Monograph on the Sub-Oceanic Physiography of the North Atlantic Ocean

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BY

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With a Chapter on the Sub-Oceanic Physical Features off the Coast of North America and the West Indian Islands

BY

PROFESSOR JOSEPH W. WINTHROP SPENCER, M.A., Ph.D.

Vidi ego quod fuerat quondam solidissima tellus,
Esse fretum ; vidi factas ex aequore terras ;
Et procul a pelago conchae iacuere marinae.

Ovid, *Metam.* xv. 262-4.

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Cartographer to the King
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The Submerged Terraces and River-Valleys of the British Isles and Western Europe

CHAPTER I

Introductory and Historical

THE appearance in the year 1895 of Professor Spencer's Memoir on "The Reconstruction of the Antillean Continent"[1] marks an epoch in Oceanic Geography. It is true that numerous writers, such as Professor Wyville Thomson, had investigated the form and depth of the floor of the ocean, and to a certain extent the streams which open out into its waters at various points. But the application of deep-sea soundings as a key to unlock the mysteries of the ocean-bed, to restore systematically its form and features, its terraces and submerged river-valleys, wherever such soundings had been made, were for the first time demonstrated by Spencer in that remarkable Memoir. In this work the author shows that the group of the West Indian Islands are only the emergent heights of a continental area which united the two Americas and enclosed the deeper portions of the Caribbean Sea and the Gulf of Mexico in the form of inland seas, bounded by two submerged terraces, those of the Continental Shelf and the Blake Plateau, which are continued round the West Indian Islands and the Gulf of Mexico, and stretch along the coast of the North American Continent to the Newfoundland Banks. He also showed that these terraces are traversed by the prolongation of the existing rivers which enter the northern shore of the Gulf of Mexico to depths of about 9000 or 10,000 feet ; and he maintains that the physical features determined by the soundings can only be explained by supposing an uplift of the whole region to the extent of 10,000 feet as compared with the present sea-levels ; owing to which uprise the waters of the present Gulf Stream were for a time shut out from the Gulf of Mexico. As regards submarine extension of the Hudson River, Professor Spencer's investigations were anticipated by America's great geologist, Professor James D. Dana, and by Admiral Charles A. Chester, U.S.N., whose investigations were made known by Mr. A. Lindenkohl. These works are fully recognised by Professor Spencer himself.[2]

From the above statement it will be seen that Spencer may rightly claim to be the founder of a new branch of Science under the name of SUB-OCEANIC PHYSIOGRAPHY, which we may interpret as the application of the sounding line to the representation of the physical features of the ocean-bed ; and not only in the Atlantic, but throughout all parts of the ocean where such soundings have been carried out to a sufficient extent to warrant their use for that purpose. Along the eastern coast of the United States and the British Dominions, as also along that of the British Isles and Western Europe, these soundings have been completed in sufficiency of number and with absolute precision by the respective Governments, including those of the Prince of Monaco ; and by the detailed soundings of the Cable Companies, to enable us by the aid of isobathic contours to restore with approximate accuracy the varied features

[1] *Bull. Geol. Soc. Amer.* vol. vi.

[2] "Submarine Valleys off the American Coast and in the North Atlantic," *Bull. Geol. Soc. Amer.* vol. xiv. (1902).

of the ocean-bed from the margin of the land to depths of over 1000 fathoms; just as by means of contour lines levelled with the theodolite or spirit-level on the land itself, we are able to present a correct picture of the physical features of the emergent areas.[1]

As it was clear that the physical features thus discovered were necessarily the result of meteoric agencies carried on over land areas, and involving enormous changes of level of the crust of the globe, it was easy to draw the conclusion that by such movements unexpected light would be thrown on various problems, such as the distribution of animal and plant life, and the cause of the Glacial Epoch. And I asked myself whether, if such great changes of level—of elevation and subsequent depression of the land as referred to above—had been determined by the researches of Professor Spencer along the eastern borders of the American Continent, similar evidence of oscillation might not be revealed on the opposite side of the Atlantic by aid of our Admiralty Charts?

Greatly stirred by these ideas, I resolved to put them to the test of actual experiment. I therefore procured copies of the Admiralty Charts, commencing with those of the British Isles, whose enclosing waters are rich in soundings, marked by numbers in fathoms. Taking the 100-fathom contour, which in some places nearly represents the edge of the Continental Platform, I traced this isobath southwards from Rockall and the Shetland Isles, round by the coast of Scotland and Ireland to the entrance of the English Channel. After that I adopted a similar course with lower levels at 250, 500, 750, and 1000 fathoms, with the result of showing that the channels of the rivers Erne, Shannon, and two others completely submerged, which I have named "The Irish Channel River" and "The English Channel River," are continued out through the British and Continental Platform, and descend through lofty walls of rock into the abyssal floor of the ocean.[2] (See Plate II.)

I need not dwell further on this part of my subject; suffice it to say that the isobathic contours as they were traced along the coasts of France, Spain, and Portugal, along the northern coast of the Mediterranean and of the coast of Africa, revealed the hidden wonders of the ancient coast lines, their bays, promontories and tremendous precipices; mouths of rivers entering the Pleistocene ocean at distances so great from the existing outlets of the same rivers now pouring down their waters from the adjoining lands, that they would be out of sight from the deck of a ship stationed directly over the submerged outlets; such would have been the case with the Congo, the Tagus, and several other rivers off the European coast.

Such are some of the physical features of the submerged landscape of Pleistocene times which will be described and illustrated by the maps in the following pages; nor can they be fully realised unless we recollect that the basement floor of the Continental Slope was at that time the actual coast-line of the now partly submerged continents at depths 1000 to 1200 fathoms from the present surface.

In the memoir, by Professor Spencer, of my researches along the European coast, in which he expresses approval and appreciation, for which I cannot be too grateful, he observes: "These contributions are new facts treated in a philosophical manner, and could now perhaps be put in a monographic form."[3] It is to be hoped that the distinguished author of the above quotation may be able to carry out this proposal as regards his own special region on the western side of the Atlantic.[4] In publishing this monograph I am encouraged to take the step by the suggestion of my friend, and thus, with the concurrence of Dr. Nansen's splendid researches in the Polar Seas and off the coast of Norway, the past history of these regions will be very fully portrayed.[5]

[1] Perhaps the most successful result of this orographic process is to be found in the representation of the mountains of Skye, known as the Cuchullin Hills, on the 6-inch Ordnance Survey Maps.

[2] The results as they were determined for successive areas were communicated in brief to *Nature* during 1898.

[3] "Professor Hull's Sub-Oceanic Terraces and River-Valleys off the Coast of Europe," the *American Geologist*, vol. xxxv., March 1905, p. 166.

[4] Since the above was written Professor Spencer has to a large extent carried out my wishes by writing for this monograph the final chapter, which adds much to the value and completeness of the work.

[5] *Bathymetrical Features of the North Polar Sea*, Christiania, 1904. This work is reviewed by the author in the *Geological Magazine*, Decade V. vol. i. No. 482, 1904.

General Conclusions

The general conclusions to which we are brought by the above investigations may be briefly summed up as follows :—

(1) That in late Tertiary times there was a general uplift of the Atlantic Ocean bed and adjoining lands to the extent of 6000 or 7000 feet or more, as compared with their present position ; the sea-level being taken as the standard of measurement.

(2) That this uprise extended from the Arctic Ocean to beyond the centre of Africa, off Cape Verd, etc., as shown by the Congo submerged valley (in lat. 6° S.), and indeed to its southern extremity.

(3) That such an uprise included the Mediterranean and bordering lands ; the Alps, Apennines, and Central Europe.

(4) That the effect of such elevation on the regions referred to would be to cause a general lowering of temperature ; and a vast increase of snow and ice in the Alps, Pyrenees, Norway, and other mountain regions ; as well as to develop snowfields and glaciers in the British Isles and other lands, such as Mount Hermon, from which they are at present absent.

(5) That at the close of the period of high elevation and intense Arctic cold, there was a general depression of the whole region accompanied by a rise in temperature ; ultimately resulting, after several minor oscillations, in the climatic conditions of land and sea at present existing.

The conclusions advocated in this volume were from the beginning accepted by several recognised Geologists and Men of Science, amongst whom I may specially name the late Professor Etheridge, F.R.S., a former President of the Geological Society ; Lord Avebury, F.R.S. ; Professor McKenny Hughes, F.R.S., of Cambridge University ; Professor J. Boyd Dawkins, F.R.S. ; and the late Professor T. Rupert Jones, F.R.S., formerly Secretary to the Geological Society, whose matured judgment on questions of physical geology will be generally recognised ; and I conclude this digression by inserting a letter received from him not long before his decease :—

CHESHAM, BUCKS, 18*th June* 1908.

DEAR DR. HULL,—I am delighted to find that your conclusions with regard to the "Submarine Platform and Valleys" have been so clearly and exhaustively reviewed with pleasing concurrence and strong support by Dr. Spencer (Professor J. W. Spencer) in his paper published in the *American Geologist* of March last, of which he has kindly sent me a copy.—Yours very truly,

THOS. RUPERT JONES.

The paper referred to is cited above, footnote p. 2.

CHAPTER II

The Continental Platform

EXPLANATION TO ACCOMPANY PLATE I

ONE of the most recent and remarkable discoveries regarding the features of the submerged region surrounding the British Isles and European Continent is the fact that these land areas do not rise abruptly from the profound depths of the Atlantic Ocean, but are separated therefrom by a continuous belt, or platform, of varying breadth and comparatively slight depth, known as "the British and Continental Platform."

This feature was originally recognised by the late Mr. Godwin-Austen as far as the region outside the Bristol Channel is concerned; and was brought before the British Association by the late Mr. Hudleston and the author at the meeting at Bristol in 1898.[1] In the chart which accompanied Mr. Hudleston's communication, the outer margin of the platform was accurately traced; but the gaps showing the crossing of submerged river-valleys, descending from the interior lands, were ignored; these, however, were indicated for the first time on the chart exhibited by the author at the same meeting.[2]

Extent of the British Shelf.—The western margin of the British Platform as shown on the adjoining map (Plate I.) corresponds, very nearly, with the isobathic contour of 100 fathoms (600 feet) running in a line from the Vidal Bank opposite the western coast of Scotland and Ireland at a variable distance southwards; and enclosing a remarkable bay or gulf having its apex at lat. 59° N.[3] The waters of the Platform bathe the shores of the Irish Sea and the English Channel and spread over the North Sea to the coast of Norway; and, as shown by Professor J. W. Spencer, extend to Iceland and Greenland; owing to which the fauna and flora of Europe are largely represented in those high latitudes, as a comparatively slight elevation would establish a land connection.[4] The Platform seldom exceeds 100 fathoms in depth, and its floor is largely overspread by silt, sand, and gravel, with shells and various marine forms of animals. Its shallowest part occurs at the Strait of Dover, which at one period formed the water-parting between the North Sea and the English Channel; throwing off the rivers in opposite directions, towards the Arctic Ocean on the one hand and the Atlantic Ocean on the other.[5]

The Continental Slope or Declivity.—From its margin as above described, the Continental Slope descends to profound depths, by a descent more or less rapid, often approaching the vertical; and, as will be shown by succeeding charts, reaches at its base a depth of 6000 to 7000 feet (1000-1200 fathoms), as indicated by the soundings. For the proof of this we have to point to the position of the submerged river-valleys,

[1] Hudleston, "Eastern Margin of the North Atlantic Basin," *Trans. Brit. Assoc.*, 1898, p. 881. Hull, "On the Sub-Oceanic Physical Features of the North Atlantic," *ibid.* p. 879.

[2] The omission of these gaps was probably due to oversight on the part of the cartographer employed by Mr. Hudleston; not to Mr. Hudleston himself.

[3] This I propose to call "The Spencerian Gulf," in honour of my American fellow-worker Professor J. W. Spencer of Washington, who contributes Chapter IX. to this monograph.

[4] *The American Geologist*, vol. xxxv., March 1905, p. 153. There can be no doubt that the North Sea bed is traversed by river-valleys emptying into the Arctic Ocean, but owing to silting up they are undistinguishable by means of the soundings on the Admiralty Charts.

[5] Though the margin of the shelf off the coast of Scotland nearly coincides with the 100-fathom contour, yet in front of the English Channel it increases in depth to 180-200 fathoms.

which open out on the floor of the abyssal ocean at the above or greater depths, as will be shown later on : for the present it is only necessary to record the fact.

Mode of Formation of the Continental Platform and accompanying Shelf.—In dealing with this problem we have to recognise that the land of the northern hemisphere has undergone enormous changes of level in Pliocene and Pleistocene times—changes of elevation and depression, and of elevation again ; this will be abundantly proved in subsequent chapters, when we come to consider the phenomena of the submerged river-valleys. The floor of the Shelf was at one time a land surface as shown by the river channels by which it is traversed, which could never have been formed under the waters of the ocean itself,[1] and the Continental Slope constituted the coast line of the ocean at various stages of elevation and depression. During this process of terrestrial movement there were doubtless pauses, when the surface of the Platform was swept by the Atlantic waves ; and the Continental Shelf was the outcome mainly of wave action and erosion on the one hand, and on the other of the action of atmospheric denudation, where the rains, rills, and streams have reduced the coastal plains to levels of no erosion ; in either case, submerged terraces or platforms result upon the sinking of the land or rise of the ocean level. The Continental Slope, formed to some extent of terraces hewn out of the rock as the land rose or fell, assumed its present form somewhat as do the now emergent cliffs on our rock-bound coasts of Norway, Scotland, and Ireland. Such, in general terms, appears to have been the process by which the submerged features were formed. It involves a recognition of a great lapse of time, which is difficult for the mind to realise, especially at so recent a stage of the world's history ; nevertheless the evidence appears conclusive that, given the necessary time, these great terrestrial results have been accomplished mainly by wave action on the lands during periods of elevation and depression, accompanied by occasional pauses giving rise to terraces.

We must not, however, lose sight of the fact that very different views regarding the origin of the continents and deep oceans have been held by eminent men, and they ought not to be passed over without due consideration. There have existed two principal schools of geographical evolution, and of the theories regarding the permanence or non-permanence of the greater features of the earth's crust. Under the former view, the depths of the ocean, as also the position of the chief continental areas, retain traces of their primeval structure, and have been only slightly modified by subsequent events. Thus, Lord Kelvin held the view that continents and ocean depths were due to differences of composition in different parts of the liquid matter which constituted the earth's surface before solidification, and from this heterogeneousness he considered that the irregularities of the present surface followed as a dynamical necessity. According to the latter view, which is that held by the author, the land and the sea have at various geological periods changed places ; and this can be demonstrated by considerations based on the distribution of the geological formations on both sides of the North Atlantic Ocean.

In a paper which was read by the author before the Geological Society some years ago,[2] it was shown how the strata constituting the Carboniferous and Mesozoic formations become attenuated when traced from their north-westerly margins towards the south-east of England ; or, in other words, swell out in thickness towards the Atlantic coast—a view supported by the results of the Geological Survey. These strata being in nearly every case of marine origin, it was inferred that the sediments of which they are composed must have come from lands lying in a direction towards which they augment in thickness ; in other words, the North Atlantic Ocean. On the other hand, Sir C. Lyell, when treating of the distribution of the Carboniferous rocks of North America, shows that the sedimentary strata increase in thickness, and become coarser in texture, as they approach the north-eastern seaboard ; attaining in Nova Scotia, according to Dawson, a thickness of 14,000 feet.[3] The conclusion, therefore, which has been drawn from

[1] In order to understand the argument underlying the conclusions adopted in this work, the reader is supposed to understand that rivers and river-valleys cannot be formed under the waters of the ocean. The effect of these waters is to retard and ultimately to destroy the eroding action of the streams on entering the sea.

[2] "On the South-Easterly Attenuation of the Lower Secondary Formations of England," *Journ. Geol. Soc.* vol. xvi. (1860).

[3] Dawson, *Acadian Geology.*

a consideration of the relations of the formations in the British Isles is supported and strengthened by that drawn from the American side of the Atlantic ; namely, that this part of the great ocean was in the condition of a land area when the bordering lands were submerged—a conclusion which is incompatible with the theory of permanence of land and sea. We are, therefore, forced to the inference that the relations of land and sea at the present day are the result of interchanges of land and sea, and movements of the crust itself.

Such changes are quite intelligible when we recognise those which have taken place in Tertiary times in the Alps, and other mountain ranges where Eocene and Oligocene beds of marine origin and containing fossils are found at elevations of thousands of feet above the ocean.

In the succeeding Pliocene period began the general uprise of the land and retreat of the sea, accompanied by increase of cold conditions which culminated in the Glacial Period. On this account, Pliocene strata are only found within comparatively short distances of the coast ; but are rich in representatives of the fauna and flora of the period.[1]

Continental Attraction. — Although we have necessarily taken the surface of the ocean as the standard of comparison for depths at any place, it is not to be supposed that this is constant over the whole globe ; on the contrary, it is well understood that the continental lands exercise an important influence on the level of the surface as measured by its distance from the centre of the globe. The land attracts the sea, and the sea attracts the land ; but as the former is (so to speak) immovable, the sea is drawn towards the land, and consequently the waters rise above the normal level as they approach the coast ; while the water being withdrawn from the central parts of the ocean, the surface falls. This is a physical result which the researches of Professor Sir G. G. Stokes, Fischer, and Hann have established. Suess lays stress on this result, which is determined by the difference of the oscillations of the pendulum in 24 hours, on an oceanic island and on the margin of a continent.[2]

An important physical result of the lowering of the surface of the ocean is, that some of the islands, now rising into land, owe their presence as such to the withdrawal of the ocean water, and others have their areas very much enlarged thereby. The present distribution of the volcanic islands of the Pacific is largely affected by the above results of continental attraction. There is an apparent discrepancy between the views of the above-named mathematicians and those of Lyell, as will be found from the following quotation : "There is no evidence from human experience of a rising or lowering of the sea's level in any region ; and the ocean cannot be raised or depressed in any one place without its level being changed all over the globe" (*Student's Elements of Geology*, p. 48 ; edit. 1874). But this does not affect the question of the results of continental attraction in determining the level of the sea above or below the mean ellipsoidal, or geodetic, surface. Fischer's formula is found by taking the difference between the observed and calculated observations of the seconds pendulum at any station or stations, and multiplying the result by 122, which gives the rise of the water surface above the mean ellipsoidal surface in metres. We must concur with Fischer as a general result that the ellipsoidal surface will intersect the actual surface in the ocean outside and beyond the margins of the continents.

[1] Prestwich, *Geology*, vol. ii. p. 425.

[2] *Das Antlitz der Erde*, vol. i. p. 2 ; trans. by Miss H. B. C. Sollas.

CHAPTER III

Coast of France and Bay of Biscay with Submerged River-Valleys

EXPLANATION OF PLATES II AND III

IN the previous chapter I gave a general description of the widespread platform from which rise the British Islands and Western Europe. But in Plate II. we are confronted with the remarkable phenomena that this platform is trenched not only by the submerged valleys of rivers descending to the sea from the bordering emergent lands, and which are visible to us through part of their course, but also by the channels of some streams which rose from land now beneath the ocean ; have never been seen by the eye of man, and which would never have been discovered by him but for the invaluable aid of the soundings. These latter streams are included within the area of the British Seas, and to them I have given the names of "The Irish Channel River Valley" and the "English Channel River Valley" respectively. Of their existence there can be no doubt whatever ; and for this we have the authority of Professor Spencer derived by a similar process to that which led to their discovery by myself.[1] We shall consider these latter channels, as being the most northerly and close to our shores, before proceeding to the former and more distant cases.

The Irish Channel River Valley.—This channel begins to be traceable opposite Milford Haven, though it probably has its origin much farther north, but is apparently silted up under the stagnant waters of the Irish Sea. Opposite the entrance to the Bristol Channel a distinct arm is thrown out which we may well infer to be the submerged portion of the Severn, which thus became a tributary to the river. Thus the combined streams, augmented by those from the south-east of Ireland, must have produced a river of considerable volume which pursued a rather serpentine course of over 250 miles across the Continental Platform till it descended with a double outlet into the outer ocean.

The North Channel Submerged River Valley.—There is known to be a river channel in the narrow strait between the coast of Antrim and Scotland which, when the Irish Channel Tunnel scheme was first projected, caused anxiety to the promoters, as the depth of its bed, filled with glacial mud and silt, was unknown and could scarcely be determined ; it lay right in the way of the proposed tunnel to connect Ireland and Scotland. It is in all probability correct to say that this hollow is the channel of a former river ; but the soundings do not enable us to infer whether the stream ran northwards into the ocean or southwards to join the Irish Channel River.

The English Channel River.—If the course of the Irish Channel River was tortuous this was not the case with its counterpart of the English Channel. Through a distance of about 300 miles from its rise somewhere near the Strait of Dover to its exit at the margin of the Continental Platform, the river pursued its nearly straight course, till its waters issued forth on the ocean through a well-defined ever-deepening cañon in the meridian of 7° W.

North of Cherbourg it appears to have received the waters of the Seine in a submerged channel of no great depth, and the streams entering the Solent in all probability formed a junction with the main channel above the meeting of the Seine. Thus augmented, the river entered on that part of its course marked on the chart as "The Hurd Deep"—a well-defined channel of 70 miles in length which, at its upper end, is about 186 feet in depth, at its centre 336 feet, and at its lower end 162 feet below the general level of the valley-floor. Along this part of its course the river channel has been kept clear by the strength of the tidal current, owing to the narrowness of the present channel between England and France. But above and below the Hurd Deep the English Channel widens considerably ; owing to which the old river cañon has been silted up until, on approaching the margin of the Continental Platform, it again becomes recognisable by the soundings, and it enters the ocean between lofty walls of rock.

