantic coast are repeated on the eastern side of that basin and elsewhere, the author could not possibly imply a general drainage of the basins, but rather that there have been alternations, whereby great regions have been elevated while others have been depressed, as, for instance, the West Indian islands alternating in altitude with the lands of Central America. We know that in the epeirogenic movements the changes of level are unequal, with the rate of elevation or subsidence increasing or diminishing, and from the writer's observations such rates increase on approaching mountain regions and diminish in the direction of the plains. This, extended to the great continental slopes, would favor the theory of their having been abnormally bent downward; consequently the land may not necessarily have stood 12,000 or 15,000 feet higher than now, although the bottom of the slopes had been emerged to that extent. Still the land stood very much higher than at present, probably sufficient to give rise to glacial conditions in the north.

While the amphitheaters, coves, or canyons indenting the edge of the submerged continental shelf are known to have a breadth increasing

from 3 miles (that of the Hudson) to 5 or 10 miles, or where farther down the continental slopes the valleys open into embayments of 20 or 30 miles, even that breadth is no greater than can be seen in the lower reaches of many land valleys. It is seldom that we are able to restrict the channels to their actual breadth for want of closer soundings, such as have been made along a part of the Hudson valley and along the submerged extension of the Congo river, the last of which I may be permitted to refer to as a most detailed piece of work in revealing buried channels. Here the soundings were taken so as to obtain contours at given depths apart, which were often not more than half a mile. Thus Mr J. Y. Buchanan* found the depth of the river to be 900 feet at a dis-

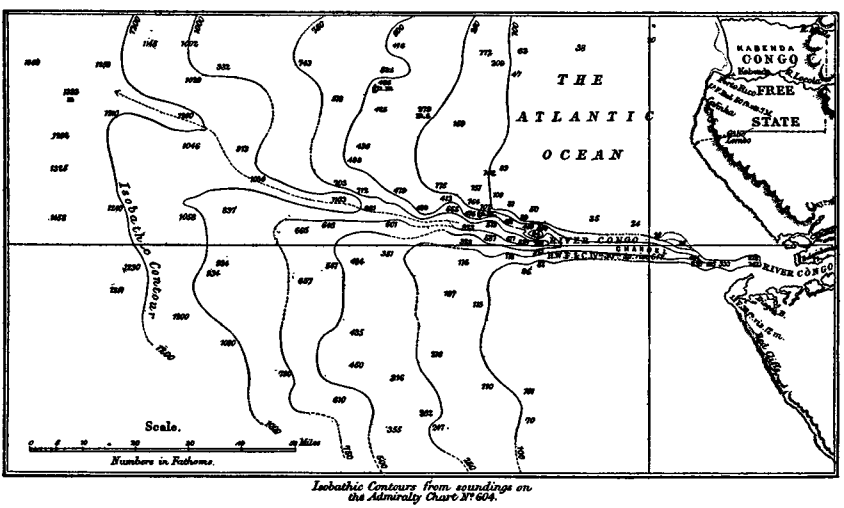


FIGURE 1.—*Submarine Channel of the Congo River.*

Soundings in fathoms.

tance of 20 miles above its mouth, where there is an obstructing bar. At 35 miles from the coast line the canyon has a breadth of 6 miles and a depth of 3,000 feet below the submerged plateau. The 6,000-foot contour of the continental slope recedes landward for 30 miles at this point. Beyond, Professor Edward Hull finds that the valley at over 7,500 feet indents the great slope for 20 miles landward. On account of the excellency of this study, the map of the Congo channel is here reproduced.

Again, outside the region of the present study we find many illustrations better revealing the form of the valleys than those so far deter-

*Chart taken from "The suboceanic river valleys of the west African continent," etcetera, by Professor E. Hull. Trans. Victoria Institute, vol. xxxii, 1900. Also see Mr Buchanan's paper, Scottish Geog. Mag., vol. iii, 1887, pp. 217-238.

mined off our own coast. Thus on the chart between Jamaica and Central America there is a submarine plateau rising almost to sealevel, and in the accompanying illustration this may be seen in places incised by narrow channels, and, again, these, uniting from the opposite side of the submarine plain, divide it into separated banks or islands. These suggest, not merely a moderate elevation that formerly obtained, but also one of considerable amount, as, for example, those seen between Jamaica and Haiti, where the lower plateaus are indented by the 500 and 1,000 fathom contours.

