recently obtained of the continuity of animal life on the Atlantic sea-bed from the Cretaceous epoch to the present time.

Important information as to the changes which the sea-bed of the Atlantic has undergone within the later geological periods, may be gathered from the structure of the islands which lift themselves above its surface. Along its eastern border, at no considerable distance from the coast of North Africa, there are three principal groups,—the Madeiras, Canaries, and Cape Verd,—all of which have an evidently volcanic origin, and rise up from the eastern slope of the basin, where it is progressively shallowing towards its continental shore-line. Further out, in mid-ocean, lies the group of the Azores, which also is volcanic, and rises from the plateau already spoken of; but between this area and the slope from which the Madeiras and Canaries are based is a very deep channel, ranging downwards to at least 15,000 feet; and a like depth is also found between the Azores and the coast of Portugal. The structure of all these groups of islands gives obvious indications of their formation by separate igneous eruptions in a sea of great depth; and the earliest of these eruptions seems to have taken place in the later Miocene period. As soon as the first solid lavas raised their heads above water, and were thus exposed to the action of the waves, fragments were detached and rounded on the shore; and these being swept off, with the *débris* resulting from their attrition, formed deposits of various kinds upon the slope of the cone, in which corals, shells, &c., were embedded. These fossiliferous deposits have been subsequently elevated to heights of from 1500 to 2000 feet above the level of the sea, showing a rise of the base of the craters; progressive additions have been made to their upper part by the piling up of basaltic and trachytic lavas.[1] That this state of activity still continues is proved by the fact that in 1811 a new island was temporarily formed in the Azores group, off St Michael, by the throwing-up of ashes, and the formation of a cone about 300 feet high, with a crater in the centre. This island, to which the name Sabrina was given, was soon washed away by the waves. And only a few years since, another submarine eruption in this neighbourhood was indicated by earthquakes, jets of steam and columns of smoke, and floating masses of scoriæ. All these considerations concur (as Sir Charles Lyell, *loc. cit.*, justly urges) to negative on geological grounds the hypothesis which has been advocated by some eminent naturalists, that the Azores, Madeiras, and Canaries are the last remaining fragments of a continuous area of land which once connected them with the west of Europe and North Africa.

Proceeding to the south of the equator, we meet with similar evidence of volcanic activity in the structure of the only two islands, Ascension and St Helena, which lie near the line stretching from the Cape Verd group to the Cape of Good Hope; and these also arise from a plateau of considerably less depth than the circumjacent area whose eastern slope gradually shallows to the coast of South Africa. This plateau stretches in a north-westerly direction towards the equator, so as to meet it in from 20° to 22° W. long.; and here indications of volcanic activity — earthquakes, troubled water, floating scoriæ, and columns of smoke—have been several times observed since the middle of the last century, betokening the probable formation of an island or an archipelago in that locality.

Nearly midway between the southern prolongations of the African and American continents, the solitary peak of Tristan da Cunha (fig. 2) lifts itself above the ocean; this also is volcanic, and seems to rise from a broad base of general elevation, resembling the plateau of the North Atlantic.

The entire chain of the Greater and Lesser Antilles, which stretches from the delta of the Orinoco to the peninsula of Florida, and forms the eastern boundary of the Caribbean Sea, seems to have been in like manner elevated by volcanic action. That this elevation, like that of the groups of islands on the eastern side of the Atlantic, took place for the most part during the later Tertiary period, is shown by the occurrence of shells, corals, &c., of upper Miocene age, in the upraised sedimentary beds of several of the islands; while the presence of "fringing reefs" of coral around the shores of many of the West India islands is an indication that they lie in an area in which elevation is still proceeding. The channels by which they are separated are so deep as to render it very unlikely that there was ever a continuity of land between them; and the occasional recurrence of earthquakes and volcanic eruptions at different points of this "line of fire," shows that the plutonic action by which the islands were raised is still going on beneath.