[1] *American Geologist*, vol. xxxv. (1905).

Coast of France and Bay of Biscay

I have dwelt at some length on these two remarkable river channels, because they appear to be unique cases of valleys in which the streams from source to outlet have been unseen by man, and whose existence would have been unrecognised had not the sounding-line led to their discovery.

Strait of Dover Watershed.—If we endeavoured to restore the condition of the Strait of Dover during a stage in the general elevation of the Glacial Period, we should find that the chalk formation which connects England with France forms a saddle of a minimum depth below the surface of the sea of about 25 fathoms (150 feet), and that from this level the solid floor gradually slopes away westwards towards the Atlantic, and northwards towards the Arctic Ocean, thus constituting a water-parting. Down along its floor towards the Atlantic flowed the English Channel River, which we have just traced to its outlet; and we might expect to find a corresponding channel sloping to the Arctic Ocean along the North Sea; formerly conveying the waters of the Thames and other British streams, on the one hand, and of the Rhine, the Weser, and the Elbe, on the other, into the Arctic Ocean. But such an expectation would be doomed to disappointment; for the solid floor of the North Sea has been "the waste-heap" for enormous masses of glacial refuse brought down from the Scandinavian Highlands, both by ice-sheets and by floating ice-rafts, at successive stages of the Glacial Period, and spread over the floor of the North Sea. By this means as well as by the silt of existing rivers, the old river channels, which undoubtedly exist, have been filled up and buried out of sight, and are generally unresponsive to sounding appliances.[1]

Over the region of the North Sea, from the shores of the British Isles and of Holland and Denmark to the Shetlands, the depth of the water seldom exceeds 80 fathoms, and this only on approaching the margin of the Continental Platform. This margin has been traced, by means of the isobathic lines and soundings, as passing by lat. 61° N. and long. 2° E. southwards, and by the late Cav. W. P. Jervis, as indicated by a steep valley following the coast of Norway as far as the Skager Rak, where the depth reaches 430 fathoms (2580 feet) opposite the northern promontory of Denmark. This descent represents the Continental Slope on the eastern margin of the platform off the British Isles. Cav. Jervis has endeavoured to trace a possible old channel for the Rhine valley, as passing between the Orkneys and Shetlands; but the channel ("Palaeorhine") is not very clearly indicated on the charts.[2]

The Loire.—This river, in its submerged portion, traverses the Continental Platform where its breadth is about 100 miles. Its channel has been silted up, so that there is difficulty in tracing its course by means of the soundings for some distance from its mouth. Indications, however, may be observed south of Belle Île, and again at a distance of 50 or 60 miles farther west in long. 4° 10′ W. From long. 5° 30′ the channel is fully developed, and may be traced continuously by the deepening of the soundings below the general floor of the platform to its outlet, where it takes the form of a double cañon with which it passes down to the abyssal floor at a depth of about 1500 fathoms.[3]

The Gironde (*Garonne*).—A well-defined bay pointing N.E. breaks through the margin of the Continental Platform in long. 2° 40′ W. and lat. 44° 55′ N., which may be inferred to be the outlet of this large river, which enters the ocean at a distance of 70 miles from its present mouth, but owing to silting cannot clearly be connected. The relative positions of the gap and the present embouchure seem to justify the inference.

The Adour.—Of all the submerged river channels to be met with along the coast of Western Europe, none is more strikingly developed than that of the Adour.[4]

This fine river has its source amongst the highest valleys of the Pyrenees and enters the ocean at the base of this range near Bayonne. It is unique in this respect, that its submerged channel is continuous with the existing stream from its present mouth to its former outlet at a distance of about 100 miles from

[1] The direction of the flow from the Norwegian Uplands will be seen by reference to Plates VII. and VIII.

[2] Jervis, "Thalassographical and Thalassological Notes on the North Sea," *Trans. Vict. Inst.* vol. xxxii. p. 317 (1900).

[3] 9000 feet—an unusual depth.

[4] Dr. Nansen in his work on the Polar Ocean (vol. iv.), when describing the submerged river-valley of the Adour, says: "It is almost impossible to give any other explanation of its existence than of a former river-valley at a time when the whole region was elevated into land."

the coast of France; and the channel is recognised on the Admiralty Chart for some distance from the shore under the name of "La Fosse de Cap Breton." The channel reaches a depth of 1050 feet at a distance of 5 or 6 miles from the shore, and 700 feet below the surface of the platform. At a distance of 15 miles another channel joins that of the Adour on the south side; and from this point it rapidly deepens, assuming the features of a grand cañon bounded by steep, sometimes precipitous, walls of rock of 4000 to 6000 feet in height; and ultimately opening out on the floor of the ocean at a depth of about 1200 fathoms (or 7200 feet). At a few miles above the embouchure the channel bifurcates, the two arms embracing a tract (once doubtless an island) of shallower ground; thus the Adour opens out on the floor of the abyssal ocean through a double outlet of lofty walls.

Were there no other sub-oceanic channels throughout the whole coast of Europe than that of the Adour it would of itself be sufficient to demonstrate its own fluviatile origin and that of all the others here described; as throughout its course it presents all the characters of a river, in its origin, its slope towards the sea, and the branches which unite with it.[1]

Along the north-western side of the Bay of Biscay the Continental Platform reaches its greatest breadth of about 150 miles; but along its southern shore this is reduced to a very narrow breadth not exceeding 50 miles in the meridian of long. 6° W. in its widest part. But here it is trenched by channels of streams which descended from the Pyrenees between precipitous walls of rock several thousand feet in height; and precipices of similar altitude and precipitancy occur along the N.W. scarp in the vicinity of lat. 46° N. and long. 4° W. Outside these stupendous walls, and toward the centre of the bay, the nearly level floor of the ocean, formed of Globigerina ooze, descends to a depth of 2600 fathoms, or 15,600 feet. This concludes our description of this part of the European coast.

The Spectacle.—Before taking leave of this celebrated bay, the terror of the mariner, being open to the tremendous waves of the Atlantic driven by the westerly winds, we may be allowed to revert for a moment from the purely descriptive phenomena which are now disclosed by means of the sounding-line, to picture to ourselves the scenic aspect which primeval man, had he existed, would have witnessed when approaching its shores, say, from "The Islands of the Blest," and opposite the entrance to the Gironde. In front of his ship would have appeared a huge wall rising from the ocean, stretching northwards till lost in the distance, capped by a nearly level terrace, indented by bays, and breaking out at intervals into headlands, beyond which the land would be seen receding into the plains of central France overspread by the woods and forests in the distance.

Turning to the south he would see this wall ranging westward, and supporting at a short distance a range of lofty snow-capped mountains rising into the clouds, from which descended streams of ice glistering under the rays of the western sun—the whole composing a spectacle unique in its way, but scarcely surpassed in grandeur except it may be by the view of the Savoy Alps rising from Lake Leman, and seen from the crest of the Jura by the traveller descending towards the beautiful city of Geneva from France.[2]

It is one of the attractions of Geological investigation that it frequently calls the imagination into play in the endeavour to reproduce to the mind the physical features of the earth's surface in past times. In using our imaginative faculties we have before us the scenery of the existing landscape to assist us; and, with this as our guide, we can picture to our minds with much certainty that of past Geological times.

This being so, it is surely allowable, in presence of such varied and stupendous physical features as those we are now contemplating, to endeavour to picture to our minds the character of the scenery bordering the Atlantic coast at a time when Nature confronted our imaginary spectator with features so striking and so grand!

[1] These have been recognised by Dr. Nansen, Professor Spencer, and others. M. Elisée Reclus abandons the attempt to explain the origin of this remarkable "gulf" (*The Ocean*, vol. i. p. 7).

[2] As I beheld the scene half a century ago, before the snowfields and glaciers had receded to their present diminutive dimensions.

CHAPTER IV

Submerged River-Valleys off the Coast of Portugal

EXPLANATION TO ACCOMPANY PLATE IV

THE Continental Platform off the coast of Portugal is throughout its length comparatively narrow, resembling that of the coast of Spain along the southern margin of the Bay of Biscay, with which it is continuous. It seldom exceeds 30 miles in width ; and its descent into the abyss is generally steep, descending from 120 to 1200 fathoms (720-7200 feet) in a short space, and from this going down to 2000 fathoms on the ocean floor.

It is incised, however, by several well-defined cañons ; most of which are connected with the rivers now entering the ocean at the borders of the land ; but owing to the narrowness of the platform, and the consequent silting up of the channels within the limited distance, there is much difficulty in tracing the connection between the existing rivers and the channels by which they entered the ocean.

The Arosa.—In the description of some of these streams we may commence with the Arosa, near the margin of Spain and Portugal. This river probably formed a junction with the river Lerezo Veda before entering the head of the deep and wide ravine which descends from the Continental Platform at the 200-fathom contour, and opens out on the abyssal ocean at about the 1000-fathom line after a course of 35 miles, in long. 9° 35′ W. and lat. 42° 35′ N. The form of the isobaths indicates the occurrence of wide platforms bounded by cliffs on either side of the cañon.

The Lima.—The platform at this part of the coast being narrow, the head of this gorge (long. 9° 5′ W.) approaches to within 20 miles of the mouth of the river Lima at Viana. At its upper part the gorge is narrow, and descends within a distance of 10 miles to a depth of 1137 fathoms (6822 feet) below the surface of the ocean. Absence of soundings prevents any attempt to connect the outlet with the river itself across the plateau ; but there can be little doubt of the continuity of the channel.

The Douro.—Proceeding southwards along the coast, the next important river is the Douro, which has its source in the Sierra de Gata and enters the ocean at Oporto. The inward bend of the 200-fathom contour for a distance of 8 or 10 miles opposite the mouth of this river leaves no doubt that we are here in the presence of its submerged channel; and the curves of the 50- and 100-fathom contours enable us to trace the channel across the platform to a distance of only 14 miles from the mouth of the river itself below Oporto. Owing, however, to the absence of soundings in the deeper portions of the submerged bay, the exact form of this part of the channel cannot be determined ; but sufficient remain to show that the river formerly entered the outer ocean through a wide bay and with rapid descent at a depth of about 1500 fathoms.

The Mondego.—The submerged mouth of this river is the most remarkable of any off the coast of Portugal for the precipitate form of descent from the margin of the platform to its base on the edge of the abyssal ocean. For, within a distance of about 8 miles, the channel descends from the 100-fathom contour to that of 1200 fathoms, which works out at 6600 feet ; with a descent of 825 feet per mile. The walls on either side rise almost vertically several thousand feet, and enclose an exceedingly narrow passage, producing a cañon of limited length, but in its features grand in the extreme; only represented, perhaps, by some of the fjords of Norway at their upper sources. The river descending this ravine must have given rise to a series of lofty cascades or waterfalls, rivalling some of the finest of the present day. This cañon may have received the waters of the Vouga, which enters the ocean at Barra Nova and has numerous tributaries. But presumably the silting up has effaced from the chart the connecting channel.

Cañon off Cape Carvoeiro.—A profound and well-defined cañon indents the Great Declivity off the coast of Portugal, N. of Cape Carvoeiro in lat. 39° 30′ N., and is remarkable for the fact that it does not appear to be directly connected with any important river now descending from the adjoining lands. From its apex at the 100-fathom contour to its embouchure at a depth of 1500 fathoms (9000 feet) its length is about 25 miles. Its southern side is nearly a straight line, and is a precipice of several thousand feet in its deepest part—suggesting a line of fault or fracture. Its most precipitous part is immediately to the north of Burling Island, where there occurs a sheer descent of about 5000 feet; and its apex is 8 miles from the coast.[1] The unique character of this cañon, so well defined and remarkable for its features, leaves us in complete ignorance regarding its origin and mode of formation.

The Grand Cañon of the Tagus.—In the case of this, the chief river of Portugal, the submerged channel is almost continuous with that of the river itself when it emerges from the lake which constitutes the magnificent harbour of Lisbon, 11 miles in length and 7 broad, with a narrow channel (Entrada do Tejo) down which the current flows very swiftly into the ocean. There can be no doubt regarding the identity of the submerged channel with that of the river itself on issuing from the lake, as its apex is directly opposite the latter at a distance of only 5 or 6 miles, immediately south of Cape Razo. The small quantity of silt by which the channel is encumbered, as compared with the other streams above described, is due to two circumstances: first, because the mud of the river above the lake is precipitated over the floor of the lake itself; and secondly, because of the strong current above described, by which the clear waters are discharged into the ocean through the channel.

Like several of the submerged valleys already described, that of the Tagus is characterised by a double outlet, forming in plan a Delta. After descending from its apex for a distance of 35 miles in a westerly direction, and to a depth of 600 fathoms, the channel divides: one branch, which is the deeper, continuing very much in the same direction; the other sweeping round in a semicircle to the north-west, and ultimately entering the deep ocean at a distance of about 15 miles from the mouth of the former and deeper channel. There is thus enclosed a large tract, the highest part of which rises to within 66 fathoms of the present surface of the ocean. Towards the embouchures of these rivers, the waters must have entered the ocean in a series of cascades, with a total descent of over 5000 feet within a distance of 6 or 7 miles.[2]

During this period of great land elevation, the uplands and mountains of Portugal were covered by snow and glaciers, which have left their remains and effects very clearly over the surface of the land at the present day, in the form of ice-worn rocks, *roches moutonnées*, and moraines—vividly described by Sgr. J. F. Delgardo,[3]—and which must have sent down vast floods of water through the Tagus, especially during the "*période pluvieuse et tempérée*" which characterised the Interglacial Epoch, both in Portugal and in the British Isles. The phenomena which characterise the past and present conditions of this great river are of much interest, and are well worthy of investigation by students of geography. With this digression we conclude our observations of the submerged river-valleys of the Peninsula.

[1] In the series of sections crossing this cañon, in *Trans. Vict. Inst.* vol. xxxi. p. 283, at three successive stages, I have endeavoured to represent its increasing depth from east to west by scale. See Plate VI.

[2] The soundings indicate a descent of 600 to 1200 or 1300 fathoms (7200 or 7800 feet).

[3] *Note sur l'existence d'anciens glaciers dans la vallée du Mondego* (Lisbon, 1895).

CHAPTER V

Submerged River-Valleys off the Coast of West Africa

EXPLANATION TO ACCOMPANY PLATE VI

AFTER passing the Straits of Gibraltar, and following the coast of the African Continent, a change takes place in the general character of the submerged region between the coast and the abyssal ocean beyond. The Continental Platform loses much of its uniformity and importance, and sometimes altogether disappears, or passes into a more or less gradual slope from the 100-fathom contour to that of 1200 fathoms. This slope, in all probability, consists of a succession of minor terraces breaking off in steps, which it would be difficult to determine with certainty, unless with the aid of maps on a large scale containing very numerous soundings. The change seems to be indicated by the contraction of the shelf on approaching the vicinity of Cape St. Vincent, where its breadth varies from 10 to 20 miles only. Directly opposite the Straits, and again along the coast of Morocco, between 31° 10′ N. and the Canary Islands, there occurs a narrow terrace, with a steep slope from the 100- to the 614-fathom contour, and from this latter a gently shelving terrace of prolonged extent is continued down to the abyssal region of the ocean.

Along other parts of the coast, however, the descent into deep ocean is very rapid ; sometimes precipitous. Such is the case off the coast of Cape Coast Castle (Ashanti), and again off Dahomey. From Cape Lopez southwards as far as Cape Lombo, the soundings on the charts are few, except in the vicinity of the Congo ; but they indicate a wide expansion of the Continental Platform from the coast to the 100-fathom contour—in striking contrast with the precipitous coast described to the north of this tract.

Of the several great rivers entering the ocean along the western coast of Africa, including the Senegal, the Niger (or Quarra), the Congo, the Coanza, the Cunene, and the Orange, only the Congo can be traced from its source to its original outlet at the margin of the abyssal ocean. There can be no question but that the channels of all of these rivers are continued under the ocean ; but they cannot be traced on the map owing to the insufficiency of the soundings on the charts. Such is the case with the Grand Bassam (in lat. 5° N.), described on the charts as the "Bottomless Pit," which was sounded by the officers on board the ss. *Buccaneer* in 1886. The submerged channel is only traceable to the depth of the 400-fathom contour, and crosses the Continental Platform, which is here from 40 to 50 miles broad. It was originally described by Mr. Edward Stallibrass before the Society of Telegraphic Engineers ; and more recently by Mr. Henry Benest.[1]

The Niger or Quarra.—In the case of this great river we are met by a similar disappointment owing to the absence of soundings failing to reach the bottom of the old channel ; and we are only able to follow its course to the depth of about 270 fathoms, or 1620 feet. For the purpose of the soundings, this was doubtless considered sufficient by the officers employed, and it is not surprising that the experiments were not followed to a greater depth.[1]

The Orange River.—This important river, in a position not very distant from the southern end of the African Continent, would, if the data for determining its channel under the ocean had been available, have

[1] *Journ. Soc. Teleg. Eng.* vol. xvi. (1887). From a statement made by Mr. Henry Benest (*Transactions of the Victoria Institute*, vol. xxxii. p. 161), it would appear that the soundings taken over the "Bottomless Pit" by the Silvertown Company's steamer *Bree*, in 1886, were under the supervision of Mr. J. Y. Buchanan. The latest observations show the width of the channel at less than a mile and a half from the shore to be 170 fathoms. At about 7 miles from the coast the depth is 327 fathoms, and at 9 miles, 452 fathoms (or 2712 feet). Soundings are, of course, undertaken with the one object, for the information of navigators ; and when they fail to reach the bottom, at depths much below the possibility of interfering with the course of ships, or offering favourable ground for anchorage, they are discontinued.

been of much interest, as indicating the extent of the uplift of the continent in a southerly direction. But here the soundings fail us; and we are left in the same uncertainty as regards the course of the river channel after entering the ocean in lat. 28° 38′ S. as in the case of the Niger. The day may come, however, when in the interests of scientific investigation, as also of oceanic telegraphy, the defects here referred to may be rectified.

The Congo.—For a very full revelation of the physical features of the region extending under the ocean from the western coast of Africa, we are indebted to the investigations not only of the officers of the British Admiralty, but of those engaged in the important work of laying telegraphic cables for commercial communication—with results of the highest importance in connection with oceanic telegraphy in this part of the world. The following narrative of the discovery of the Congo channel is full of interest :—

In 1887 Mr. Edward Stallibrass, F.R.G.S., when engaged in laying the cable under the ocean opposite the mouth of the Congo, in company, apparently, with Mr. J. Y. Buchanan, found that at certain positions under the surface the cable broke off by its own weight; showing that the bed of the sea was intersected by some sharp obstruction or deep hollow. In order to ascertain the cause of this obstruction to progress, these engineers carried out a detailed series of soundings; by means of which they discovered that the river channel itself was continued for a distance of 100 miles from the coast and down to a depth of 1000 fathoms. They produced a map with isobathic lines agreeing very closely with that of the author, but on a smaller scale than that of the Admiralty Chart; and it only fails to give the full length of the submerged channel, which actually extends about 20 miles further out to sea than is shown by the chart of Mr. Stallibrass.[1] The break in the cable was thus proved to be caused by the sudden drop alongside the edge of the submerged valley. (See Plate VI.)

The Congo is one of the largest rivers of the African Continent, and enters the ocean in lat. 6° S. Its depth opposite Banana Creek reaches 49 fathoms. But at a distance of 5 miles, under the ocean, the soundings suddenly plunge down to depths of 228 and 242 fathoms (1368 and 1452 feet). At this point its breadth is 2 miles, with steep or precipitous sides. At a distance of 50 miles the breadth of the channel has increased to 10 miles and its depth to 813 fathoms (4878 feet). From this position the floor has a gradual descent for the next 57 miles till it reaches the maximum depth of 1200 fathoms (7200 feet) below the surface.

The total length of the cañon from its head below Banana Creek to its embouchure is about 122 miles. Throughout this distance, owing to the remarkably uniform slope of the floor of the ocean from the 100-fathom contour downwards, there do not appear to have been any great falls, or cascades; such as appear on the eastern side of the continent, as in the case of the Zambesi.

In order to realise the length of the submerged valley we may compare it mentally with distances with which we are familiar. For example, the submerged valley is twice the distance from Kingstown to Holyhead across the Irish Sea; it is more than twice the distance from London to Brighton; it is longer than the distance from London to Bristol or Birmingham; and it would require three hours to traverse by a train going at 40 miles an hour. We have also to recognise that the breadth of this valley is 7 miles near its centre, and that the cliffs are in some places nearly vertical, and rise over 2000 feet from the supposed bank of the stream.

The remarkable results derived from the soundings in the case of the Congo go far towards compensating for the small number of the river-valleys we have been able to trace, owing to the paucity of the soundings at other places along the west side of this great continent; but we may be well content with the results of our investigations, because they all tend to show, that the great uplift of the land, indicated by the phenomena bordering the coast of Western Europe, has been continued through almost, if not altogether, the whole extent of the western coast of Africa.

[1] For the first sight of this chart I was indebted to Professor Boyd Dawkins, F.R.S., and I afterwards undertook to work out the details on the Chart of the Admiralty. It is impossible to praise too highly the results attained by the original investigators.