One other point may be again referred to here—the gradients of the valleys down the continental slope. As the great descent is usually

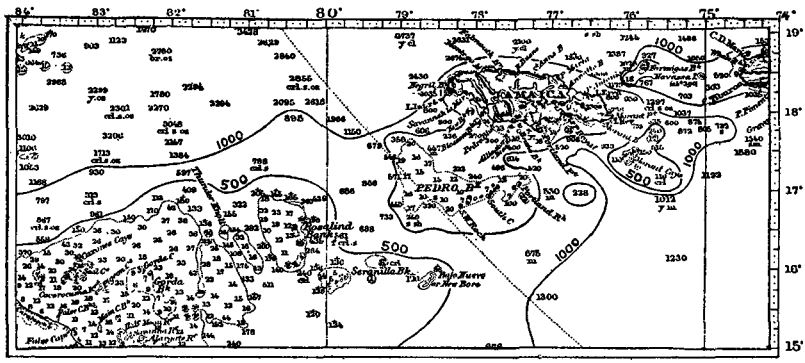


FIGURE 2.—*Chart of Area between Haiti and Central America.*

Showing dissection of banks by narrow channels and valleys. Soundings in fathoms.

restricted to a comparatively short distance, the mean declivity of the valleys at first seems too great for comparison with those of the land, but, as we have already found, these are often characterized by abrupt steps, with more gentle gradients between, similar to the valleys descending from the high plateaus of Mexico and Central America or the tributaries of the Colorado canyon, which descend 3,000 feet in perhaps 10 miles. But, in order to reveal their true character, the soundings must be made close together for this purpose, as the mean slope gives us no information whatever; and so, for the present, the best the writer can do is to compare them with land valleys from high plateaus, which is justified in the study of the Floridian channel, which descends by long stretches, with gradients of a foot or less per mile, as small as that of the Mississippi, succeeded by precipitous steps like those from one submarine plateau to a lower.

To cover all the questions raised would far exceed the limits of this

paper, the object of which is to record the facts given, with a brief statement of the writer's explanation of these most interesting phenomena.

Summary and Conclusions

The coastal plains of the continent pass under the sea and extend for 20 miles off cape Hatteras, 70 to 80 miles off New Jersey and beyond, again somewhat reduced in breadth, but widening out to 300 miles southeast of Newfoundland, now forming the banks. Their gradient is almost unappreciable to a depth of 200 to 250 feet. In front of this margin is a lower terrace, extending for a few miles to a depth of 400 to 450 feet, beyond which the great continental slope begins. The terrace form is best shown on the Newfoundland banks, while the outer slope of the submerged plain is wanting off cape Hatteras. These plains are often incised with channels to depths of 100 to 200 feet or more, suggesting their more reccent elevation of 400 to 600 feet. Adjacent to the coast the channels are apt to be filled by delta deposits or by sands drifted by the currents during the slight changes of level of the land, in the same way that great sandbars, with lagoons behind them, have been formed along the Atlantic coast.

The Laurentian valley has a breadth of 30 to 60 miles, with a depth of 1,200 to 1,500 feet below the submerged continental plain. The Fundian valley and its tributaries have a somewhat less depth. The drowned lands in this region have the same general physical characteristics as the coastal plain farther south, except the irregularities due to drift and to the less prevalent coastal sands, so that the Tertiary deposits of the banks may be seen, traversed by river-like channels.

Although the Laurentian and Fundian valleys are of greater age, they were kept open or reopened in the late geological epoch when channels were made in Tertiary beds. They were a feature when the land stood about 2,000 feet above the present altitude and not much higher, else the deeper outer valleys would have receded farther landward; but the margin of the continental shelf is everywhere incised in continuation of the channels of existing rivers by coves, amphitheaters, or gulfs to depths of 2,000 to 3,000 feet, where the submergence of the plains is from 250 to 400 feet or a little more. These features are the same as those on the border of the Mexican tableland. The submarine canyons widen into valleys, more or less apparent, to the foot of the great continental slope. So noticeable are they in contouring the soundings that they force our attention to them, although the data is not as full as could be desired. In descending the slope there are apparently lower gulfs or