The case is very different, however, in regard to the Bermuda group, which constitutes a singular exception to the general fact of the absence in the Atlantic of those coral islands that are so numerous in the Pacific. This group consists of about 300 islands, of which, however, only five are of any considerable size; and these rise from a shoal or platform of about 23 miles long by 13 miles broad, the channels between the islands being very shallow, while at a small distance from the edge of the shoal, the bottom rapidly deepens to 15,000 feet. The islands are entirely composed of upraised beds of coral, shells, &c. (the highest elevation being only about 180 feet above the sea-level); and the shoal itself appears to have the like structure throughout, no traces of any other rock than a limestone formed by the metamorphoses of coral being anywhere met with. Hence, as this insular platform proves to be the summit of a submarine column of 15,000 feet high, rising from a very small base, and as nothing we know of the structure of mountains—volcanic or other—would justify us in supposing that a column of such a height could be formed in any other way than by coral growth, the structure of the Bermuda group would seem to indicate a progressive subsidence of the bed of this part of the Atlantic during its formation, corresponding to that which (according to the well-known views of Mr Darwin) is at present in progress over a large area of the Pacific. It is probable that this coral growth was determined in the first instance by the existence of a submarine mountain, of which the summit lay near the surface, or lifted itself above it; that as soon as this came to be submerged, the coral formation commenced; and that by its continued growth at the summit, at a rate equal to that of the subsidence of its base, the platform has been kept up to the sea-level. The slight elevation which has raised its highest portion above that level may not improbably have taken place in connection with the much larger recent elevations already referred to.

Thus, then, we have evidence of considerable recent local modifications in the level of the Atlantic sea-bed, without any such change as would affect its general character as an ocean basin; while all geological probability seems in favour of the remoteness of the principal depression of the Atlantic area, even if we do not regard it as dating back to the period when the surface of the globe was first undergoing solidification.

Currents of the Atlantic.—By the term "current" will be here meant that *sensible* movement of ocean water in particular directions which can be generally traced, directly or indirectly, to the action of wind upon its surface. A current thus directly impelled by wind is termed a "drift-current," whilst a current whose onward movement is sustained by the *vis a tergo* of a drift-current is called a "stream-current." But there is another source of current-movement, which has been overlooked by most writers on this subject, namely, the indraught which necessarily takes place to keep up the level of any area from which the surface-water is constantly being drifted away. Such currents, which may be designated as "indraught" or "supply currents," complete the "horizontal circulation" that must necessarily take place in any oceanic area of which one part is subjected to the action of a wind almost constantly blowing in the same direction. Of such a circulation we have a very characteristic example in the South Atlantic, the principal currents of which we shall see to be very easily accounted for.

[1] See Sir C. Lyell's account of them in his *Principles of Geology*, 11th ed. p. 407, *sqq.*

The initial movement of the current-system, alike of the North and of the South Atlantic, is given by the trade-winds, which are continually driving the water of the inter-tropical region from the African towards the American side of the basin, so as to produce what is known as the *Equatorial Current*. The position of the northern and southern boundaries of this current shifts, like the area of the trade-winds, in accordance with the northward and southward declination of the sun;—a steady westward drift being generally met with to the north of the tropic of Cancer in the summer of the northern hemisphere, and to the south of the tropic of Capricorn in the summer of the southern, whilst in the winter of each hemisphere the border of the drift lies within the tropic of that hemisphere. But as the *thermal* equator lies from two to three degrees to the north of the *geographical* equator, the entire zone of the trade-winds, and of the Equatorial Current propelled by them, is wider on the northern than on the southern side of the latter; and while the northerly trade often reaches 30° N. in July, and rarely extends south in January within 2° or 3° of the geographical equator, the southerly trade does not extend farther than 25° S. in January, and generally crosses the equator in July, even extending occasionally as far as 5° N. As between the northerly and southerly trades there is a region of "equatorial calms," so there is a corresponding interval between the northern and southern divisions of the Equatorial Current; and in this interval there is a counter-current (resembling the "back-water" often to be noticed in a stream that is flowing rapidly past some obstacle, such as a vessel at anchor, or a projecting angle of a river-bank), that runs eastwards, sometimes with considerable velocity, towards the Bight of Biafra, which may be considered the "head-water" of the Equatorial Current. From the recent observations of Capt. Nares in the "Challenger," it appears that the Equatorial Current, like other drift-currents, is very shallow, its depth being not much greater than 50 fathoms. He estimates its rate at the surface to be about 0·75 miles per hour, or 18 miles per day, whilst at 50 fathoms it only moves at about half that rate.[1] Its surface temperature generally ranges between 75° and 80°; but the thermometer falls to 60° at a depth of little more than 100 fathoms,—the temperature of this belt of water, as will be hereafter shown, being kept down by the continual rising of polar water from below.