CHAPTER VI

The Mediterranean Basin and Submerged River-Valleys

EXPLANATION TO ACCOMPANY PLATE V

THAT this great inland sea, at least in its western half, has partaken of the vertical oscillations which affected the coast of Western Europe and Africa will be readily understood. The general elevation of the ocean-bed and adjoining lands which have been shown to have taken place in the case of these countries must necessarily have extended into the adjoining regions of the Mediterranean coasts and sea-bed. But while this is the case, it is not to be expected that the physical features of these submerged lands should be as clearly developed within the confined area of the Mediterranean basin as along the Atlantic coast, confronted by the prevalent westerly winds originating powerful wave action on an exposed coast.

The coastal features of the Atlantic, both submerged and above the sea-level, including the Continental Shelf formed during a long pause in the vertical movements of the crust, and the more or less precipitous descent into the abyss, are less pronounced in the case of this inland sea. But nevertheless the old submerged coast, at the edge of the Continental Shelf, is found to descend into deep water by a broken slope down to a depth of 1000-1200 fathoms, when it gives place to the abyssal region, which descends to depths of about 1500 fathoms, or 9000 feet. As a consequence of this restricted area, the submerged river-valleys are also less clearly definable than those off the Atlantic coast of the Peninsula.[1]

The only submerged channels of the Mediterranean which I have been able to trace on the Admiralty Charts are those of the Ebro and Rhône, together with that discovered by the late Admiral Spratt, between "Adventure Bank" and Cape Bon. But, in addition to these, we have to note the remarkable discovery of similar channels recorded by the late Professor Arturo Issel off the northern coast of the Gulf of Genoa. These are of especial value as tending to confirm the results arrived at by the author—coming from an independent source—regarding the Geological period of the great uplift.

The following are some details regarding the submerged river-beds of this great inland sea :

1. *The Submerged Channel of the Ebro.*—The number of soundings off Cape Tortosa, tor the purpose of determining the course of the submerged valley of this river, are not as numerous as might be wished ; still the inward bend of the contours from that of 40 fathoms down to that of 1000 fathoms immediately opposite the mouth of the river, cannot be mistaken as other than indications of the course of the channel. Along the Gulf of Valencia the representative of the Continental Shelf is unusually broad and well defined, breaking off at the 100-fathom contour at a distance (opposite Valencia) of 60 miles from the coast, and with a very steep descent for a depth of 500 fathoms, beyond which it cannot be traced.

2. *The Submerged Channel of the Rhône.*—This channel is perhaps even more definitely indicated than that of the Ebro by the inward bend of the isobaths extending from 100 to 1200 fathoms. The channel commences directly south of the city of Marseilles at a distance of about 30 miles to the east of the point where the river itself now enters the sea ; but it is in a direct line with the course of the main stream below Arles ; and between the two points the submerged channel may be supposed to pass through the Continental Shelf, though not apparent by the plumb-line owing doubtless to silting up. The Shelf

[1] They were found, in fact, too insignificant for insertion on the map of a small scale.

itself is here of considerable breadth, varying from 25 to 50 miles in the Gulf of Lyons, and limited by the 100-fathom contour.

3. *Submerged River-Valleys in the Gulf of Genoa.*—The remarkable series of submerged valleys continuous with the streams descending from the Apennines into the Gulf of Genoa were determined by the late Professor Issel, of the University of Genoa, and are of peculiar interest from their number, and from the light they throw upon the geological age of these submarine channels. These were described by Issel as far back as 1887, but have scarcely received the attention they deserved except perhaps in his own country.[1]

The soundings upon which the determination of the submerged valleys depend were carried out by Captain J. B. Magnaghi in the ship *Washington*, of the Royal Italian Navy, and were laid down on charts which enabled Professor Issel to trace the isobathic contours; thus it was found that the sinuosities became especially well defined along the contour of 200 mètres (about 110 fathoms) which marks the edge of the Continental Shelf at a distance of about 7 miles from the coast, and were always directed towards the coast itself. The following are the names of the streams entering the sea along the coast; the channels of which are actually, or inferentially, continuous with those under the sea, and can be distinctly followed to a depth of 900 mètres, viz., the Bassagno, Polcevera, Giuliano, Aquila, Merula, Arma, and the Roja.[2]

The valleys which descend through a brief but steep course from the Apennines are eroded through strata of successive geological ages in an ascending series as we approach the coast; and from the fact that the channel of the Roja is eroded through Eocene, Miocene, and Pliocene formations, and is continued under the bed of the sea, it becomes clear that it is more recent than the newest of these formations; thus establishing the view of the Pleistocene age of the erosion. Issel was able to carry out the soundings as far as the 900-mètre contour (nearly 3000 feet), indicating an addition of this amount to the height of the Alpine region. But this is only a minimum; as the channels of the rivers might have been followed to a greater depth than 900-mètre soundings had they been entered on the charts; but apparently they were discontinued at this depth.[3]

4. *The Nile.*—It is much to be regretted that the solid channel of the Nile valley cannot be traced under the Mediterranean, owing to the enormous amount of sediment which, from year to year, has been carried down from the Abyssinian highlands and deposited in the Delta, and beyond in the basin of the sea. That there does exist a continuous channel eroded through the Tertiary or still older strata under the bed of the Mediterranean, and now covered by its waters, there can be no question. During the great Pliocene uplift the solid channel must have undergone similar vicissitudes to those of the submerged river-valleys off the northern shores of the Mediterranean, when the river poured its waters into the most eastern of the three large lakes into which the sea was then divided.

On the occurrence of the subsequent Post-Glacial submergence, the conditions were entirely changed; and the turgid waters deposited the mud, filling up the channels and ultimately constituting the Delta from before the time of the Pharaohs down to the present day. The history of the formation of the valley of the Nile is clearly written in the position of the geological formations of Egypt; and on a former occasion I have endeavoured to reproduce it in accordance with the evidence these formations afford, together with the changes which the Mediterranean has undergone in past Tertiary times.[4]

[1] Issel, *Comptes rendus des sciences*, Nos. 24th and 31st January 1887; also in his work *Il Terremoto ael 1887 in Liguria*, and again in *Liguria geologia e prehistorica* (2 vols., Genoa, 1892).

[2] Owing to the small scale of the Admiralty Charts (No. 2158) I was unable to confirm Professor Issel's observations by personal detail; but there can be no question regarding their accuracy.

[3] The subject is more fully discussed in the *Trans. Vict. Inst.* vol. xxxii. p. 148. In the discussion which followed the reading of my paper, Mr. Henry Benest gave some interesting details regarding several submerged river-valleys of the Atlantic, and of the "Swatch off no ground" off the mouth of the Ganges.

[4] "Sketch of the Geological History of Egypt and of the Nile Valley," *Trans. Vict. Inst.* vol. xxiv.

CHAPTER VII

Recent Changes in the Mediterranean Sea

EXPLANATION TO ACCOMPANY PLATE V

OUR sub-oceanic researches having taken us through the Strait of Gibraltar into this great inland sea, and having recognised that the region of which it is the centre was subjected to similar physical changes to those which affected the coast bordering the Atlantic, it will not be considered superfluous if we devote a short chapter to the recent changes which converted three fresh-water basins into the salt-water lake of to-day during the Pliocene period. The high salinity of the waters of the Mediterranean is due to the excess of evaporation over the supply from the waters of the rivers entering the basin together with the rainfall; owing to which, the water of the ocean is always flowing into the Mediterranean, and thus adds to its salinity. But during the period of land elevation when the outflow was reversed, the evaporation was necessarily reduced, and the fresh water of the lakes flowed out into the ocean (see Map). How these changes were brought about we shall now endeavour to explain.[1]

1. *Condition of the Mediterranean area at the Commencement of the Tertiary period.*—It is generally admitted that at the close of the Cretaceous and Eocene periods the area of the Mediterranean basin and adjoining lands formed a portion of the Atlantic Ocean, and over its bed the limestone formations of North Africa, Palestine, and Asia Minor were deposited, mainly by the accumulated remains of organic forms such as *foraminifera* and *mollusca*. But these dominating oceanic conditions were destined to come to an end; and in the succeeding Miocene stage there were important terrestrial movements in the direction of development of land conditions. At the commencement of the succeeding Pliocene period these movements took the form of a general uplift of the land and sea-bed, accompanied by flexuring and faulting of the strata; resulting in the elevation of the mountain-chains of the Alps, Pyrenees, the Apennines, together with the formation of the Arabian and African plateaus, and other table-lands and ridges of Asia and Europe, on which we may not further dwell.[2]

2. *Formation of the three Mediterranean Basins.* — Amongst the more important results of the terrestrial movements of the Pliocene period was the conversion of the Mediterranean area into three distinct basins connected with each other by channels, and ultimately with the Atlantic. One of these channels through the "Medina Bank" has been identified by Admiral Spratt, connecting the central with the eastern basin; the other connecting with the western basin was discovered by Admiral Smyth.[3] Owing to these movements, a chain of large lakes was formed, commencing with the Black Sea, which was connected with the Eastern Basin by the Straits of the Dardanelles; this latter again by a channel with the western lake, and this ultimately by the Straits of Gibraltar with the ocean. By the land

[1] The problem is more fully discussed in the author's paper "On the Physical Conditions of the Mediterranean Basin," *Trans. Vict. Inst.* vol. xxxi. p. 111.

[2] The marvellous flexures and convolutions of the strata in the Alps have been abundantly illustrated by Professors Heim, Schardt, C. Schmidt, and Baltzer, and are chiefly referable to this epoch.

[3] *Quart. Journ. Geol. Soc.* vol. xxiii. pp. 288 and 292. The hollows in which the basins lie were probably due to local subsidences occurring at the commencement of the Pliocene period. In such a volcanic region such subsidences would be very probable. The views here stated regarding the epoch of the formation of the three basins have the support of Dr. A. R. Wallace and Sir A. C. Ramsay.

connection through the islands of Sicily and Malta, according to Wallace, the animals inhabiting the European Continent gained access into Africa, and as they consisted chiefly of genera more powerful or ferocious than those then inhabiting that continent (mainly Lemurs) drove them southward, and ultimately exterminated them on the mainland. The remains of the genera of invaders have been discovered in the caves of Sicily and Malta and have been fully described by Admiral Spratt and Dr. Leith Adams.[1] Two species of *hippopotami* have been described from the Malta caves, as also two species of elephant (*Elephas antiquus* and *E. melitensis*). They appear to have inhabited the district in enormous numbers; remains of several hundred individuals having been collected by Adams alone. In the Sicilian district these animals were not less numerous, as shown by the bones of *bos*, *cervus*, *ursus*, *canis* and *felis*, and other carnivores; most of which are recognised inhabitants of Africa at the present day.

The conclusions arrived at by the authors above quoted are identical, and can scarcely be contested. They consider that there was a general uprise of this part of the Mediterranean basin at, or towards the close of, the Miocene period, by which Europe was joined to Africa; those portions of the bed of the sea surrounding Sicily and Malta having been at this period in a condition of dry land. The extent of the upheaval between Sicily and Tunis would be (at the present day) 1500 feet, but may have been less in Pliocene times.

Similar evidence of the uprise of the sea-bed is derived from other islands. Thus remains of foxes are found in Minorca; while those of hares, martens, deer, and foxes have been discovered in Corsica and Sardinia. It is only by the uprise of the sea-bed and connection with the mainland in past times that we can account for such numerous remains in these islands.[2]

The subject of the uplift of the Mediterranean basin by which the existing islands were extended in size and connected with North Africa is recognised by Dr. R. F. Scharff in his treatise on the European animals and illustrated by numerous examples of such connection.[3] We have already seen how the fauna of Sicily, Sardinia, and Malta have yielded remains of large mammals which must have required areas of range greatly larger than the present islands in order to support their aboriginal inhabitants. The examination, by Dr. Forsyth Major, of the caves of the island of Elba, and other islands belonging to the Tuscan archipelago, led to the discovery in them of the remains of several large mammals, such as the deer, bear, antelope, and horse.[4] It is manifest that these small islands could not have supported such a fauna as this; they must have formed the unsubmerged portions of a larger land area within recent geological times.[5] But this community of mammalia between the islands of the Mediterranean and North Africa is not confined to the larger forms, but extends to the reptilia and amphibia, as also to the mollusca; and to such an extent has been this community of forms as to induce Dr. Major to apply to the faunistic province the term "Tyrrhenis."[6] Thus the great uplift of the Pliocene and Post-Pliocene periods is abundantly confirmed by the discoveries of the remains of extinct animals found in the caves.

Advancing Cold in Europe.—If we inquire the cause of the crowding of these and other forms of mammalia in the southern borders of Europe, and the invasion of Africa by them in the Pliocene period, the answer is to be found in the fact of the advancing cold in the northern parts of the Continent owing directly to the increased elevation of the land, and the consequent accession of snow and ice on the mountainous regions, which culminated in the glacial conditions of the succeeding Pleistocene period. These will form the subject of a future chapter. Towards the solution of the problem of the cause of the "Great Ice Age," which has been attempted by so many writers in recent times, all our conclusions regarding land elevation clearly point, and will occupy our attention.

1 Adams, *Notes of a Naturalist in the Nile Valley and Malta*, Edinburgh, 1870, also "On the Dentition of the Maltese Fossil Elephants," *Trans. Zool. Soc.*, London, vol. ix. (1873).

2 Jamieson, *Geological Magazine*, May 1885, p. 199.

3 Scharff, *European Animals* (Constable & Co., 1907).

4 Major, *On the Caves of the Tuscan Archipelago*.

5 Scharff, *European Animals*, p. 213.

6 *Ibid.* p. 214.

CHAPTER VIII

The Physical History of the Norwegian Fjords

EXPLANATION TO ACCOMPANY PLATES VII AND VIII

THE western coast of Norway comes as a necessary part of the physical phenomena discussed in this treatise, and may well be regarded as a crowning subject for our consideration owing to the exceptional position which the fjords occupy amongst the physical features of Europe. These arms of the sea entering from the western coast penetrate for long distances into the very heart of the lofty, snow-capped plateau of the Scandinavian promontory ; and while descending to great depths below the surface along their central areas, are often bounded by cliffs and walls of rock, the summits of which are sometimes decked by snow even during the heat of summer.

In no other country in Europe have we examples on so grand a scale of profound channels invaded by the waters of the ocean and lined by walls of rock, generally precipitous, often vertical like that of Romsdal, and rising several thousand feet till culminating in some stupendous "horn" or peak ; or else forming the margin of that vast snowfield which covers as with a white sheet the surface of the great central tableland. This central snowfield, visible from the sea at a distance of one hundred miles, sends down into the adjoining valleys glaciers, such as that known as the Jostedals Glacier, unsurpassed in magnitude by any in Europe, which, in the northern end of the peninsula, are almost bathed in the waters of the sea itself. Nor can we fail, when coasting along these great waterways, to notice from time to time the evidence both of former submersion, in the form of terraces at levels of several hundred feet above the present sea-level, and subsequent elevation, which has placed them where they are.[1]

1. That these arms of the sea were at a former period the channels of glaciers, on a vastly greater scale than at present, will be recognised from the polished and striated surfaces of the bare rocks cropping out from under the turf along the hillsides.[2] On the other hand, the flat surfaces of terraces lining the sides of the valleys, especially in protected spots, may constantly be noticed, occasionally affording a footing for dwellings and land for cultivation. That these terraces ("Strandlinien") are ancient sea-beaches or ocean-margins cannot be doubted ; and they indicate the extent to which the whole of Norway was submerged at a former period ; amounting, according to Professor Reusch, to over 600 feet in the Christiania and Trondhjem regions.

2. *Depths of the Fjords below the Surface of the Sea.*—But the subject which most strongly excites our interest is the profound depth to which the fjords descend below the surface of the waters, reaching in the case of the Sogne Fjord to nearly 4000 feet (665 fathoms), as shown by the soundings on the Admiralty Charts. If these gulfs were, as we are compelled to believe, the channels of former glaciers, and filled with ice down to their very floors, and much above the present water-level as shown by the glaciated rocks, the thickness of the ice would appear to have reached to not less, probably more, than

[1] Professor Brögger considers that the late elevation of Norway reached to at least 8530 feet during the epoch of the early glacial ice-sheet ; this conclusion being arrived at from the occurrence of a bed of littoral shells at a depth of 2600 mètres.

[2] First described by the late Professor James Forbes in his great work *Norway and its Glaciers* (Edinburgh, 1853).

5000 or 6000 feet in the central portions of these deep sea-lochs, through which the ocean waters are carried to the very roots of the central tableland.

3. *Age of the Scandinavian Rocks.*—Without going to any length into the subject of the geological age and nature of the rocks bordering the Atlantic coast of Scandinavia, it may be mentioned that they are of great geological antiquity, and are known under the name of *Archaean* and *Silurian*—consisting of varieties of granite, gneiss, hornblendic and micaceous schists, quartzites, and dolomites. They are often contorted or highly inclined and foliated or metamorphosed. Some of our more beautiful marbles to be seen in public and private buildings come from Norway or Sweden, as they are susceptible of a fine polish and are exceedingly hard. These rocks seem to have constituted a portion of a primeval continent; and while in the European area to the south strata with organic remains were being deposited under the ocean, those of Norway constituted land. Scandinavia was unsubmerged, and as the Archaean age seems to have been azoic, its rocks are destitute of fossils. This most ancient of continents appears to have extended from Northern Russia westward into the British Isles, to Greenland and Labrador, and was in form a vast undulating plateau. From this elevated tableland streams descended, eroding their channels and supplying sediment to build up the newer formations over the bed of the ocean during successive geological periods. In such a manner, we may suppose, the channels now forming the fjords had their origin, and became wider and deeper as time went on. From all this it will be seen that the fjords were river-valleys of immense geological antiquity, and have assumed their present form and position owing to partial submergence.

It is impossible to view the lofty cliffs of the Romsdal, the Gudvangen, the Sandven, and other valleys, rising from 3000 to 4000 feet from the water's edge, without being impressed by the fact that the erosion of such valleys must have taken an enormous lapse of time for the streams to accomplish even after allowance is made for the effects of glacial action at a recent period; and from the fact that a large number of geological formations are absent in the Scandinavian peninsula, we may conclude that, from the time of the Silurian to the Tertiary ages, the peninsula remained mainly in the position of unsubmerged land, during which rain, frost, snow, and river-action had free play in eroding the existing channels.

The outcome of these natural operations is grandly displayed at the profound gorge of Stalheim, which comes suddenly into view as the traveller approaches the Vossevangen valley, and is calculated to impress him with a feeling not only of admiration, but of awe; a feeling shared by the late Professor James Forbes when viewing the Sogne Fjord, into which the Vossevangen immediately descends.

4. *Unequal Depths of the Fjords.*—Not less profound must be our astonishment when we come to realise the great depths to which some of the larger fjords descend below the surface of the sea, as we have already noticed. These depths are, however, very unequal; for, while that of the Sogne descends to almost 4000 feet (665 fathoms), the Hardanger Fjord, a few miles farther south, only descends to 2550 feet (425 fathoms), the Volden to 2298 feet (383 fathoms), and the Nord to 1800 feet (300 fathoms); these two latter lying some distance north of the Sogne. Now, as the Sogne Fjord is by much the largest of the Scandinavian sea-lochs, and drains a larger tract of mountain land, there would seem to be a clear connection between their size and their depth; as would be expected under the view that they have been formed under the erosive action whether of rivers or of ice, or of both.[1]

5. *Cause of the Rapid Shallowing of the Fjords seaward.*—It has already been shown that the fjords attain their maximum of depth near their central areas, decreasing upwards towards their sources, as might be expected; but also in the direction of their outlet along the western coast. This, in all probability, is due to two causes. First, it was over the central part that the ice, during the earliest glacial epoch, attained its greatest thickness, and consequently its greatest erosive power in deepening the

[1] These important results are derived from the soundings of our own Admiralty Charts, transferred from the Norwegian surveys, and ought to be consulted by all travellers amongst the Norse sea-lochs and valleys. It may be well to state that the erosive action of a glacier is due to the blocks of rock, stones, and sand which are enclosed in the glacial ice; pure ice has probably little or no erosive effect.

floors of the valleys; and secondly, because of the obstruction to the outflow of the ice caused by the chain of islands rising from the shallow floor of rock which runs along the coast throughout the greater extent of its length. That these islands are only unsubmerged portions of an extensive tract of continental land is clear to any one who has sailed along their shores, and they have been regarded by Dr. Nansen as a second and minor terrace, called by him "the Coast Platform," of more recent formation than the Continental Platform already described.

In the former condition of high elevation and ice accumulation the obstacle presented by these uprising ridges and bosses of solid rock to the movement of the glacier ice descending from the interior mountains would naturally result in the piling up of huge masses of moraine matter in the hollows between the islands—filling the valleys, and lessening their depth. Thus, the combined result of these two conditions, namely, the erosion of the glacier and the accumulation of moraine matter, may be taken to explain the deepening of the fjords at the centre of their channels as indicated by the soundings on the Admiralty Charts, and the shallowing of their outlet into the ocean. These outlets are themselves largely silted up outside the barrier.

We may now conclude this part of our subject, which will be recognised as having a close connection with that which precedes it, by a statement of the geological events through which the Scandinavian peninsula has passed from the earliest to the latest periods:—

General Succession of Events in the History of the Norwegian Fjords

(a) *Earliest Stage* (Pre-Silurian).—Continental conditions; land formed of Archaean rocks. Erosion of river-valleys commences.