stretches with exaggerated gradients, separated by reaches of only gentle decline, forming steps. Occasionally outlying portions of the continental slope seem to become terraces or more deeply submerged plains of slight inclination, with promontories extending from them, overlooking the deep valleys; as, for example, the valley of the Chesapeake passes over two precipitous declivities of 2,000 to 3,000 feet each, and it is traceable for upward of 60 miles from the edge of the continental shelf, where it enters an embayment at the foot of the continental slope. The coves or gulfs of the Delawarean, Hudsonian, Fundian, Cansoan, and Laurentian valleys are each characterized by the deep steps just noted. So also there are amphitheaters indenting the edge of the coastal plain submerged far away from present shores. These valleys traceable down the continental slope are in size no greater than those of existing rivers. The phenomena of all these strikingly repeat themselves. The valleys seem quite independent of mountain folds and are more or less at right angles to the orographic system, though the rivers entering them may either cut across the mountains or occupy depressions parallel with them.

The incisions in the floor of Baffin bay and Davis straits are magnificent examples of coves, canyons, and valleys indenting the land masses, though they are now sunken to form fiords. The Greenland-Iceland-Shetland ridge, which comes near the surface of the sea, is also incised by similar valleys trending in opposite directions toward both the Arctic and Atlantic basins, so much so that it would not be a bold prediction to expect to find submarine river valleys descending the North Atlantic plateau if close soundings were made. Even these deep gulfs have been discovered far north, off Spitzbergen. Thus, while there are local variations, the exact phenomena of land features are found from tropical to arctic zones and from regions of volcanoes to those of glaciers, whose forces are subordinate to atmospheric action, which appears to have stamped itself upon the great submarine slopes of the continent.

Passing over the old topography of the continent to its margin, it appears that the features described are newer than the remnants of the Miocene accumulation of the coastal plains; but the period when the broad valleys were deepened into canyons was subsequent to the Lafayette epoch, and while of shorter duration than the ages which gave rise to the general features, was sufficiently long to form the amphitheaters, canyons, and valleys which we have described. These last appear to belong to the general period of glacial deposits, and suggest a recent great elevation of the land, following out the teachings of Lyell, that where now the sea is the land once stood. The minor inter or post

Glacial elevation did not exceed from 200 to 450 feet above the present level.

Appendix

As Mr Lindenkohl, of the Coast Survey, had previously made the studies of the submarine valleys along the coast, I submitted this paper to his consideration, in reply to which I received the following communication, with permission to use it, and as it brings out one or two points, I take the liberty of adding it to the foregoing paper:

"Washington, D. C., *December 26, 1902.*

"Dear Sir: I have perused with great interest your paper on 'Submarine valleys," etcetera. . . . Your statements accord very well with my recollections, and your conclusions seemed to have been reached by sound logical reasoning. . . . Are there no indications of a submerged Connecticut river, a river in which Professor Dana was greatly interested? Some years ago I traced a river channel from the entrance of Narragansett bay to two-thirds the way from Gay head to Block island, where a terminal moraine is incised by a deep gorge (216 feet). This channel disappears in a bar of about 165 feet below sealevel. Allowing 15 feet for effective depth of bar, these figures indicate the subsidence of about 150 feet since the Glacial period. There is a similar submerged channel between Block island and Montauk point.

"The channel of the Narragansettan river passes through an inner or later moraine, stretching to the northern shore of Long island. A branch of the Narragansettan river enters the sound. I have no doubt that more indications of submerged channels will be found wherever they are not obliterated by glacial drift or other sediments when a careful search shall have been made. The fact of the existence of similar channels from the European side of the Atlantic appears to me to favor the theory of an accumulation of water in the northern part of the ocean" (meaning a change of ocean level by transference of the waters, as shown in the subsequent letter) "rather than the subsidence of the land, but I assume that your close investigations into the geological structure of the Antilles has enenabled you to correctly explain the physiographical features of the adjacent sea bottom.

"Yours very truly, A. Lindenkohl."

So far as the information is before me, it seems that the Connecticut river was a tributary to that from Narragansett bay, as I know of no buried channel across Long island, nor is there sufficient indentation or corresponding cove in the edge of the continental shore, as is the case in front of Narragansett bay.

With regard to the causes of change of level of land and sea, I do not exclude Mr Lindenkohl's suggestions that part of the change may have been due to the movements of the oceanic waters, as there are many observations which sustain the hypothesis; yet at other points the deformation of the land is independent of the ocean level and in part has given rise to the changes.