The Equatorial Current passes directly across the Atlantic towards the chain of the Antilles and the coast of South America; and as not only the whole of the northern division, but a considerable part of the southern, strikes the American coast-line to the north of the salient angle of Cape St Roque (about 5° S. lat.), the portion of the current which is deflected into the northern hemisphere is much greater than that which is turned to the southward. It is a general fact, that where a current encounters any partial obstruction,—such as a coast-line meeting it obliquely, a narrowing of its channel, the lateral pressure of another current, or even that of a mass of stationary water,—its velocity increases; and so the portion of the Equatorial Current that is pressed to the northward by the coast-line between Cape St Roque and the mouth of the Orinoco (known in the first part of its course as the *Cape St Roque Current*, and afterwards as the *Guiana Current*) acquires a greatly augmented rate, running ordinarily at the rate of from 30 to 50 miles, and occasionally at a rate of 80 miles, in the 24 hours. Entering the Caribbean Sea, it is reinforced by the portion of the Equatorial Current which flows in between the Lesser Antilles; and it then passes westwards along the northern coast of South America, until it is deflected northwards by the coast-line of Central America, and driven between the peninsula of Yucatan and the western extremity of Cuba into the Gulf of Mexico, at the rate of from 30 to 60 miles per day. A portion of it passes direct to the N.E. along the northern shore of Cuba; but by far the larger part sweeps round the gulf, following the course of its coast-line, and approaches the coast of Cuba from the N.W. as a broad deep stream of no great velocity, seldom running at more than 30 miles per day. The reunited current, being met by the Equatorial Current from the outside, which is pressing to the west along the north coast of Cuba and between the Bahama isles, is deflected northwards through the passage termed the Florida Channel, which is bounded on the one side by the southern extremity of the peninsula of Florida, and on the other by the coast of Cuba and the Bahamas. The rate of movement of the powerful current that flows through this channel, henceforth known as the *Gulf Stream*, is considerably augmented in its narrowest part, which is also its shallowest; but although its velocity sometimes reaches 4 (nautical) miles per hour, or even more, its *average* rate through the whole year may be confidently stated at not more than 2 miles per hour, or 48 miles per day.[2]

The Gulf Stream current, however, does not by any means occupy the whole of the sectional area of the Florida Channel; for it is separated from the American coast by a band of cold water, which occupies about three-eighths of its total breadth of 40 miles, and which also dips under the outflowing current. The movement of the cold superficial band is perceptibly inwards, and that of the cold under-stratum is presumably so; and it is the opinion of the American surveyors that the depth of the warm outward current is not more than one-third of that of the channel through which it flows. It is probable that the rate of movement decreases from the surface downwards; but upon this point we have as yet no certain information. The meaning of the cold inflow will hereafter become apparent.

The course taken by the Gulf Stream in the first instance is nearly parallel to the line of the United States coast, from which it is everywhere separated by a band of cold water,—the boundary line between the two being so distinct as to be known as the "cold wall." It does not show for some time any great disposition to spread itself out laterally, though a division into alternate bands of warmer and colder water, the cause of which seems to lie in the contour of the bottom of the Florida Channel, becomes perceptible before it reaches Charleston, and is very marked off Cape Hatteras. The Stream there presents the form of a fan, its three warm bands spreading out over the Atlantic surface to an aggregate breadth of 167 miles,

[1] Mr Laughton, however, states the average velocity to be between 20 and 30 miles per day.

[2] This statement, which is much lower than that adopted by most writers on the Gulf Stream, is based on the entire aggregate of observations collected by the Meteorological Department, which further show that, for six months of the year, the monthly mean averages only 1·4 miles per hour, or 34 miles per day, whilst for the other six months it only averages 2½ miles an hour, or 60 miles per day.