(b) *Second Stage.*—Partial submergence during Silurian times.

(c) *Third Stage.*—Elevation of land during later Palaeozoic, Mesozoic, and Tertiary times; continuous erosion of river-valleys.

(d) *Fourth Stage* (Glacial period).—Great upheaval of land and sea areas accompanied by valley erosion. Refrigeration of climate; extension of snowfields and glaciers, which descended and filled the valleys and moved out over the North Sea floor; deepening of the valleys by glacier erosion.[1]

(e) *Fifth Stage* (Interglacial).—General subsidence of land and sea; amelioration of climate; marine terraces (or "Strandlinien") formed along the coast of the submerged lands and fjords, the sea filled with floating ice and bergs.

(f) *Sixth Stage* (Post-Glacial).—Slight re-elevation of area, accompanied by recurrence of cold conditions, but not to the extent of the fourth stage.

(g) *Seventh Stage* (Recent).—Gradual depression of land and amelioration of climate to present conditions; sea-beaches formed at intervals of subsequent emergence along the coast down to the commencement of human occupation of the country.[2]

[1] See Plate VIII., Map of the British Isles during the Glacial Period.

[2] The above subject and its connection with the physical features of the West of Scotland is more fully dealt with in the author's paper published in the *Transactions of the Victoria Institute*, vol. xxxiv. p. 125 (1902).

CHAPTER IX

BY JOSEPH WILLIAM WINTHROP SPENCER, M.A., Ph.D., F.G.S.A.

The Submarine Valleys and Cañons off the American Coast

EXPLANATION TO ACCOMPANY PLATES X and XI

SCOPE *of Investigations.*[1]—The following pages contain a short account of the more important submarine valleys and cañons which dissect the Atlantic margin of the American Continent. These valleys are the continuations of those on the land, crossing the Continental and Island Shelves and their bordering platforms. The lower stretches of the continental valleys are now partly refilled with deposits, the character of which has been found by borings. Analogous physiographic forms have been studied in the high plateau regions of Western America, where great cañons within cañons, and amphitheatres or short steep valleys, dissect the border of the tablelands.

In the submerged land-tongues connecting the islands important features are found.

The study of all of these features shows that there have been great changes of level of land and sea, the occurrence of which is confirmed by the distribution of mammals, plants, etc. Their investigation forms a new branch of sub-oceanic physiographic science. It is the counterpart under the sea of the land forms to which the term Geomorphology is applied. It includes the investigation of the Continental Shelves, submarine cañons, flooded and buried river-valleys, land-tongues, and even some basins.

Development of the Study of Sub-Oceanic Physiography bordering the Continents.—Passing over the earlier recognition of the Continental Shelves, we come to the time when their forms were first systematically studied in their relation to the valleys indenting them.

In the navigational soundings leading seaward from New York Harbour erratic depths were found. These "holes" were regarded by Professor J. D. Dana (since 1863)[2] as indicating a continuation of the Hudson River Channel. They were then known only to a depth of 720 feet where the adjacent sea-floor was submerged to half this amount. These "holes" awakened the interest of Mr. (now Admiral) Colby M. Chester, while he was in charge of the surveying ships of the United States Coast Survey, who caused a scientific survey of them to be made by Mr. (now Admiral) Willis Bronson. Soon afterwards these soundings were used by Professor A. Lindenkohl to show that the deep gorge reached to 2800 feet below the surface of the sea. Years subsequent to this, I found from other soundings, made by Captain Z. A. Tanner, that a true cañon reached to a depth of 4000 feet.[3] All of us have regarded this Hudson Cañon as evidence of changes in the level of the land and sea.

Sir William Dawson (before 1872) had called attention to the deep fjord of the Saguenay (125 miles below Quebec) as also being evidence of change of level.[4] Professor George Davidson called attention to the similar submarine valleys off the Pacific Coast.[5] In 1889 I made a fuller study of the submarine

[1] In the following pages Professor Spencer uses the term "Continental Shelf" for "Continental Platform" of Professor Hull in the previous pages, also "Slope" and "Declivity" are synonymous terms.—Ed.

[2] *Manual of Geology*, 1st edition.

[3] *Geog. Journ.*, London, Feb. 1905.

[4] *Can. Naturalist*, Montreal, vol. vi. (1872).

[5] *Proc. Cal. Acad. Sci.* 3rd ser. vol. i. (1897).

features of the Gulf of St. Lawrence, and Gulf of Maine, and correlated them with those of the Hudson River, thus covering a wider field.[1] The breadth of the Continental Shelf off the Carolinas and Florida, and other features among the Bahamas, have been surveyed by Mr. (now Admiral) Pillsbury and Professor A. Agassiz, but the study of submarine river-like valleys and cañons was not undertaken.

My investigations in the Gulf of St. Lawrence were commenced in connection with the researches into the origin of the Great Lakes of America. These studies were subsequently extended to the Southern States and the West Indies, in order to determine what evidence of change of land and sea could be found there. I had the good fortune of investigating almost unstudied features, in a field where many soundings had been made for navigational and cable purposes, and these brought to light the most valuable scientific data. Besides these, I visited the West Indian Islands, Mexico, and Central America, for the purpose of examining the relation of the submarine valleys to the land features, while the region farther north was already familiar. The varied observations resulted in the systematic treatise entitled "Reconstruction of the Antillean Continent,"[2] followed by many subsequent papers descriptive of local phenomena. These investigations, together with those of Professor Edward Hull,[3] on the eastern side of the Atlantic, and of Professor Fridtjof Nansen,[4] off the coast of Norway and in the Northern Seas, with his review of the subject, have now given rise to the study of a distinct branch of oceanography, of world-wide possibilities, which throws much light on the later history of the continents.

The Hudsonian Cañon and its Age.—The three most perfectly surveyed submarine cañons are those of the Hudson River,[5] the Congo,[6] and another off the island of Cape Verde. These latter two were surveyed in great detail on account of the breaking of the cables crossing them.[7] But the origin of the Congo Channel was not then understood. It was later explained by Professor Hull and Dr. Warren Upham.

The Hudson Cañon may be taken as a type. Soundings by the U.S. Coast Survey were made for the purpose of discovering the character of the "holes" in the Hudson River extension. The results, as then known, were published by the writer in 1905.[8] Additional soundings have since been made. From all of these it is seen that—

In passing down New York Harbour the ancient Hudson Channel is buried by the sandbars which rise to within 20 or 30 feet of the surface, although it is now known that the gorge within its rocky walls, at New York City, reaches to more than 300 feet. In proceeding seaward, the sandbars are passed, and the partly refilled channel becomes apparent. Its bottom is composed of clay, while the surface of its banks is covered with sands.

At 93 land miles from Sandy Hook, where the sea has a depth of 330 feet, the channel plunges into a chasm 800 feet deep. Here its direction is nearly eastward. Four miles beyond, it turns due south, and at this point are other falls aggregating 550 feet. After a farther distance of four or five miles still other falls of 600 feet occur, beyond which the trench again turns sharply eastward. From this point another stretch reaches for more than 15 miles, with a low gradient, and the soundings show subordinate windings. The cañon crosses the border of the Continental Shelf, here arbitrarily defined at 500 feet below sea-level. Beyond, it trenches the Continental Slope with other great falls of 2000 feet. Farther down the sharply winding gorge two falls of 1200 and 900 feet occur. The maximum depth of the cañon reaches 4000 feet (where the Continental Slope is submerged only 1000 feet). Its length is about 50 miles with the valley known for 25 miles farther.

1 *Bull. Geol. Soc. Am.* vol. i. (1890).

2 "Reconstruction of the Antillean Continent," cited before.

3 Published in numerous papers by the Victoria Institute, 1898-1908.

4 "Bathymetrical Features of the North Polar Sea." One of the scientific monographs published by the Nansen Fund for the Advancement of Science. Christiania, 1904.

5 *Am. Journ. of Sci.* vol. xix. pp. 1-15 (1905).

6 By J. Y. Buchanan, *Scottish Geog. Mag.* vol. iii. pp. 217-238 (1887), with later studies by Professor Hull.

7 By Henry Benest, *Geog. Journ.*, London, vol. xiv. pp. 394-413 (1899).

8 *Geog. Journ.*, London, Feb. 1905.

In its descent the great chasm crosses two plateaus, one at 2700-3000 feet and the other at 5000-5500. Beyond the cañon section the valley opens into the great Hullian Embayment of the Continental slope.[1] The cañon and submerged valley of the Hudson River has been explored to a depth of 7500 feet below sea-level, where the valley is bounded by ridges 1200 feet in height. The cañon is double—the outer one being about 4 miles wide and 1200 to 1500 feet deep; the inner gorge is perhaps little more than a mile wide with a farther depth of 2800 to 2500 feet.

If we go to plateau regions, such as those of Mexico, short indentations may be seen in their borders, formed by streams of little length or perhaps by only rain-washes. In this manner the submarine Hudson cañon and adjacent borders of the plateaus have their walls dissected by short tributaries or amphitheatres, a name applied to such features seen at the Grand Cañon of Colorado, with gradients of 200 to 500 feet per mile. These amphitheatres when closely situated soon lead to large embayments. All of these features are well developed in the edge of the Continental Slope or Declivity adjacent to the Hudson Channel.

The sea-floor of the Hudsonian Channel is covered with sand, clay, or, farther down the Slope, with ooze. On Long Island and in New Jersey there are some drift accumulations, with underlying and unconsolidated Tertiary and Cretaceous clays, sands, and marl. From their thickness, found on the continent adjacent, it does not appear that the formations—Cretaceous to recent—can exceed 3000 feet. At Fort Monroe, near the seashore, some 300 miles to the south, these formations have a thickness of only 2000 feet, below which the drill reached crystalline rocks. Farther back, on the mainland, are Triassic sandstones, slates, and igneous rocks. From such evidence it may be inferred that the lower part of the submerged cañon of the Hudson River has been principally excavated out of crystalline rocks, although these may have been covered by Tertiary deposits, for samples of such have been brought up by dredges operating farther eastward.[1]

From the character of this deep valley—having an outer and an inner cañon, winding in sharp turns, with its floor interrupted by abrupt steps, and its lower reaches opening out into a broad embayment with more gently sloping banks; having associated tributaries and the amphitheatres dissecting the submerged plateaus, or terrace steps of the Continental Slope—one cannot fail to regard this series of features as due to atmospheric and river erosion during changes of level of land and sea. Nothing has been found suggesting other than the complete analogy between physiography of this valley, although now submerged to a mile and a half or more, and the great cañons of our higher Western plateaus, even if these inductions conflict with speculations or prejudices against great changes of level at a late date, though smaller oscillations are readily conceded, or greater ones in more ancient times.

It may be added that the surfaces of the Continental Shelves show evidence of other minor oscillations, belonging to a later date, not mentioned here.

Submerged Valley and Cañon of the Gulf of St. Lawrence.—The Gulf of St. Lawrence, the scene of my earliest studies, occupies a broad depression between the Laurentian Mountains to the north, composed of crystalline rocks, and the extension of the Appalachian Mountains to the south, with their old Palaeozoic shales, sandstones, etc. It is a submerged river-valley, the floor of which is covered by drift deposits. Even so far up as a point 100 miles below the city of Quebec, the open depth reaches to over 300 feet and the breadth is 13 miles. At 125 miles below Quebec the St. Lawrence River receives the Saguenay fjord with a depth of 882 feet, which farther down is partly refilled with moraine or delta deposits. At a point 50 miles below the Saguenay the open depth reaches 1200 feet, and, beyond, a great valley traverses the Gulf of St. Lawrence. South of the island of Anticosti it is 30 miles wide, with the depth increasing to 2000 feet below sea-level. It is bounded by escarpments steeply rising 800 feet above its floor, and more gently to greater heights. The greatest

[1] This indentation is sufficiently large to be shown on small oceanographic maps, and leads to much greater depths than are fully explored. It received not only the Hudson cañon, but others from the north, such as that from the Connecticut River. I named it after Professor Hull, who has interpreted similar features off the coast of Europe.

depth of the channel is 2300 feet, but this appears to be obstructed by morainic ridges of 200 or 300 feet in thickness, as should be expected in this region. The submerged Laurentian valley has tributaries, the largest coming from the submerged land-tongue between Labrador and Newfoundland. From the point taken as the mouth of the St. Lawrence River, its very deep channel extends for 700 miles to the margin of the Continental Shelf, 200 miles south of the line of the coast.

Inside this line a deep cañon begins to trench the border of the Continental Shelf. Here it reaches to 3666 feet below the surface, but no soundings have been taken to define its course down the Continental Slope, although the corresponding embayment is shown at lower depths.

The two distinct features of the Gulf of St. Lawrence are—the long broad valley bounded by high cliffs, and the beginning of the cañon at its lower end. Each has had its own history.

The broad valley was apparently the result of long-continued erosion, when the region stood at least 2300 feet higher than now, and yet not more than a few hundred feet higher than this amount, so that the drainage slope was such that the river cut out its channel down to the level of no erosion; after which the denudation only widened the valley to more than a score of miles.

The cañon trenching its end is characteristic of the new conditions, when the land rose very much above the present ocean level. Then the river rushing down the Continental Slope gave rise to the new gorge. Compared with the period of the broad valley above, the cañon-making epoch was of very short duration. It was terminated upon the waters rising and flooding even the upper valley so as to produce the Gulf of St. Lawrence and the submerged river branches above.

The Gulf basin is mostly excavated out of Palaeozoic formations, but upon the south-western side are somewhat extensive sheets of Triassic strata. On the frontal banks of Newfoundland and New England the occurrence of Tertiary limestones has been found in dredging operations. Accordingly, the completion of this great valley belongs to a late date, although the beginnings of it go back a long way in time.

Land-like Features of the Newfoundland Banks.—South of Newfoundland, the Continental Shelf extends for nearly 200 miles, with the higher portions forming the "Newfoundland Banks." South-eastward, these extend seaward for about 300 miles. I have taken the edge of the Continental Shelf at the isobath of 450 feet; but at a greater depth the most eastern spur of the American mass extends 425 miles beyond the land. This is a submarine plateau, surmounted by ridges, the terminal portion of which is partly separated from the main mass by indentations or deep embayments and valleys on both sides, to which I gave the name of Hullian and Lesleyan Bays[1] (see Map). This feature is the repetition of a well-developed similar one between Honduras and Jamaica, where different stages of dissection, according to the width of the plateau, may be seen, even to the complete separation of the terminal plateau.[2] On the land such features are represented in many regions.

This most eastern sub-oceanic tableland of the continent I shall name in honour of Professor Hull, who first reduced to order the data bearing on the submarine valleys of Western Europe, thus demonstrating that the features are alike on both sides of the Atlantic. The Continental Slope bordering this Hullian Plateau descends to the ocean depths, over precipitous cliffs, thousands of feet in height!

The soundings on the Newfoundland Banks show the plateau to be indented by many valleys, with cañons dissecting the Continental Slope, some of which, however, are of the characteristic form of amphi-theatres on the borders of plateau regions.

Submarine Cañons of the Gulf of Maine and of Chesapeake Bay.—In the border of the Continental Shelf, opposite the mouth of the Gulf of Maine, the Continental Slope is trenched by a deep cañon. It is now known to a depth of at least 7020 feet below sea-level. The gorge itself is more than 1500 feet deep;

[1] See map of "Submarine Valleys of the Atlantic Coast," *Bull. Geol. Soc. Am.* vol. xiv. opp. p. 208 (1903).

[2] See map, p. 116, *Bull. Geol. Soc. Am.* vol. vi. cited.

but it has not been sufficiently explored to give such complete details as are known in the Hudsonian Cañon. Adjacent to it amphitheatres dissect the continental border. Accordingly we may consider the submerged land forms here to be repetitions of those found elsewhere.

Soundings show the deep embayment in the Continental Shelf heading towards Chesapeake Bay, into which both the Susquehanna and Delaware valleys enter. Here the Continental Slope is very much reduced in width, and the surface sands of the Shelf obscure the buried valleys; which, however, the incomplete exploration, so far made, shows to exist, although the details cannot yet be furnished.

In referring to the shifting sands, partly burying the more ancient valleys, it may be said that some of the sandbars occur below the present level of current action. These were formed during minor oscillations, when the waters were shoal; for changes of level are recorded in the more recent drainage channels over the surface of the Continental Shelf.

Continental Shelves and Land-Tongues between the Southern States and the West Indies.—Off Cape Hatteras the Shelf is reduced to a breadth of 15 or 20 miles. Southward it, together with the lower plateau, widens to 300 miles in front of Florida. The Continental Slope descends steeply in all places, and precipitously in some, to more than 13,000 feet. The Shelf, to 450 feet below sea-level, extends south-eastward to the deeply dissected Bahama Banks and islands in front of Cuba and Haiti, although they are separated from Florida by the Straits of Florida, where the col rises to within 2100 feet of the surface. Between the Bahama Banks and Cuba the col is submerged only 1800 feet.

The Continental Shelf west of Florida has a width reaching to 150 miles. It is somewhat broader north of Yucatan. Were it not for channels crossing it, one reaching to 6400 feet, the Shelf would connect Honduras with Jamaica and Yucatan with Cuba. The Shelf has a considerable breadth on the southern side of the Caribbean Sea, but on its northern side, adjacent to the greater West Indian Islands, it is in many places reduced to a narrow fringe. The Lesser Antilles or Windward Islands surmount a very much dissected tableland, extending from the Greater Antilles to South America, which is cut through by one very deep channel. Throughout this region the outer margin of the Continental Shelf seems to be at a depth of less than 300 feet, beyond which the Atlantic slope plunges precipitously down to the ocean abyss.

The outer and broader plains, in front of Carolina and Florida, are now submerged 2400 to 2800 feet. This same depth is repeated in a terrace adjacent to the Hudson Cañon, and also in steps in the Gulf of Mexico, and in the submerged land-tongues among the West Indian Islands.

Lower than the surface of the Continental Shelf, the terrace plateaus are manifestly old coastal plains during a former moderate elevation of the land.

Although the Blake Plateau in front of Florida and Georgia is swept by the Gulf Stream, yet this has not produced the planing down of its surface, for Pillsbury has found that the current is effective only to about 300 feet. At greater depths the current diminishes to zero before reaching the floor of the Straits of Florida. Indeed, a submerged valley is situated between two of the Bahama Islands, heading in Florida, and on either side of it higher ridges form the floor of the strait. Had the currents deepened the Straits, the lateral ridges of this cross-channel would have been planed down, and the main channel refilled with deposits.

The repetition of plateaus observed at different points at similar depths in the northern regions has been especially emphasised by Nansen as evidence of changes of ocean-level. I believe to be of equal importance the similarity in depth below sea-level of many summits of the submerged land-tongues. The corresponding land features are low passes across mountain plateaus, where the atmospheric agents have lowered the valleys nearly to the level of no erosion. The minor variations in their height depend upon the breadth of the ridges dissected and the changing character of rock structure.

The Submerged and Submarine Valleys of the Southern States.—For a considerable distance from the coast, the Continental Shelf is covered with sand, thus burying the channels coming from Carolina and Georgia.

Submarine Valleys and Cañons off American Coast

Before reaching the ocean, the rivers everywhere pass over valleys many miles in width, refilled by Pleistocene (or possibly late Pliocene) loams, sands, or gravels. These valleys are excavated out of earlier Tertiary formations. The depths of the channels are not known, but borings show that of the Savannah River to reach at least 250 feet below sea-level. Borings made in the Tertiary limestones of Florida have already revealed caves to a depth of 800 feet or more. These were the underground river channels which carried off the surface drainage when the land was high. Such were mentioned by Professor N. S. Shaler as evidence of the recent depression of Florida.

After passing the sand-filled stretches of the submerged valleys, these again become apparent in crossing the Continental Shelf and lower plateaus, from which they descend through great cañons, and enter embayments of the ocean basins. Their walls are often precipitous and reach to thousands of feet in depth.

The Buried and Submerged Valley of the Mississippi.—On the northern side of the Gulf of Mexico, outside of the shifting sand zone, all the principal rivers of the Southern States show their valleys continuing to depths of 10,000 feet. The Mississippi River, above its mouth, is 200 feet deep, while the sandbars in front almost block the channel. Here are also other submarine channels with their upper extensions refilled, so that they do not reach to the land, nevertheless they show where the rivers formerly ran.

The valley of the Mississippi, for 500 miles above its mouth, is a plain from 30 to 80 miles wide, which was liable to overflows before the river banks were diked. By borings at New Orleans, Corthell found, at least, 1000 feet of river silts and Pleistocene loams, without reaching the bottom of the channel.

The depth of the buried valley of the Mississippi is thought by Professor G. D. Harris to be 3000 feet. This inference is based upon borings for salt some distance to the west, which show buried valleys or amphitheatres 2300 feet deep in the now submerged plateau. These increase in depth in passing eastward. Pleistocene shells are the only organisms occurring in the filling of the valleys which are excavated out of Tertiary deposits with underlying Cretaceous formations. This is the positive palaeontological evidence of a late high continental elevation, confirming my views regarding systems of submarine valleys which were later submerged.

The Submerged Floridian Channel and Cañon.—The Floridian Channel extends from the Straits of Florida, with a depth of 2100 feet, to the floor of the Gulf of Mexico, at 12,000 feet,—a distance of 400 miles. The descent is by three principal long reaches of low gradient, separated by abrupt steps, each reach of which is incised by a cañon 3000 feet deep, opening on the valley floor below. This is the grandest submarine valley explored. The length is a great advantage in studying its development. There are several important tributaries besides many shorter ones of amphitheatre form. To the westward of its mouth is also the fine cañon of the Yucatan Channel, which is now submerged to its head.

The Bahama Banks and their Valleys.—Leading from the Straits of Florida, the Abacan Cañon (see Map) dissects the Bahama Banks between two of the islands; and the Bahaman Channel leads from the northern end of the Straits of Florida into the deep cañon separating the Bahama Banks from the submerged Continental Plateau.

The Bahama Banks are further dismembered by entirely submerged valleys heading in amphitheatres. These were partly explored by Professor A. Agassiz, who, however, did not understand their origin. The low Bahama Islands are covered by coral sand resting on Mid-Tertiary limestones. Immediately in front of the banks, the descent to the oceanic abyss is very steep, so that if the region were high, the tropical rains would rapidly excavate deep wash-outs or amphitheatres, even though no long rivers were flowing through them. Indeed, the absence of long rivers would favour the relatively greater breadth of the valleys, as compared with their length. These deep valleys suggest no other relationship than gigantic wash-outs or amphitheatres, in front of high tablelands, made by rains, rills, and rivers.

Submarine Valleys and Cañons off American Coast

In Cuba, Jamaica, and Barbados, beneath the superficial limestone, are deposits of oceanic ooze forming a marl, which, when wet, tends to move. For example, on the eastern side of Barbados is a broad amphitheatre in the capping limestone. After a protracted rain, in 1901, hundreds of acres of the underlying marl began to flow, thereby undermining and widening the embayments in the surface limestone. It was still moving when last visited by myself, eighteen months after the great rain-fall. Oceanic oozes logically should underlie the Bahama Banks, and at no great distance away such are found at the south-eastern end of Cuba. Their occurrence would fully explain the broad character of the deep channels among the Bahama Banks capped by harder strata.

The Lesser Antillean or Windward Banks and their Valleys.—The most eastern of the Greater Antilles is the island of Puerto Rico, but from it a submarine plateau, surmounted by islands, extends in a crescent form to South America. It has a maximum breadth of a hundred miles, but farther south the natural frontal plains seem to have been washed away into the Atlantic, leaving only a few remnants (such as the eastern plains of Guadeloupe and the mass of Barbados) ; so that the ocean rolls against the chain of Pleistocene and modern volcanic islands.

Southwards from the plateau of the North-Eastern Islands, a submarine spur, surmounted by the Aves Banks, extends southward in the Caribbean Sea, but this does not reach to South America.

The steep slopes of the volcanic and other islands have their surfaces trenched with deep ravines, and these may be followed by soundings across the island shelves to the embayments in the Continental Slopes.[1]

Many of the smaller islands rise from larger separated plateaus, now mostly submerged to inconsiderable depths in the shallow seas. These are dissected by the beginnings of cañons and valleys which extend to thousands of feet below sea-level. In many cases their walls are almost precipitous. Their characteristics are in no wise different from those indenting the border of the Continental Shelf or that of the high plateaus of Mexico.

Between the larger islands are channels with a breadth of 20 to 40 miles. The one between the Grenadines and South America is broader, but here the Continental Shelf extends seaward some sixty miles, and approaches the southern extension of the island shelf. The summits of the land-tongues between the islands are submerged to no more than 2000 to 2400 feet, except between Martinique and the islands on either side, where the depth reaches 3500 feet below sea-level. Barbados surmounts an outlying mass, with the land-tongue, between it and the main chain of islands, submerged to a depth of 5500 feet.

The broad channels belong to an earlier period than the deep valleys and cañons. They resemble the lower breaches in denuded tablelands, broadened, after submergence, by wave action. Their origin is somewhat more complex in the vicinity of the volcanoes, where limited areas of the sea-floor have been locally raised. Nevertheless, the character of the dissecting cañons and valleys has not been materially altered thereby.

While such is the general character of the Lesser Antillean Plateau, all the way from South America to the Virgin Islands, this last group is dissected by the deep Anegada Passage, between St. Croix and St. Thomas, islands of the Virgin group, where the summit of the land-tongue is depressed to 6400 feet below sea-level. This is the great physiographic break between the Lesser and Greater Antilles. The depths between Haiti and Cuba, and Haiti and Jamaica, are a little less, while the channel between Cuba and Yucatan has exactly the same depth as that between the Virgin Islands. It cannot be too strongly insisted upon, that the submerged passes from Haiti and Cuba directly to Central America, on one side, and, on the other, by way of the Windward Islands, to South America, are now at equal depth beneath the surface of the sea.

[1] See papers on the Geological and Physical development of Antigua, Guadeloupe, Anguilla, St. Martin, St. Bartholomew, and Sombrero ; Dominica ; Barbados, etc., *Q.J.G.S.* vols. lvii. lviii. (1901-2).

Submarine Valleys and Cañons off American Coast

In parts of the West Indian plateaus the surface rocks consist of coralline limestones of Pleistocene age. Beneath these, the newest formations are the white limestones of Oligocene or older Miocene age. They reach a thickness of 2000 to 3000 feet in Jamaica. At Matanzas, in Cuba, I found 1600 feet of the same (above a fault-line). Opposite this point, at Key West, Florida, borings in the same formation show a thickness of 2000 feet or more.

These limestones are widespread over the West Indian region, showing that it was mostly under water in Mid-Tertiary days. There are also older crystalline schists. The modern volcanoes are confined to the minor portions of the chain of the small Windward Islands ; but some of these also date back into the Tertiary period or before.

Date of the Great Cañon-making Period.—As shown by the character of the rock formations, the modern physiographic development of the West Indian region dates back only to the later Tertiary days. Even this being the case, I find, from the great amount of work performed on the land and sub-oceanic features, that the period of erosion was of long duration. The upper portions of the now submerged plateau became separated tablelands, which upon later subsidence formed the larger islands. It was then that the broad, rolling, open valleys were produced, reaching down to the then level of no erosion. This elevation of the region during the Mid-Pliocene period was moderate, yet 2000 feet of white limestones have been carried away from many places. Later followed another epoch of elevation of much shorter duration, so that the secondary valleys were excavated in the older broader ones. Then followed a subsidence somewhat below the present level, after which there was the great elevation with the formation of narrow deep cañons. From all of the evidence, on any theory whatsoever, the date of the great cañon-making period is found to have been at the close of the Tertiary or the beginning of the Pleistocene period.

Biological Evidence of the Connection of the Islands and Continent.—Three living (and one fossil) species of the rodent *Capromys* occur in Cuba and the same number in Haiti. These are related to Brazilian remains found in Pleistocene caves. Another species lives in Jamaica. One species of the insectivore *Solenodon* lives in Cuba and another in Haiti. This is related to a Madagascar type. Among the fossils found in caverns is the *Oryctotherius* (*Myomorphus*) *cubensis* (Pomel). This sloth is related to *Megalonyx* of North America. From Anguilla (one of the small north-eastern Antilles), Professor Cope described two species of *Amblyrhiza* (rodents as large as deer), related to Patagonian Pleistocene forms. These notes were given me by the late Professor E. D. Cope. I have found the *Amblyrhiza* in a cavern on the neighbouring island of St. Martin. Until recently, but little more was known of mammals of the West Indies.

Although this collection seems meagre, it is sufficient to establish the former land connection between the West Indies and the continent. A writer on invertebrate fossils, Dr. T. W. Vaughan, published a paper attempting to show that fossil mammals did not exist in these islands, even the earlier-discovered great sloth. On the other hand, Professor Cope thought that many mammals had roamed over these lands, with their remains now occurring in the submerged lands. Confirmatory of their former existence in Cuba are the recent remarkable discoveries of Professor De le Torre, who has obtained additional specimens of the *Myomorphus*, and about eight species of mammals, besides other groups, from the Pleistocene caves of Central Cuba.

At the time of his death, Professor Cope was investigating a large collection of remains of Pleistocene mammals from a cave at Port Kennedy, near Philadelphia. Among them were those of numerous bears of South American type, which had no corresponding relatives in the Western United States or in Mexico. This fact, and the physiographic evidence obtained by myself, led Professor Cope to the hypothesis that the migrations from South America had been by way of the West Indian bridge.

Numerous species of plants occurring on the island of St. Croix, on the south-eastern side of the deep Anegada trench, are found on St. Thomas and in Puerto Rico, on the north-western side, but many of these may not afford evidence of land connection.

Submarine Valleys and Cañons off American Coast

Concerning the great *Agave* family, Dr. William Trelease, after long investigation, expresses conclusions of which he has no doubt. He says that their seeds could not have been carried across even narrow channels of water, and "that they went dry-shod from Cuba around the West Indies to Venezuela." He is convinced that Cuba was the primary centre of their distribution. It is immaterial whether they made a short circuit by way of the Lesser Antillean Plateau, or followed the longer route by way of Central America. The Jamaican and the Haitian species are more closely related than those of Jamaica and Cuba. This is what should be expected, for Jamaica and the south-western ridge of Haiti are continuous, with their land-tongues submerged to probably much less than 6000 feet. But Jamaica and Cuba are to-day separated by the deep trough of 18,000 feet, which dates back to a time prior to the Pleistocene period.

As has already been stated, the passage between Cuba and Yucatan, with its sides incised by cañons and land-features (indicating the former elevation), is at the same depth (6400 feet) as the Anegada Channel, among the Virgin Islands. Accordingly, a change of level which would have permitted of the migrations of the *Agave* in one direction would have been sufficient in the other. From the occurrence of *Amblyrhiza* in St. Martin, the biological evidence proves that the Pleistocene elevation in the east was more than 3500 feet. Such an elevation would have also joined the islands to North America, as the deepest land-tongue between the Bahamas and Florida is now submerged only 2100 feet. To question the former land connection here, while admitting the extension of Cuba to Central or South America, would be simply an evasion.

In Southern Florida and in the Islands there are related land shells, and also plants (Dr. R. M. Harper).[1]

Results establishing Changes of Level of Land and Sea.—In the plateau regions, cañons are found within cañons,[2] showing former changes of drainage level. In their courses they meander and make many sharp turns. Their descent is by a succession of steps such as produce rapids and waterfalls, the lowest being the newest. As the waterfalls are developed, the higher and older ones continue to recede, but their retreat may be faster or slower, so that the great steps become farther apart or come together or unite. All of these features are found in the submarine cañons studied. We know of no great open fissures like these valleys and cañons, except such as are produced by streams, although joints and cracks may have caused their location and facilitated their excavation. Hence the natural explanation is that those beneath the sea were land-valleys, although now submerged.

I was once asked if the formation of these gorges by tidal currents had been considered—that is, if tides acting hundreds or thousands of feet below the surface of the sea could produce cañons and valleys, associated with terraces. It seemed like a last effort to evade the evidence of great changes of level. However, the ocean currents are worthy of consideration, although they commonly sweep crosswise of the submerged valleys, which could not be affected thereby. Some others, such as the Gulf Stream, flow in the direction of the submerged channels, but this loses its velocity and abrading action at about 300 feet below the surface. I have also shown, on a previous page, how the Gulf Stream has not planed off the floor of its physiographic summits.

The wide channels between the islands are commonly across the ridges, although sometimes parallel with them. As their lateral slopes are also incised with cañons and amphitheatres, it is evident that they were not fashioned by ocean currents. This feature also shows that the depressions between the islands are not due to block subsidence, for they must have been elevated during the formation of the lateral valleys. The rolling features of these wide channels were formed earlier than the cañon-making epoch, but after the Mid-Tertiary period. The submarine platforms and the land-tongues, repeated at the similar depth over widely separated localities, become further evidence in favour of late changes of sea-level.

[1] Dr. Roland M. Harper has kindly furnished me with a list of 70 species of plants common to Florida and the Bahamas and other islands. This list excludes weeds, mosses species confined to the coast, and those with fleshy fruits that might be carried by birds.

[2] The Grand Cañon of Colorado consists of three components, one 5 to 13 miles wide, another of 3 to 5, and one less than 1 mile wide, with depths of 2000, 1000, and 3000 feet (for the innermost gorge).

Submarine Valleys and Cañons off American Coast

No one has offered evidence showing that the cañons and valleys crossing the Continental Shelf or the island plateaus are the remains of open fissures made by earth movements.

There are basins and troughs in the ocean deep about which little is known,[1] but the occurrence of terraces upon their upper slopes, with dissecting valleys and gorges, opening into embayments, show that their sinking was completed only at a later date, although the basins were pre-existent, while their upper slopes formed land-features.

Even in Northern regions the origin of deep valleys by glacial erosion is disputed ; but their occurrence in low latitudes must remove the possibility of this hypothesis being applied here to these submarine cañons.

From all of these features investigated on both sides of the Atlantic, and their occurrence in other parts of the world, there seems no possible escape from the conviction that there have been great changes of level in recent geological times, amounting to thousands of feet. Such naturally affected the climatic conditions, and the distribution and extinction of animal and vegetable life. While these movements occurred in late geological times, they were of long duration in years. The sea-level may have changed,[2] and the land also was deformed over large areas.

There were minor oscillations subsequent to the great movements, which are not considered here. Some of the phenomena already described may yet be separated more precisely as to their date. But the beginnings of a new science have been made. To this, Europe and America furnish complementary parts on the two sides of the Atlantic, with only such differences as would be expected from the variation of land-features ; but the high plateaus of the Western Hemisphere, surmounted by the newer geological formations, more completely reproduce the submarine features bordering the continent, on a clearer and broader scale than is found in Western Europe.[3] Also the distribution of biological forms in America confirms the physiographic evidence of changes of level, to the extent of at least more than a mile and a quarter, during the early Glacial period or immediately before.

Utilities.—Pure science commonly leads to its economic application ; the investigation of the submarine valleys is no exception. Professor Hull has referred to the importance of the charts in laying out oceanic cables ; the following cases illustrate their importance for purposes of navigation.

Professor Davidson mentions that two vessels were lost on the Pacific coast during a violent gale. The anchors were unfortunately dropped into submarine channels, where no anchorage was obtainable, and the ships were blown upon the adjacent coast and wrecked. Had the captains known of the existence of these channels they could have saved their ships by sailing at right angles away from them, and found anchorage.

During the prevalence of heavy fogs, the wise captains approaching New York drop the sounding-line to great depths, and hunt for a submarine Hudson Cañon, so as to establish their position, after making a dead run.

Professor William Libbey also found that the colder waters of the Hudson Cañon have affected the migration and destruction of fishes.

Time will doubtless bring to light other uses to which this branch of oceanic physiography can be applied.

The scope of this paper relates to North America only, but investigation of the submarine valleys off the coast of South America have been made by Prof. J. C. Branner, to whose works the reader is referred.[4]

[1] The basin of the Gulf of Mexico is 12,000 feet deep, that of the Caribbean Sea 15,000 feet, while the trough in the Sea of Honduras, between Cuba and Jamaica, reaches 18,000 feet. The basin north of Puerto Rico is the deepest known depression of the Atlantic, discovered to 27,366 feet.

[2] Lyell has discussed this question of the permanence of the sea-level, and concludes that it remains permanent, in that its surface is approximately everywhere at the same distance from the centre of the earth.

[3] In a plateau region of Central France, named the "Causses," magnificent cañons occur, reaching to 1200 feet in depth, but their features are more mature than many in Mexico, where younger forms may also be seen.

[4] "The Stony Reefs of Brazil: their Geological and Geographical Relations," by J. C. Branner, *Geol. Series VII., Mus. Comp. Zool. Harvard*, pp. 1-285 (1901-4). Also "The Geography of North-Eastern Bahia," *Geog. Journ.* vol. xxxviii. Nos. 2-3 (1911).

CHAPTER X

Cause of the Glacial Period

EXPLANATION TO ACCOMPANY PLATE IX

Part I.

IT has been shown in previous pages[1] how a general elevation of the earth's crust extending from the Gulf of Mexico all round the North Atlantic to an extent of several thousand feet has taken place towards the close of the Tertiary period, and that such elevation commenced in the Pliocene epoch, and was followed by subsidences of the land which have left their vestiges in the form of raised sea-beaches at various places and levels throughout the British Islands, Scandinavia, and North America.

It is impossible to conceive that such a great uprise of the crust could have taken place without producing effects on the climate and temperature of the regions which came within its influence. And when we ask ourselves what must have been the character of these effects, the answer is inevitable ; namely, a fall of temperature and influx of colder climatic conditions than before or after the uprise. At the present day, in whatever part of the globe we make the inquiry, even in regions under the Equator itself, a rise in elevation above the sea-level is accompanied by increase of cold. Thus in Africa the great volcanic mountain of Kenia, which reaches an elevation of 18,370 feet, almost under the Equator, is covered by snow down to over 3000 feet from its summit.[2] But in order that the British Isles should be shrouded in perpetual snow a comparatively small additional elevation would bring them into that condition, as the summits of our highest mountains in Scotland, Wales, and Ireland reach elevations not far below the snow-line.[3]

The concurrence in time of the Glacial epoch with that of the Pliocene and Post-Pliocene is sufficient evidence that the former was the direct result of the conditions which prevailed in the latter ; in other words, that the extreme cold was due to the elevation of the land. But in addition to this result there is to be added another effect of the uprise ; namely, the variation in the temperature and direction of the Gulf Stream, which has through so many ages powerfully influenced the climate of the British Isles and Western Europe ; and to this result we shall now proceed to direct our attention.

Part II.—The Gulf Stream

During the uprising of the Antillean continent, that branch of the great equatorial current which now enters the Caribbean Sea and passes on into the Gulf of Mexico must have pursued a very different course from that of the present day. Its passage into the Gulf was debarred by the coast of high continental land, the direction of which must have caused the current to pass directly northwards into the North Atlantic, as shown on the accompanying map (Plate IX.). Such a change in direction would

[1] See also Chapter IX., by Professor Spencer. [2] *Geographical Journal*, iv. pp. 413 *et seq.*
[3] If Ben Nevis and Ben MacDhui were a few hundred feet higher, they would be snow-capped all the year round.

result in a difference of temperature ; and we shall endeavour to ascertain, with some degree of accuracy, the amount of variation as compared with that of the present day.

It is known that the Gulf Stream receives a large accession of heat between the time that it enters the Caribbean Sea and leaves the Gulf of Mexico through the Straits of Florida. Off Cape San Roque the surface temperature is 73° Fahr., and on issuing from the Gulf it has risen to 86° Fahr., having in its passage gained thirteen degrees of heat. Increasing its latitude by ten degrees it loses but two degrees of heat, and with this temperature of 84° Fahr. it crosses the 40th parallel, and spreads itself out over thousands of square leagues—carrying its warmth into the Arctic regions, and giving an increase of twelve degrees of temperature to the climate of the British Isles above that due to latitude.[1]

Geographers have exhausted the powers of illustration in endeavouring to estimate the calorific effects of this great oceanic river. Croll states that each cubic foot of water carries from the tropics for distribution upwards of 1,158,000 foot-pounds of heat.[2] The estimates of Maury and Herschell are still larger. According to the calculations of Meech the amount of heat transferred to the Arctic regions by the Gulf Stream is nearly half as much as that derived from the sun.[3] Lastly, Professor J. D. Forbes calculated that the quantity of heat thrown off in the Atlantic area by the Gulf Stream on a winter's day would raise the temperature of the atmosphere which rests upon France and the British Isles from freezing-point to summer heat.[4] These statements will suffice to represent the effects of the Gulf Stream as it exists at the present day ; we have now to inquire to what extent they would be modified under the view of the uprising of a barrier of land connecting North and South America along the line of the Antilles.

We have already seen that the Gulf Stream gains thirteen degrees of heat between Cape San Roque and the Florida Straits. If we allow one degree for the increase between Cape San Roque and the entrance to the Caribbean Sea, the gain between this point and the Narrows will be twelve degrees. If, instead of entering the Caribbean Sea, the Stream passed northwards along the coast of continental land, it would have been deprived of twelve degrees of heat, but it would have gained some heat while flowing for 1000 miles under the rays of a tropical sun. If we allow two degrees for this, then the total loss of heat on passing the coast of Florida will have been ten degrees as compared with that of the present day ; and instead of crossing the 40th parallel with a surface temperature of 84° Fahr. as stated above, the Gulf Stream of the period referred to would have only had a temperature of 74° Fahr., which would not be very much in excess of the summer temperature of the waters due to latitude at this parallel.[5]

We have now to inquire what would have been the effect of so great a reduction of temperature upon the climate of the North Atlantic and adjoining regions. A diminution of ten degrees of heat as compared with that of the present day would undoubtedly exercise a very important influence on the climate of the regions bordering the North Atlantic, and the coast and islands of the Arctic Ocean. Not only would the annual mean temperature be considerably reduced, but the increase of snow and ice over those tracts which are at present on the verge of perpetually glacial conditions would have the effect of lowering the temperature far beyond their own limits. As Lyell has truly observed, land in Arctic regions conduces to cold ; and owing to the great extent of additional land in Europe and Asia which would have been brought under the influence of an arctic climate by the elevation of the land, the cold would be increased in the adjoining regions lying to the south.

There is one way, perhaps the only way, by which we may indicate diagrammatically the climatic

[1] Croll calculates that on leaving the Gulf the *mean* temperature of the Stream is not under 65° Fahr. (*Climate and Time*, p. 25).

[2] *Ibid.* p. 25.

[3] Meech, *Smithsonian Contributions to Knowledge*, vol. ix.

[4] Forbes, *Travels in Norway*, p. 202.

[5] Rennell has calculated that the waters of the Gulf Stream on leaving the Gulf of Mexico with a surface temperature of 86° Fahr. are ten degrees above that of the Atlantic in the same latitude ; quot. by Lyell, *Principles*, 2nd edition, p. 244. A portion of the waters of the equatorial branch even now passes along the east coast of the West Indian Islands, ultimately joining the Gulf Stream. All this time, however, they are acquiring heat, but not to the extent which would be the case if they followed the main stream. The amount, however, is unimportant in its bearing on the question before us, as the conditions of this branch of the equatorial current would have suffered no change.

conditions of which we are in search under the hypothesis of a North Atlantic current taking the place of the Gulf Stream, but with a temperature ten degrees lower than the latter. If we suppose that the annual mean temperature of all those regions influenced by the Gulf Stream as far south as (say) the parallel of 40° N. is reduced by about ten degrees below its present range, then we shall have the present isotherm of (let us say) 32° Fahr. taking the position of that of 42° Fahr., and that of 42° taking the position of that of 52°; there will, in fact, be a general advance of cold southward. Then by observing the climatic conditions of the regions crossed by the present isotherms of 32° and 42° we shall be able to form an approximate idea of the climate, under the hypothetical conditions of temperature we are here considering. I am well aware that this mode of determination would not, in all cases, give strictly accurate results. Climates depend not only on temperature, but on relations of land and sea, on levels, prevalent winds, and other conditions; but temperature is a main factor, and the mode of determination here suggested will probably afford fairly reliable results.

Isotherms.—Of all the isothermal lines representing annual mean temperature that may be drawn across the chart of the Northern Hemisphere, none is more important than that of 32° Fahr., the freezing-point of water. This isotherm, according to Berghaus,[1] crosses America, from lat. 58° N. on the west coast, to Cape Charles, lat. 52° 35′ N. on the east; skirts the southern coast of Greenland and crosses the Atlantic by the northern coast of Iceland; entering Europe near the North Cape; then trending southwards along the coast of Norway to the south of the Arctic Circle, it crosses the Europe-Asian Continent nearly along the 60th parallel to the coast of China. This isotherm is everywhere to the south of the Arctic Circle except in that part of the Atlantic bordering the coast of Norway and lying to the south-east of Iceland, where it passes the Circle along the arm of the Gulf Stream which, even in these high latitudes, gives evidence of its power to ameliorate the rigour of the climate.

The isotherm of 32° Fahr. may be regarded as a convenient line of demarcation between the permanently glacial regions and those which enjoy a temperate climate. To the north of this line are situated the frozen regions of Hudson Bay, Labrador, Baffin Bay, and Davis Strait (regions only accessible during two or three months in the year), the continental island of Greenland enshrouded in eternal snow and ice,[2] the Greenland Sea blocked by ice-floes, the glacial isles of Spitzbergen and Franz Josef Land, Novaia Zemlia and Liakov Isles (New Siberia), with the surrounding Arctic Sea, whose surface of ice is only penetrable during three months in the year; lastly, the mountains of North Norway and Lapland and the frigid tracts of Siberia bordering the ocean, where the soil is permanently frozen a few inches below the surface. Of all these regions it may be said, that if their temperature ever rises above freezing-point of water, it is only to the extent of a very few degrees during the three summer months.[3]

Isotherm of 42° Fahr.—Very different is the climate enjoyed by those regions lying under the isothermal line of 42°. Leaving the western coast of America at Vancouver it crosses that continent by the Great Lakes to Nova Scotia in lat. 45° N.; then driven northwards by the Gulf Stream it crosses the 60th parallel half-way between Iceland and Scotland and reaches the coast of Norway a little north of Bergen; then curving round the southern shores of Scandinavia, passes into Russia south of St. Petersburg, and crosses Central Asia near the intersection of the parallel of 45° N. by the meridian of 90° E. This isotherm, except when it passes over the Atlantic, is characterised by extremes of heat and cold; but the heat predominates, and glacial conditions are impossible except at high altitudes such as are afforded by the mountains of Norway.

1 *Physikalischer Atlas* (Gotha, 1892). See map (Plate X.).

2 Except along the margin, and inland valleys as shown by Nansen, *Northern Mists* (*passim*).

3 The following are some of the temperature observations within the Polar regions:—

		Three Summer Months.	Three Winter Months.	Annual Mean Temperature.
Banks Land	Lat. 74° N.	+ 35°	− 5°.7	+ 1°.8 Fahr.
Parry Island	„ 74° 25′	+ 37°	− 10°.6	+ 1°.4 „
Cornwallis Island	„ 74° 45′	+ 36°	− 8°.6	+ 2°.5 „
Northumberland Sound	„ 77° 0′	+ 30°.8	− 11°.8	− 1°.1 „

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Cause of the Glacial Period

Effect of the Conversion of the Isotherm of 42° *into that of* 32°.—We are safe in supposing that if the isotherm of 32° once occupied the position of 42° of the present day, the climate along this line was very different from that which now prevails ; let us endeavour to define its conditions in outline.

As regards America, it may be inferred that the Great Lakes were in their northern portions permanently frozen over like the waters of Hudson Bay throughout eight months in the year, while Labrador and the lands lying along the western shore of Hudson Bay and extending to the shores of the Great Lakes were covered by snow which the sun of summer would be unable to melt. There would not be much change in the condition of Greenland or of the neighbouring seas except in the direction of increase of cold and greater accumulation of snow and ice. As regards Scandinavia, we may safely infer that, owing to the increase of cold and the enormous precipitation of snow on the western slopes of the mountains, the snow-line would descend far below its present limits, and glaciers would enter the sea north of the Arctic Circle, where the ocean would resemble that of Davis Strait at the present day. That the highlands of the British Islands would be sufficiently cold to support perennial snow and glaciers may also be assumed. At the present day some of the highest parts of the Grampians are not much below the snow-line, and snow often lies on Ben Nevis and Ben MacDhui all the year round. But we need not follow the subject further except to observe that the additional accumulations of snow on the higher regions would tend to intensify the cold throughout all the adjoining tracts of Western and Northern Europe and Asia.

Part III.—Effects of Elevation of Land

But we must not forget that, as shown by Professor Spencer, and more recently by Mr. Warren Upham, the submerged platforms and river-valleys occur along the American coast at least as far north as the Susquehanna in lat. 42° N., while other drowned "fjords" have been determined by Lindenkohl in connection with the Hudson—descending to 2250 and 2844 feet below the surface of the sea.[1] These features indicate elevation of the American Continent along the Atlantic coast, but though not to the extent which was indicated in the case of the Antilles, still sufficient to have produced very marked effects on the climate of Eastern America. If this be so, then to the cold produced by the lowering of the temperature of the Gulf Stream must be added that due to increased elevation of the continental land itself. The combined effect of these two factors would, as it seems to me, suffice to call into existence a glacial climate of great severity over the region lying to the north of the St. Lawrence and the Great Lakes.

As regards the area of the British Isles and Western Europe a few words may be added to those on a previous page. It has been established, as above stated, by the observations of Mr. Godwin-Austen,[2] Prestwich,[3] Delesse,[4] and Rupert Jones,[5] that the platform upon which they are built was elevated to the extent of the 100-fathom line, owing to which Great Britain was united to Europe on the east and Ireland on the west. The distribution of the land fauna and flora requires such an hypothesis ; as does the extension of the glaciers and sheets of ice over the area of the Irish Sea and the isles which border the western coasts of Ireland and Scotland from their centres of dispersion. At the time of this elevation, which, according to Mr. Godwin-Austen, was the close of the Pliocene period, Snowdon would have reached an elevation of 4200 feet, Ben Nevis and Ben MacDhui about 5000 feet each, and the Reeks, 4014 feet. The whole region would have suffered a considerable decrease of temperature as compared

[1] *Report U.S. Coast Survey for* 1884, pp. 435-841 ; J. D. Dana, *Am. Journ. Sci.* iii. vol. xl. pp. 425-437.

[2] *Quart. Journ. Geol. Soc.* vol. vi. p. 69.

[3] *Geology*, vol. i. p. 118, and vol. vii. p. 118.

[4] *Lithologie des mers de France*, 1871.

[5] "Antiquity of Man," *Rep. Croydon Micros. Club*, 1877, p. 2. This paper is accompanied by a map showing the land area produced by an uprise of 600 feet (100 fathoms) above the present sea-level. It is remarkable that this platform corresponds in position to the Continental Shelf of Eastern America above described. The descent from the 100-fathom plateau to that of 1000 fathoms is remarkably steep along the western margin off the coasts of the British Isles, France, and Spain ; see Professor C. Wyville Thomson's *The Depths of the Sea*, Plate VII. p. 362 (1873).

with that of the present day; and if, in addition to this cause of increased cold, we add that arising from a reduction in the temperature of the Gulf Stream, we seem to be warranted in coming to the conclusion that such physical conditions would have brought about a glacial climate in this region.

Region of the Mediterranean, Southern Europe, and Western Asia.—It may be objected that the hypothesis here advocated is insufficient to account for the colder conditions of climate which affected Southern Europe and the regions bordering the Mediterranean and extending eastward to the Himalayas. Throughout all these regions we have evidence that the climate was colder than at present during the Pleistocene period, resulting in the extension of the glaciers in the Alps, the Pyrenees, Caucasus, and the Himalayas themselves; while, as the late Sir Joseph Hooker has shown, glaciers were formed amongst the mountains of the Lebanon from which they are now altogether absent.[1]

To this objection there may be offered two very forcible answers. *First.*—It may be confidently asserted that a general lowering of the temperature and change in the climate of Western Europe would necessarily produce some effect in the same direction on the regions lying beyond. If the climate of Scandinavia, of the British Isles, of France, Spain and Portugal became sensibly more rigorous, it is clear that owing to the circulation of the air currents the climate of the adjoining regions to the eastward would also experience at least a proportionate change in the same direction owing to the greater accumulation of ice and snow in the higher altitudes. It is impossible to say to what distance this influence would extend, and did extend, during the Pleistocene period, especially during the epoch of maximum cold. I think it may safely be assumed that none of the regions above enumerated were altogether unaffected by it; and for my own part I am inclined to believe that the entire Northern Hemisphere felt the loss of heat due to the diminution of temperature of the Gulf Stream. *Second.*—But there remains a still more potent cause for the greater prevalence of glacial conditions than is the case at present in the regions referred to. It has been shown (Chapter VII.) that towards the close of the Pliocene period the vast tract embracing the basin of the Mediterranean and adjoining regions extending eastward was undergoing gradual changes as regards the relations of land and sea. After a slight depression—during which sea-beaches were formed along the old coast-lines in the lands bordering the Levant, there ensued a process of elevation ultimately resulting in the conversion of the Mediterranean basin into a chain of fresh-water lakes connected by rivers with the Black Sea, and closed against the influx of the Atlantic waters by the uprise of the sea-bed at the Strait of Gibraltar. At this period Sicily was connected with Malta and Tunis, while the island was inhabited by elephants and hippopotami, as shown by Leith Adams and Spratt. The two lakes thus formed were connected by a river channel crossing the "Medina Bank," which is now submerged to a depth of 250 fathoms.[2] Without going further into this very interesting subject it must here suffice to state that owing to the uprise of the whole region to the extent of 1200 to 1500 feet (200 to 250 fathoms) large tracts now under water were converted into land, and the adjoining areas were upraised land. This uprising of the land necessarily brought certain mountainous tracts within the limits of the snow-line—as was the case in the Lebanon, where, as already stated, glaciers were formed which have left their old moraines at a level of 4000 feet above the present surface of the Mediterranean; mountainous regions such as the Caucasus, where perennial snow lies, were subjected to a more rigorous climate. That this general elevation of the Mediterranean and Syrian region extended much farther eastward cannot be doubted—how far it is impossible to say; but there does not appear to be any reason why its influence may not have been felt as far as the Himalayas, where, as we know from the observations of Hooker, the glaciers once descended far below their present limits.[3] In all these considerations we must remember that the two possible causes—those of reduced temperature and of land elevation—

[1] Hooker, "On the Cedars of Lebanon," *Nat. Hist. Rev.*, 1862; also, Sir W. W. Smyth, Pres. Address Geol. Soc. (1868), *Quart. Journ.* vol. xxiv. p. 58. While these pages are passing through the press, the venerable form of Sir Joseph Dalton Hooker has passed away in his 95th year. As a scientific traveller who has revealed to us the glorious flora of the Himalayas and other Eastern countries, Hooker will ever be held in grateful remembrance by all lovers of Nature.

[2] Spratt, *Quart. Journ. Geol. Soc.* vol. xxiii. p. 292.

[3] Hooker, *Himalayan Journals*, vols. i. and ii. (1855).

were acting simultaneously; and it is to their combined influence that we may ascribe the general lowering of temperature, and prevalence of more arctic climatic conditions, of which we have evidence during the Pleistocene period.

Part IV.—Conclusion

The causes which have been assigned for a glacial epoch may be arranged under two heads—the astronomical and the terrestrial. Under the former may be placed the theory of the late Dr. Croll, which has the support of Professor James Geikie, and that of Sir Robert Ball more recently enunciated; under the latter is that of Lyell, who held that "in determining the climate of the globe geographical changes have exercised a preponderating influence."[1] Croll's hypothesis has been examined by Lyell, Prestwich,[2] and others, who are unable to accept its conclusions, as well on astronomical as on physical grounds. Lyell in the last edition of his great work still adheres to his original views, which find support in the conclusions here arrived at. Few will deny that, but for the Gulf Stream, the British Isles and Northern Europe would now be subjected to glacial conditions; and with the aid of Professor Spencer's researches I have attempted to show how such conditions were brought about.

I must not omit to refer to the view of Mr. Warren Upham, of the United States Geological Survey, who has dealt with this subject in an able paper communicated to the Victoria Institute in the session of 1896-97,[3] who corroborates generally the views of Professor Spencer, and other American geologists, including Dana and Le Conte, regarding the former great uprise of the continental lands at or near the commencement of the Glacial epoch; arriving at similar conclusions to those of the author of this work, but based mainly on the view of the lowering of temperature due to such elevation. I have endeavoured to show how, in addition to the lowering of temperature due to elevation of land in the Northern Hemisphere, the deflection of the Gulf Stream must have also materially influenced the climatic conditions. It need scarcely be stated that both papers were written altogether independently of each other; but their agreement in the conclusions will be regarded as confirmatory of the "epeirogenic" or "earth-movement" hypothesis.

The most able opponent of this hypothesis is Professor James Geikie, and I have re-read his elaborate communication to the Victoria Institute,[4] dealing with this subject, in order to refresh my memory as regards his views and arguments; which have also been dealt with by Mr. Warren Upham, and, as it seems to me, in the main, successfully.[5] I cannot see, for instance, upon what ground Geikie considers the American uplift to have been long antecedent to the Pleistocene epoch. Of course the uprise of the land around the shores of the North Atlantic was gradual, and the accumulation of snow and ice would also have been a very slow process; but both Spencer and Upham are agreed that this uprise commenced with the close of the Pliocene period; a view which seems the more reasonable one.[6] At the same time I agree with Professor Geikie in doubting that the oscillations of land of the Pleistocene period were to any great extent (if at all) due to the weight of accumulated snow (or its removal), as supposed by Dana. In the view of the occurrence of two cold epochs with an intervening warmer (or interglacial) stage, I have long been a believer, and maintain that it is borne out by the glacial phenomena of the British Isles, as I endeavoured to show many years ago,[7] but such movements were probably not dissimilar in their origin and cause to those of former geological periods to which the crust of the earth has been subjected.

[1] *Principles*, vol. i. ch. xii.

[2] *Geology*, vol. ii.

[3] Upham, "Causes of the Ice Age," *Journ. Vict. Inst.* vol. xxix. p. 201 (1897).

[4] *Ibid.* vol. xxvi.

[5] *Ibid.* pp. 221 and 254, also vol. xxix. p. 237.

[6] See on this point a more recent paper by Professor Spencer on "The Continental Elevation of the Glacial Period," *Geological Magazine*, January 1898. In this paper the author extends his observations on the great continental uprise to the eastern and northern coasts of the Atlantic, suggesting changes regarding the European and British area far in excess of those referred to by myself for these regions.

[7] *Physical History of the British Isles*, ch. xiii. plates 13 and 14 (1882).

Cause of the Glacial Period

CORROBORATIVE VIEWS OF SOME AUTHORITIES

Colonel H. W. Feilden, F.G.S., writes to the author, December 13th, 1896 :—

I am inclined to think that there is much force in your view that the so-called Glacial epoch was due in a great measure to some deflection of the warm current from the Polar basin.

If Professor Spencer is correct the elimination of the Gulf of Mexico would deprive the Northern Atlantic of its chief heating apparatus, and might induce glacial conditions over Scandinavia. If a system of glaciation sets in anywhere, where the precipitation exceeds the melting forces, there is no saying where it may end, given sufficient lapse of time.

There is, however, another side of the proposition, about which I should like your opinion.

Undoubtedly the glaciation of the vast island-continent of Greenland, 1200 miles in extent, north and south, is due to the refrigerating influences of the great Polar drift of cold water sweeping down its east side, swirling round Cape Farewell, and running up to Holstenborg on the west side; whilst the icy current coming down Smith Sound plays a similar part on the west side.

Now if we could deflect this Polar current, so that it came down the Baltic, as it probably did, and along the west side of Norway, would not Scandinavia be as glaciated as Greenland, and England, Scotland, and Ireland, and the Faeroes, much as Spitsbergen is to-day?

Again, is there any proof that the glaciation of North America was coincident with the Glacial epoch of Europe?

Most travellers in those regions have pointed to the proofs of remarkable rapid elevation in recent times of the islands of the American Archipelago and of Grinnell Land, where recent shell-beds stand at an elevation of 1000 feet.

If we could again sink the American Archipelago 1000 feet, the fender or buttress which keeps out the Palaeocrystic ice would be removed, and that ice would pile up on the shore of the continent of America, much farther south than now, and probably glaciate it.

Here Colonel Feilden asks my opinion on the question, whether by the deflection of the North Polar current down the Baltic and the west coast of Norway, Scandinavia would be as glaciated as Greenland? and he points out that this might take place by the submergence of the islands of the American Archipelago which have recently been upraised to the extent of 1000 feet, as shown by beds of shells.

The passage of a Polar current down the Baltic would require the submergence of Lapland to the extent of over 500 feet, a state of things which in all probability formerly existed; and the passage of a north current would doubtless have the effect described. But it is to be observed that the greater part of Greenland lies farther north by 10° than that of Scandinavia, the effect of which would be to cause the climate of the latter to be less rigorous under any circumstances; and this result would be accentuated by the prevalent wind-currents.

Colonel Feilden also inquires whether there is any proof that the glaciation of North America was coincident with the Glacial epoch of Europe?

My reply is, that although there may be no proof, the probabilities are in favour of the view, as the uplift of the land and ocean-bed seem to correspond on both sides of the Atlantic, as I have endeavoured to show. But it is otherwise with the western side of the American Continent, where reciprocal (not simultaneous) conditions appear to have prevailed, as Professor Spencer has recently shown, in his paper on the "Oceanic Connection of the Gulf of Mexico with the Pacific" (*Bull. Geol. Soc. Amer.* vol. ix., 1897).

The late Professor T. Rupert Jones, F.R.S., writes :—

January 15th, 1898.

I have read Professor Hull's paper read before the Victoria Institute, with much pleasure. He seems to establish the following facts and conclusions.

If we trace the 100-fathom line around the British Islands, as indicated on the Admiralty Charts, we notice that opposite to the river-mouths opening out on the coasts there are corresponding indentations. So also off the North-East American and other coasts the deep-sea contour lines run parallel with the bays and river-mouths; and moreover the valleys of the land are continued by definite lines of relative depths (shown by soundings) down the great irregular slopes of the sea bottom. These lines of valleys and gorges cross plateau after plateau on the ocean floor, and notch their precipitous edges with successive gaps. These valleys are traced downwards and outwards for more than 200 miles, and even to a depth of two or more miles below the present surface of the water, before they are lost on the abyssal floor of the ocean.

These successive submarine plains and plateaus were the result of littoral denudation at times when the continents, high above water, were gradually sinking (like the smaller "Raised Beaches" during uprise of land), with such intervals of stability as allowed the destructive action of the air, water, and ice to make great horizontal notches along coasts and across river-channels. Consequently certain portions of the continents have been in former times at least two miles higher above the sea-level than they are now. With this elevation and wider extent of land the climate must have been much colder, even frigid enough for what has been termed a "Glacial Age."

Other points also are considered by the author. It was in late geological times that the coasts of the Northern Atlantic Ocean, both on the American and the European side, and across its northern region, had an elevation high enough for an arctic climate. The equatorial current could not then have had the heat it now obtains by its local confinement in the torrid Gulf of Mexico; and the vicinity of the snow-laden coasts of the North Atlantic would have reduced the equatorial warmth; so that it would have had little influence in ameliorating the climate of North-Western Europe in the "Glacial Age."

He also intimates that, on account of the slow and unequal movements of the earth's surface, the coming and going of arctic conditions must have been different at times and places; and the glaciation of one region would not be quite synchronous with that of another. At all events a great part of North America, with North-Western Europe, had a glacial climate in late Pliocene or early Pleistocene times.

Mr. Warren Upham, F.G.S.A., writes :—

St. Paul's, Minnesota, *January 3rd*, 1898.

The explanation of the climatic changes and ice accumulations of the Glacial epoch presented in Professor Hull's paper, with its accompanying map, seems to me a most valuable addition to our understanding of this very exceptional and unique geological epoch. There can be no doubt that the epeirogenic uplifting ot the lands on each side of the North Atlantic Ocean produced important changes of the Gulf Stream and of its influence on the climate of Europe. The lowering of the temperature of that great sea current may well have been a chief element in the causation of the Ice Age in the British Isles and Northern Europe, supplementing the effect due to the greatly increased altitude of the land, of which the fjords bear testimony.

In North America, however, where our storms and waves of varying barometric pressure and temperature sweep from west to east and north-east across the country, thence passing over the North Atlantic, we must, I think, ascribe the chief part in the production of the Glacial epoch to the high elevation of the land, probably 3000 to 5000 feet above its preglacial and its present height.

Professor Hull's map might indeed well be coloured farther into the present sea area between Europe and Greenland, to the submarine contour of 450 or 500 fathoms, as for the Blake Plateau of America. If the preglacial uplift of the sea-bed between the Atlantic and Arctic Oceans was so great, which is very probable, these oceans were completely separated by land, and the Gulf Stream and warm superficial oceanic drift from it were wholly excluded from contact with Scandinavia. That condition, in combination with the high land uplift, gives an ample explanation of the origin of the Ice Age in Europe, which seems to have been essentially contemporaneous with that of North America.

The Rev. R. Ashington Bullen, B.A., F.G.S., writes :—

There can be but one opinion about the interest and importance of the theory set forth by Professor Hull. Huxley [1] leaves undecided the influence of the Gulf Stream in ameliorating the climate of Great Britain, and hints at the possibility of warm currents being due to the dominant south-westerly winds of the temperate part of the Atlantic. Under any circumstances, however, the lowering of the temperature of the Gulf Stream would have a marked effect on the temperature of the ocean and the air in the North Atlantic, and would affect the assumed currents due to the south-westerly winds.

To my mind the amelioration of our climate is mainly due to the Gulf Stream or to subsidiary currents proceeding from it. The existence of such fragile West Indian shells as *Spirula Perouii* on Portrush Beach, N. Ireland, and at Woolacombe, Devon, perfectly uninjured,[2] points to a branch of the Gulf Stream touching first the Irish and then the Devon coast. Mr. R. Welch of Belfast and friends have collected eight to ten at a time, especially in September.[3] *Tellina radiata*, another West Indian shell, has occurred at Courtmacsherry Bay, S.W. Ireland, and other places. Sir A. Geikie[4] points to the occurrence of West Indian plants on the Irish coast as having been drifted across the Atlantic from west to east, or north-east.

In September 1897, in the Allan liner *Parisian*, from Liverpool to Montreal, the sea-water temperatures were logged approximately as follows :—

September	10th	about	55° 20′	N. lat.	9° 0′	W. long.	58° F.
„	12th	„	56° 25′	„	25° 31′	„	55° F.
„	13th	„	56° 23′	„	35° 23′	„	55° F.
„	14th	„	55° 12′	„	43° 6′	„	48° F.
„	15th	„	53° 13′	„	51° 50′	„	35° F.
„	16th, Gulf of St. Lawrence, Cape Norman, E.S.E.						33° F.

1 *Physiography*, 2nd edit. p. 174. 2 *Science Gossip*, 1897, p. 150. 3 *Ibid.* 4 Geikie, *Physical Geography*, p. 139.

The rapid fall from 48° to 33° F. was due to the Baffin's Bay cold current.

Now, assuming Professor Hull's statement of the lowering of the temperature due to the deflection of the Gulf Stream owing to the elevation of the Antillean continent, the temperature of the waters of the Gulf of St. Lawrence even in so warm a month as September would be lowered from 33° to 23°. The St. Lawrence and adjacent seas would be ice-bound, and icebergs would be set adrift, to float even farther southward (probably 1000 miles) than at present the Greenland bergs do, with a correspondingly lowering influence upon the temperature of sea and air. Judging from the influence of a large number of bergs adrift in the North Atlantic, in producing damp and cheerless summers in the British Isles, *e.g.* 1877, 1878, 1879, etc., such conditions as Professor Hull supposes would make summer in these islands a thoroughly "glacial" one.

Judging from what I saw of geological phenomena in Connecticut in October last, the glacial conditions farther south were even more rigorous than my estimate indicates.

Professor Newcombe and Rev. E. Hill are dissatisfied as astronomers with the astronomical explanation of the cause of the Glacial epoch. Sir Joseph Prestwich[1] has fully discussed the question of recurring glaciations, which Croll's hypothesis renders necessary, rejecting these glaciations as facts, either (1) from want of evidence, or (2) because the geological evidence is all the other way.[2] As this and various other astronomical theories are unable to bear the strain put upon them, we must, I think, conclude that some geographical explanation is the more probable; and that, as an uplift such as Professor Hull postulates would be attended by glacial conditions, his theory, or some modification of it, may be accepted as best satisfying all the conditions of the problem.

The Rev. G. Crewdson, M.A., writes :—

January 18th, 1898.

May I be allowed to suggest a few considerations which seem to confirm the theory which Professor Hull has so ably expounded in his paper on "Another Possible Cause of the Glacial Epoch."

In the present day it will be observed that owing to the Antarctic cold the stream of heated equatorial water is pressed northwards, a greater breadth of the stream being north of the Equator than south of the line; consequently a larger proportion of water is diverted northwards at Cape S. Roque than would be the case if the stream were accurately equatorial.

If, however, Arctic conditions were to prevail in the North Atlantic, these conditions would be reversed, and a much larger amount of heated water would be diverted into the Brazilian current flowing southwards than is at present the case, and the North Atlantic would receive less than its due share. This would not only lessen the amount of heat available for raising the temperature of the northern regions, but would also diminish the resistance that would be offered to cold currents from the Arctic Ocean; a point which receives increased importance from the consideration of possible changes in the Pacific area.

For there is another fact which can scarcely be said to be less than paradoxical in its character, that at the time when Northern Europe and Eastern North America were enduring a climate of exceptional rigour, Siberia and Western North America were enjoying a comparatively temperate climate. Somehow or other, therefore, warm winds must have been able to find their way into the Arctic regions in that hemisphere at the same time that they were excluded from the European area. Now at the present day Behring Straits are narrow and shallow, and little or no water is able to enter from the Pacific equatorial current. But with the exception of the mountains to the south of Alaska, the land bordering the strait is, generally speaking, low and alluvial. If then this were depressed, a large free access would be opened to the Arctic Ocean on that side; and if this were the case I do not think it unreasonable to suppose that a stronger and more highly heated current would pass through than is found in the Gulf Stream, inasmuch as the Pacific is larger than the Atlantic, and the northward-flowing stream would not have to contend with any counter-flowing current, all the water finding its exit by way of the Atlantic channel. It is obvious that by the time the water had reached the Scandinavian coast it would have lost all its heat, and would very largely contribute to further reduce the temperature in the North Atlantic area; and being comparatively unopposed in its southward course, and pressed forward by the floods from the Pacific, it would probably develop a force far exceeding that of the existing Greenland current; a force that would be sufficient in fact to produce those perplexing glacial markings in Scandinavia and elsewhere which Mr. Lindvall has ascribed with much probability to the action of drift-ice rather than that of a sheet of land-ice.

It is true that the tendency of the south-flowing Arctic current would be to trend towards the Greenland side of the channel, owing to the effects of the revolution of the earth on its axis; but if Greenland shared, as it probably did, in the general elevation of the east coast of America, the current would be driven more towards the European shore, and the course of the Gulf Stream itself is an evidence that currents can be diverted by geographical or other causes into other than their natural channels.

This theory also meets another difficulty. Great cold does not necessarily mean abundant snow. A region of evaporation at no great distance is also necessary. A heated Siberian sea would afford just such an area as would be needed to produce a heavy snowfall in North-West Europe and North-East America. We should thus have every condition for producing a Glacial epoch in these regions.

This seems to me to supply a simple explanation of this remarkable era, without calling in the help of a *Deus ex*

[1] Prestwich, *Geology*, ii. p. 527, note.

[2] Prestwich, *Controverted Questions in Geology*, p. 23.

machina such as the theory of cold and warm regions in space, or such slow-working agencies as the varying eccentricity of the earth's orbit, a theory whose very supporters admit could only have produced the required effects if favoured by other exceptionally propitious circumstances.

The late Cavaliere W. P. Jervis, F.G.S., Conservator of the Royal Italian Industrial Museum at Turin, writes :—

Few geological difficulties have constantly presented themselves to my mind of such a serious kind as the explanations advanced as to the causes of changes of climate on our globe in geological times, including the intense cold during the Glacial epoch, and the converse warmer temperature during the Miocene epoch. None of the theories elicited have convinced me. But the paper read before the Victoria Institute by Professor Hull, based, as the arguments are, on the most forcible logical and palaeontological data relating to the entire eastern and southern coast-lines of North America, has dissipated, as by enchantment, all my doubts ; and the proofs he adduces of the former non-existence of the Gulf Stream appear to me to throw a bright light upon many obscure points of geological climatology.

Though Lyell laid great stress upon changes in the geographical configuration of our globe at successive periods of its existence, and showed the ever-changing elevation and depression of vast tracts of country, it would appear that enough attention has not been paid to these considerations, and hypothetical astronomical causes have found too much favour with not a few geologists—and in absence of proofs.

River-valleys have been plainly traced by Issel to great depths in the Mediterranean, in prolongation of what are now short valleys in Northern Italy, and doubtless elsewhere much progress will be obtained in our knowledge of the past, of the fauna and flora of geological epochs, and of the erstwhile distributions of land and water, by a more extensive study of soundings of the ocean.[1]

Professor Cooke describes the abundant fossil remains of elephants which he found in Malta, and draws from this fact, as also from the existence of like fossil bones in Sicily, the conclusion that these islands once formed part of the African Continent, previous to a considerable submersion of land now constituting deep sea.

Professor Hull beautifully explains how we can find Arctic forms of marine molluscs in rocks not so far from London, and proves the possibility of there having once been extensive glaciers on loftier mountains in Scotland, and of which we still find the traces.

Will the Professor permit me to suggest that it would be a most important point, in order to corroborate his views regarding the assumption of a mean lower temperature of 10° F. previous to the formation of the Gulf Stream, to take accurately into account the longitudinal breadth of the Atlantic previous to the submergence of the Continental Shelf and of the Blake Plateau, *i.e.* during the Pliocene and Pleistocene epochs, by ascertaining whether there are corresponding proofs of submergence of the South American Continent, even of the African coast, for evidently *the length of time* the superficial ocean current was subject to the rays of a tropical sun would have an effect analogous to what takes place now in the Gulf of Mexico ?

Professor Hull's able paper is calculated to open out a vast field of important geological investigations. The depression of the Atlantic coasts of North America and of North-Western Europe has no parallel in many parts of Western Africa. But changes of climate in a reverse direction after the Miocene epoch can be accounted for by the still later upheaval which has left the vast deserts of Northern Africa, Arabia, and Central Asia as clear proofs of the existence of former seas, permitting elephants to live in the long island of Morocco, Algeria, Tunisia, and Malta, and rendering the climate of Siberia milder than at present.

Geology and physical geography are twin sisters ; their requirements are so intimately united that they cannot be too closely associated ; the opening or closing of sea communication between two points, as likewise changes in the elevation of land, finally deviations of ocean currents, materially alter the climate of the globe, irrespective of all extra terrestrial agencies.

THE AUTHOR'S REPLY

The general concurrence in my views, stated by Professor T. Rupert Jones, is a matter of much gratification. He has touched on one of the points referred to by Colonel Feilden above.

[1] One of the most interesting series of six maps exhibited by Dr. Gerard de Geer in the Swedish section of the VIth International Congress, held in London in 1896, showed the glacial regions of Finland and Scandinavia at different periods. In the first map he endeavoured to prove the existence of a continuous ice barrier from Greenland to St. Petersburg, coming down as far south as Denmark and North Germany. The next map showed the retreat of the limit of eternal snow and ice, the line passing through Central Sweden ; while in another map the glaciers were confined to certain mountainous tracts of Norway ; Sweden and Finland being out of the question. This is no mere conjecture. Professor Neovius, of Helsingfors University, in a prolonged conversation I had with him on this subject, declared that the deductions were founded on the geographical distribution of the granite ice-borne boulders abundantly found along more than 15° of longitude in consecutive order.

I found that glacial boulders of Finnish granite were well known to exist in the neighbourhood of Halle, while I was engaged at work at Eisleben, but in Finland and Sweden the boulders are more common along the edge of the former isotherm of 32°.

Cause of the Glacial Period

I gratefully appreciate the suggestions of Mr. Warren Upham in reference to the greater extension of the emergent land in the North Atlantic area than is shown on my map. I also concur with him that the greater elevation of the land of the American Continent had more effect in bringing about glacial conditions in that region, than the reduced temperature of the Gulf Stream, which would have a more direct effect upon the climate of Western Europe and the British Isles.

The views stated by the Rev. G. Crewdson seem to me well worthy of consideration, though the subject they open out is too extensive to be discussed here. The depression of the North-Western American Continent during the elevation of the north-eastern side of the same continent may be accepted as an all but proven fact; and the entrance of large masses of comparatively warm and moist Pacific waters by the enlarged Bering Strait would doubtless have resulted in abundant snowfall on the Arctic land areas. On the general question regarding the reciprocal movements of the land on alternate sides of the American Continent the recent paper by Professor J. W. Spencer on "Great Changes of Level in Mexico and the Interoceanic Connections" (referred to above) has thrown much light.

I have been much interested by the views of the Rev. R. A. Bullen, in which I fully concur, and am glad to have the support of an observer who has paid so much attention to the physical conditions of the North Atlantic.

The observations of Cav. W. P. Jervis are of much interest and very gratifying. I have had several letters of acknowledgment expressing interest in the subject of my paper from Continental geologists, including Professor Dames of Berlin, Dr. C. Barrois of Lille, Professor Suess of Vienna, and Professor Geinitz of Dresden, and this of Cav. Jervis of Turin is a welcome addition to the list. The statement that Issel has traced old river-courses to great depths in the Mediterranean in prolongation of valleys in North Italy is dealt with already (Chap. VII.), and is confirmatory of the results arrived at by the late Admiral Spratt, where he proved by soundings the existence of a river-channel joining two of the lakes formed in the Mediterranean basin between Sicily and Africa during the period of upheaval and low water-level. (See *Quart. Journ. Geol. Soc. Lond.* vol. xxiii. p. 292.) The existence of this channel shows the bed of the Mediterranean to have been upraised over 150 fathoms (900-1000 feet) at this period.

THE END

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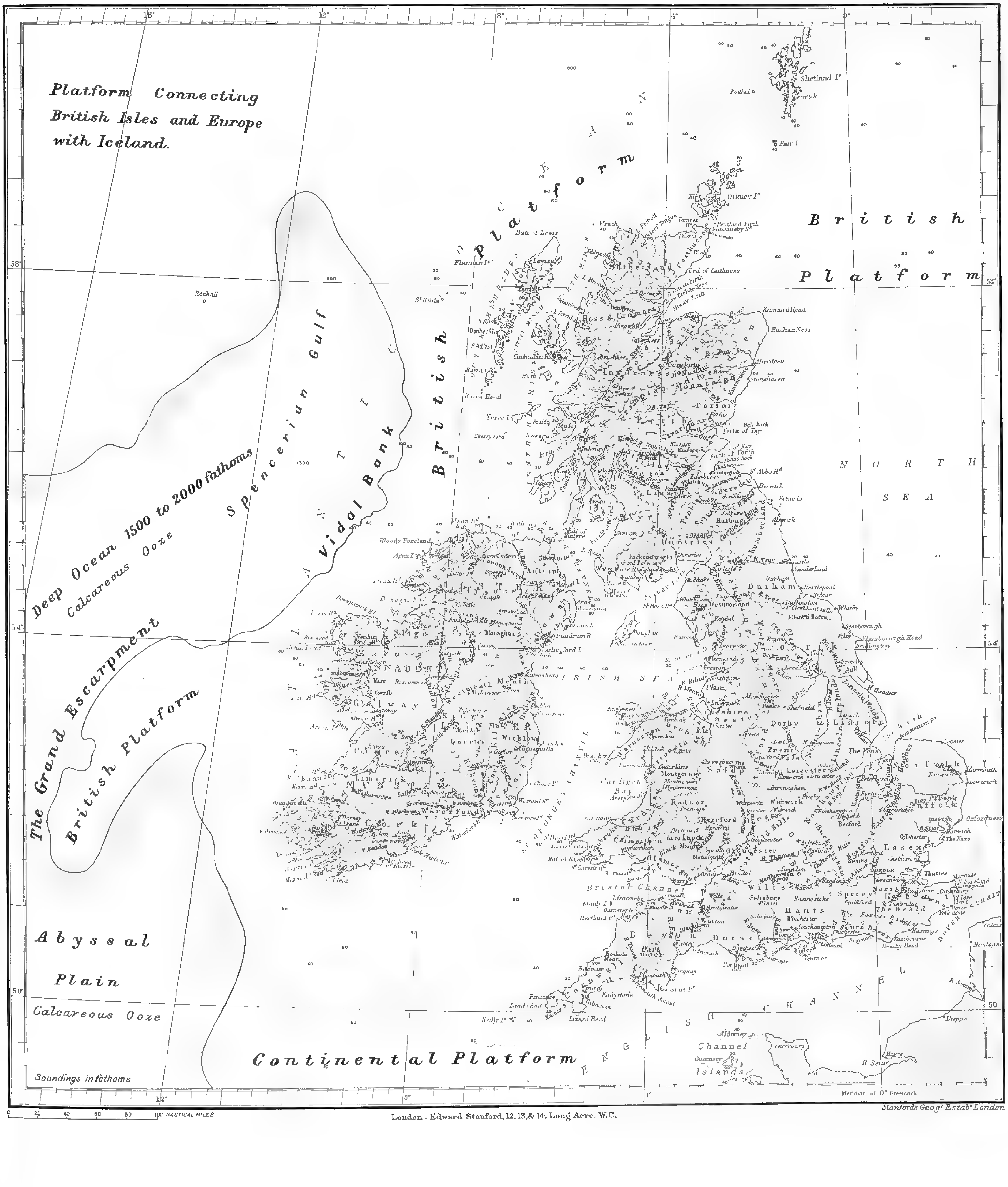
OROGRAPHICAL MAP OF THE BRITISH ISLES WITH ISOBATHIC CONTOURS, SHOWING SUBMERGED RIVER VALLEYS

PLATE II.

London Edward Stanford, 12, 13, & 14, Long Acre, W.C.

Stanford's Geog! Estab! London

OUTLINE MAP OF THE BRITISH ISLES & ADJOINING OCEAN, SHOWING THE LIMITS OF THE CONTINENTAL PLATFORM.



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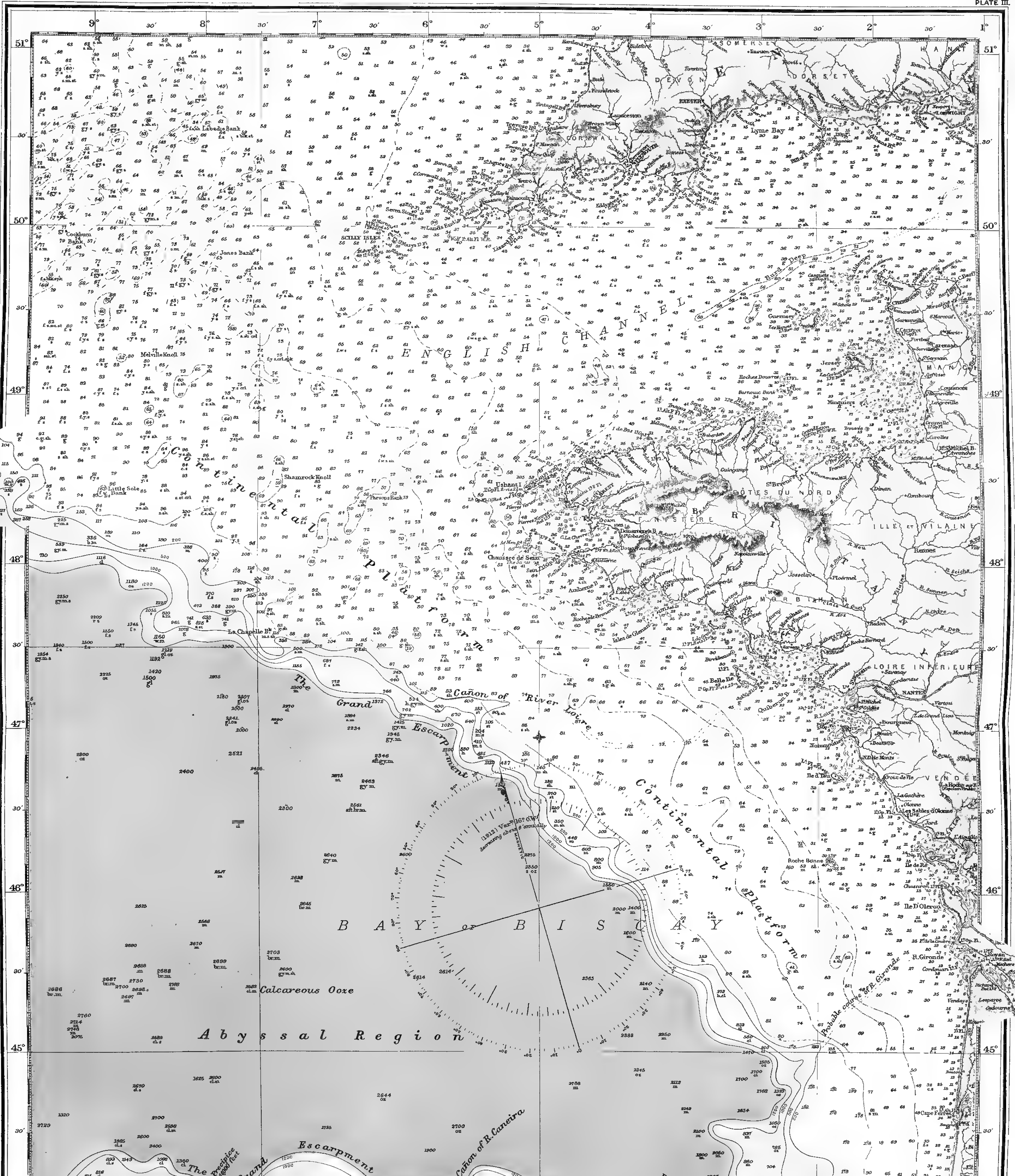
COAST OF THE ENGLISH CHANNEL AND BAY OF BISCAY.

PLATE III.



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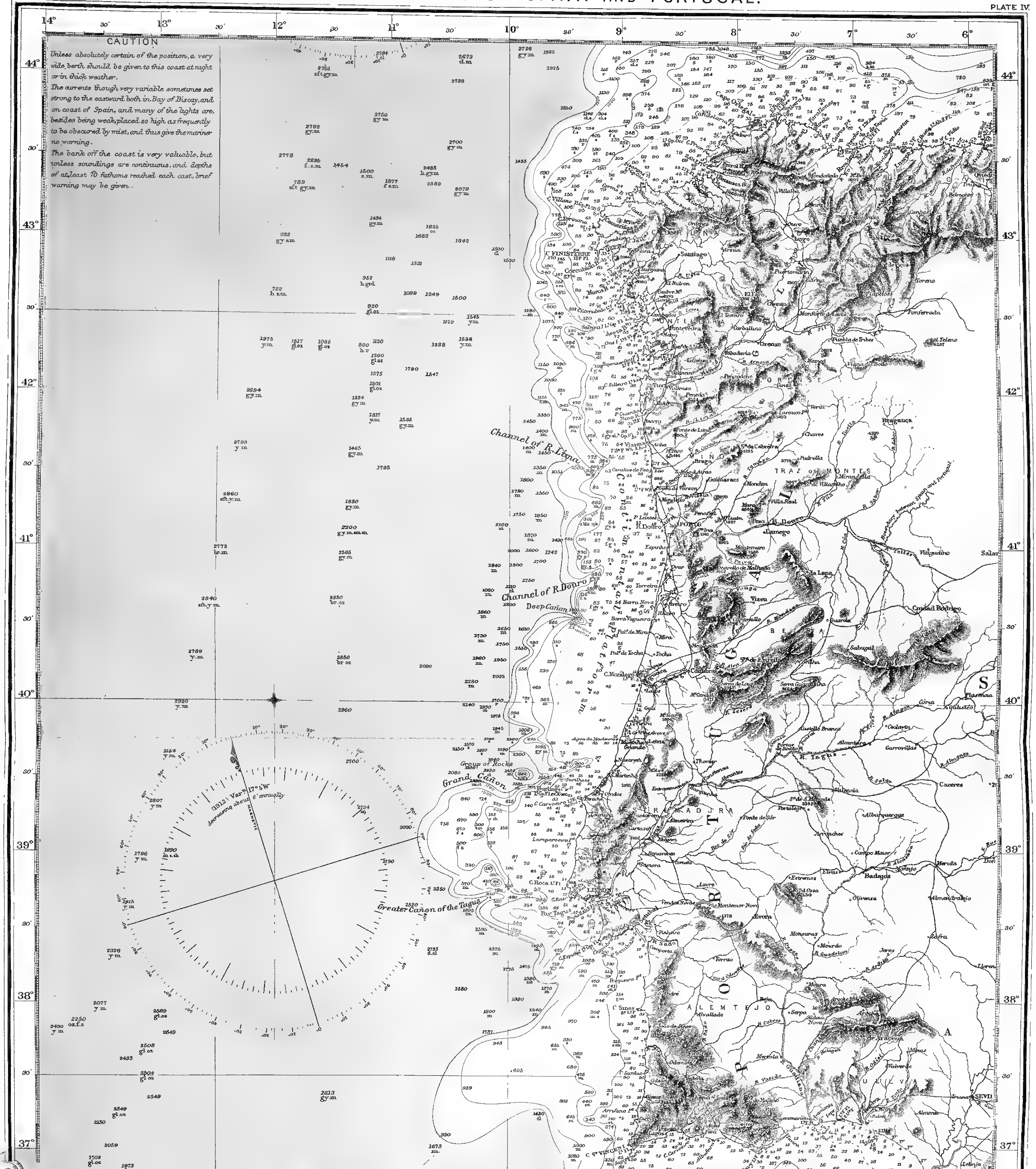
THE WEST COAST OF SPAIN AND PORTUGAL.

PLATE IV.



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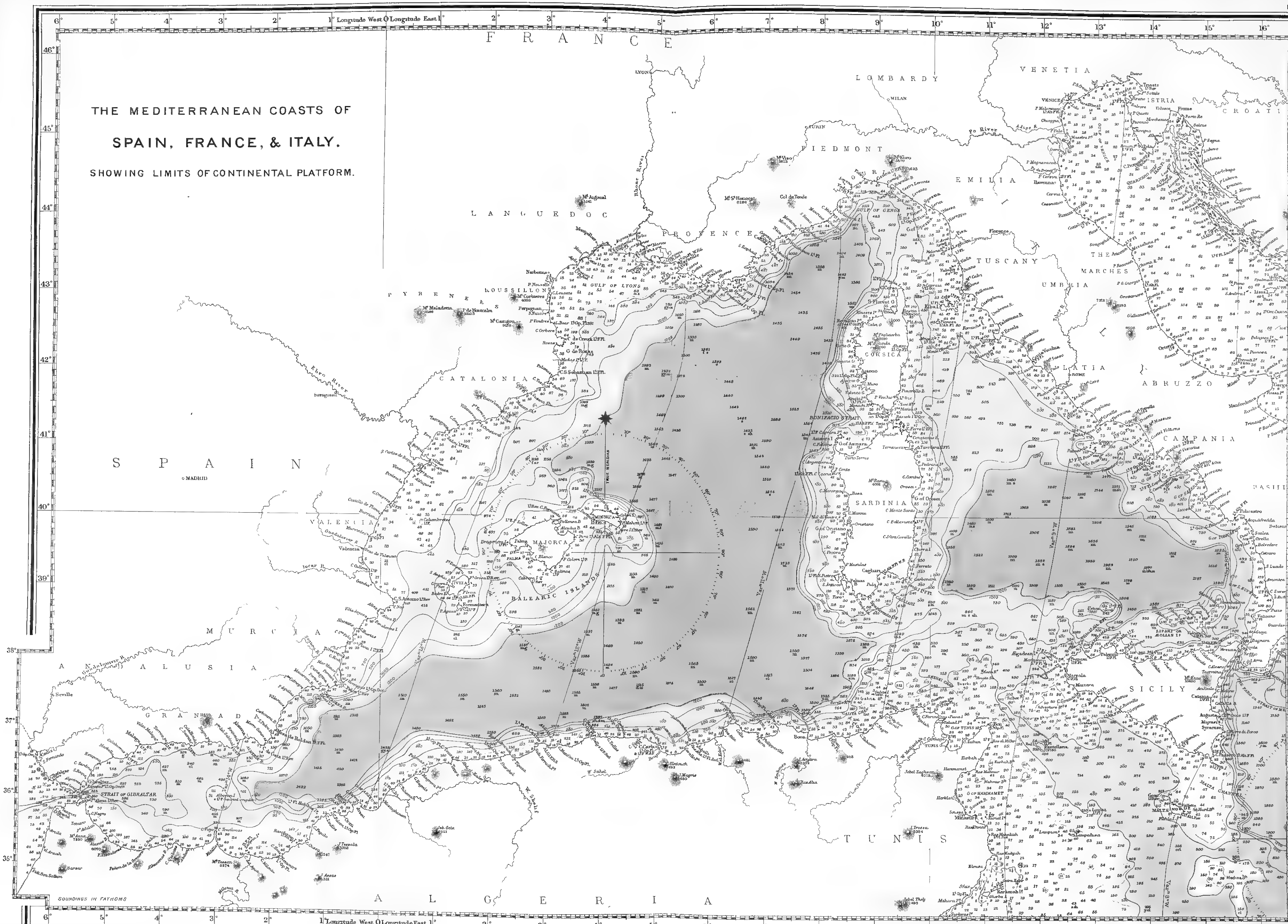

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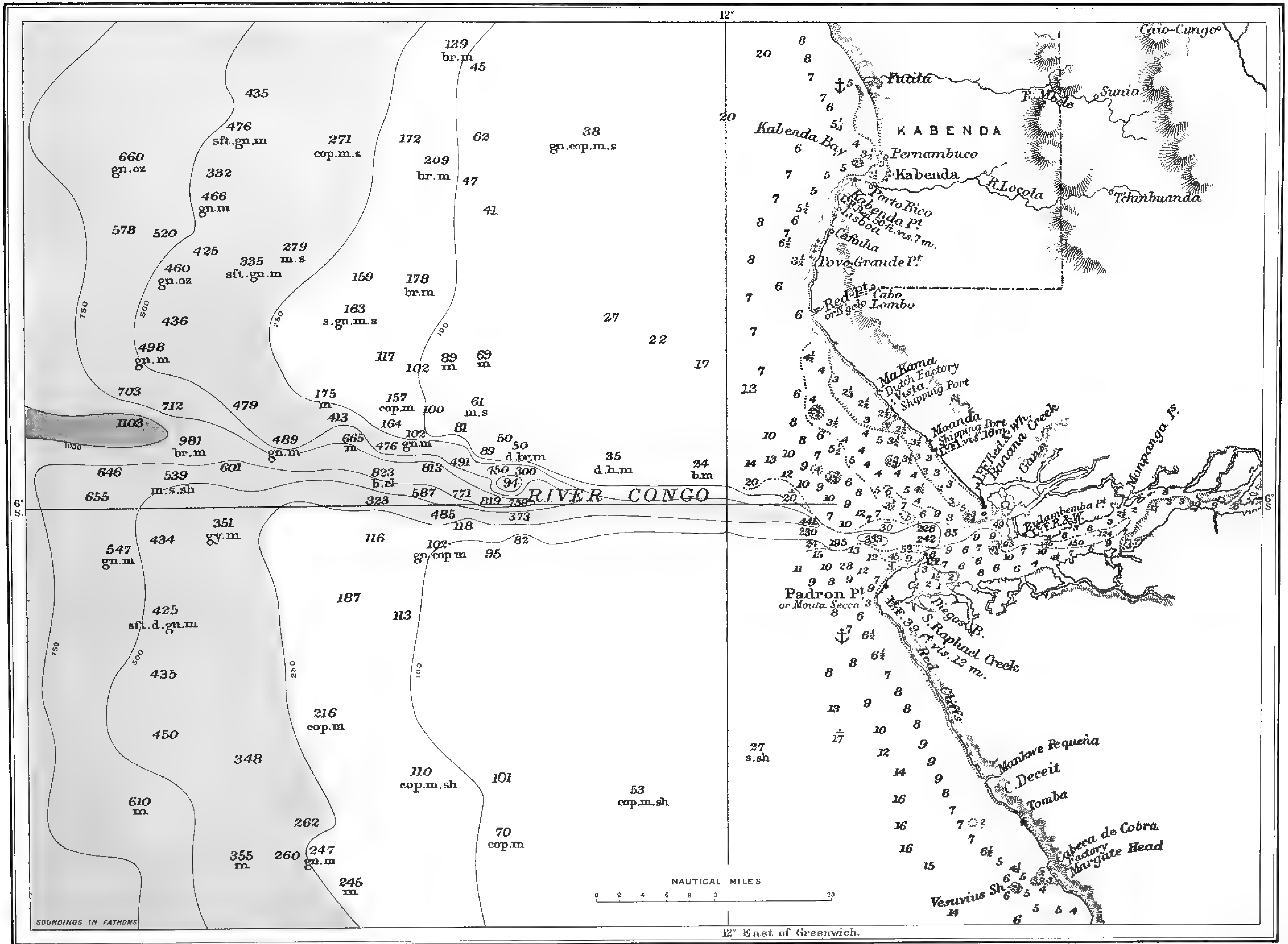
WEST COAST OF AFRICA SHOWING SUBMERGED VALLEY OF THE CONGO.



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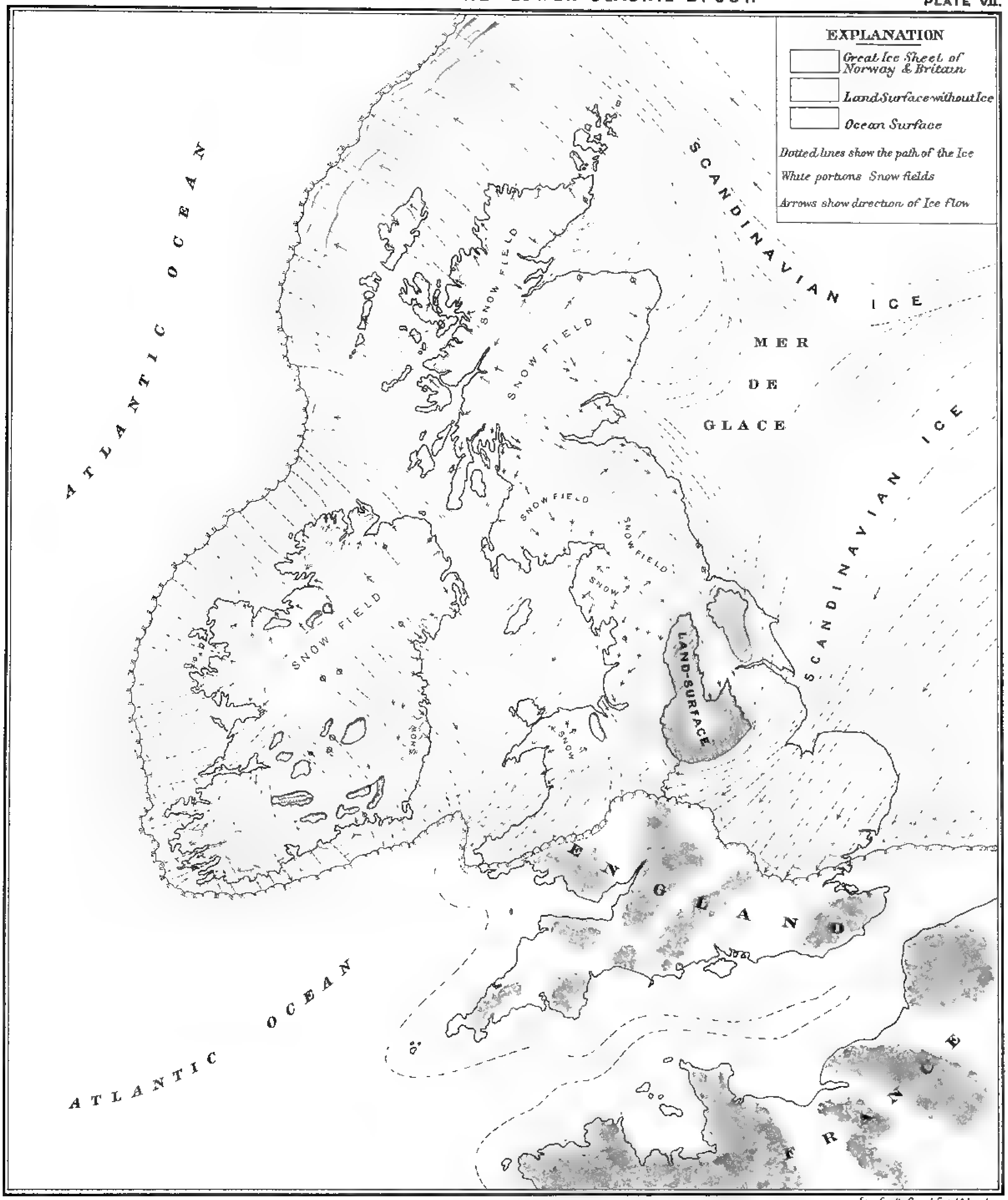
PHYSICAL MAP OF THE LOWER GLACIAL EPOCH

PLATE VII.



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MAP OF NORWAY, SHOWING THE FJORDS.

PLATE VIII.

0 10 20 30 40 50 60 NAUTICAL MILES

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MAP TO ILLUSTRATE THE PHYSICAL CONDITIONS OF THE GLACIAL EPOCH. PLATE IX.

Land Area, 100 fathoms (or Continental Shelf)

Land Area, 450 to 500 fathoms (or The Blake Plateau)

Strong black lines = Isotherms.

Strong black dotted line shows the central path of the Atlantic current, or present Gulf stream, during the period of the Continental uprise.

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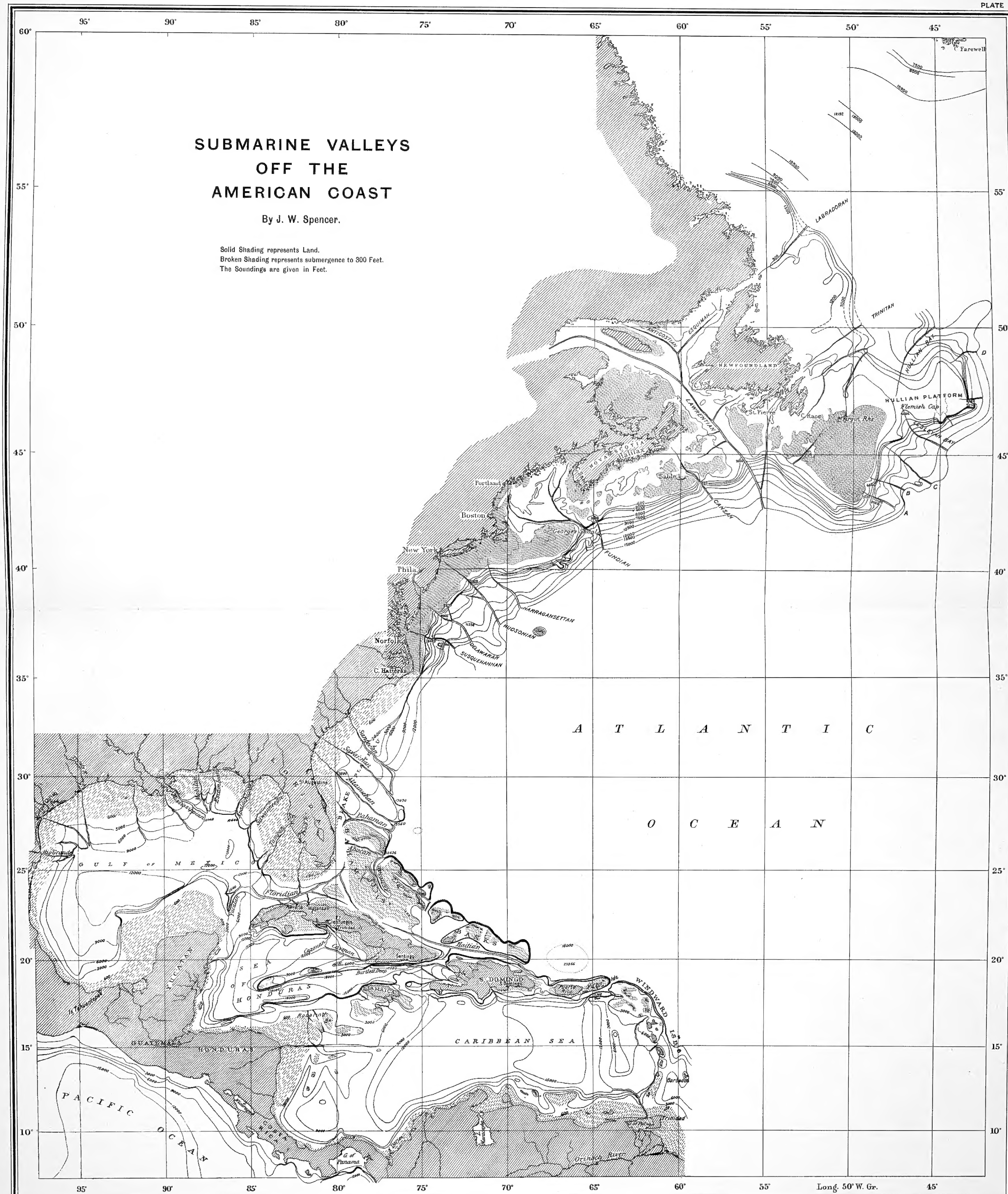

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SUBMERGED VALLEYS OF THE ARCTIC BASIN.

PLATE XI.

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