whilst two cold bands of an aggregate breadth of 52 miles are interposed between them. The innermost warm band is the one which exhibits the highest temperature and greatest rate of flow, its velocity being greatest where it is pressed on laterally by the Arctic Current, so that a rate of 4 miles per hour is occasionally observed. Capt. Nares estimates the depth of the Stream in this part of its course at about 100 fathoms, and its rate of flow in the line of most rapid movement at 3 miles per hour. The outermost band, on the other hand, graduates insensibly, both as to temperature and rate of movement, into the general surface-water of the Atlantic. It is when passing Sandy Hook that the Gulf Stream takes its decided turn eastwards,—this change in its direction being partly due to the eastward bend of the United States coast-line, and partly to the *excess of easterly momentum* which it brings from the lower latitude in which it issued from the Florida Channel. Its general rate of flow past Nantucket seems not to exceed 1 mile per hour, and to be frequently less; but several degrees to the eastward of this, the current has been found occasionally running at the rate of 4 miles an hour,—this acceleration being probably due to the lateral pressure of the *Arctic Current*, which, during the early months of the year, is driven southwards at the rate of 10 or 12 miles per day by the N. and N.W. winds then prevailing along the coast of Labrador, and which, turning westwards round the south of Newfoundland, keeps close to the coast of the United States (being left behind in the rotation of the earth, in consequence of its *deficiency* of easterly momentum), and follows it southwards, everywhere separating it from the Gulf Stream.

By the gradual thinning-out and expansion of the Gulf Stream after passing the Banks of Newfoundland, by the progressive reduction of its rate of movement, and by the loss of that excess of temperature which previously distinguished it, as well as of its peculiar blue colour (which probably depends on its holding in suspension the finest particles of the river-silt brought down by the Mississippi), this remarkable current so far loses all its special attributes, as to be no longer recognisable to the east of the meridian of 30° W. long.,—there degenerating into the general easterly drift of that region of the Atlantic which is kept up by the prevalence of westerly winds, sometimes called "anti-trades." Where the Florida Current or true Gulf Stream can last be distinctly recognised, it forms a stratum not more than 50 fathoms in thickness; and it is there flowing *almost due east*, at a rate which would require about 100 days to bring it to the Land's End. The only valid evidence of the extension of any part of it to the western shores of Europe (the amelioration of their temperature being otherwise accounted for, while the transport of trunks of trees, drift-timber, fruits, shells, &c., to the Western Hebrides, the Orkney, Shetland, and Faroe islands, and the coast of Norway, may be fairly set down to the surface-drift sustained by the prevalence of S.W. winds) is afforded by the variable current known as *Rennell's*, which, flowing eastwards into the southern part of the Bay of Biscay, is deflected in a N.W. direction by the trend of its coast-line, so as to cross the British Channel towards the Scilly Islands, whence it passes to the S.W. coast of Ireland, its strength mainly depending on the continued prevalence of the westerly anti-trades. (See Plate I.)

Of the whole mass of water, on the other hand, that is brought into the mid-Atlantic by the Gulf Stream, it may be stated with confidence that the larger proportion turns southward to the east of the Azores, and helps to form the *North African Current*; the other tributary of which may be considered as originating as far north as Cape Finisterre, under the influence of the northerly winds which prevail along the coast of Portugal. As this current flows past the entrance to the Strait of Gibraltar, a part of it, forming what is known as the *Gibraltar Current*, is drawn in to keep up the level of the Mediterranean, which would otherwise be reduced by the excess of evaporation from its surface; but the greater part keeps its course southwards along the Marocco coast, reinforcing the south-flowing extension of the Gulf Stream. On arriving at the border of the northerly trade, the North African Current divides into two parts,—the western division being at once carried into the course of the equatorial drift, whilst the eastern, which may be considered as essentially an indraught or supply current, follows the African coast-line, and turns eastward into the Gulf of Guinea, forming the *Guinea Current*, which, coalescing with the eastward "back-water" already mentioned, flows pretty constantly, sometimes with considerable rapidity, towards the Bight of Biafra. There it meets the *South African Current*, which forms the other great feeder of the Equatorial Current; and the circulation thus completed may be considered as recommencing from this "head-water." The large area of comparatively still water which lies in the interior of this North Atlantic circulation is called the *Sargasso Sea*,—a corruption of the name (Mar de Sargaco) which it received from Columbus and the early Spanish navigators, on account of the quantity of sea-weed that floats on its surface. The boundaries of this area, which is of an irregularly elliptical shape, and nearly equals that of Continental Europe, are somewhat variable; but it may be considered to lie between the parallels of 20° and 35° N., and between the meridians of 30° and 60° W. Into it is collected a large proportion of the drift or wreck which floats about the North Atlantic.

Proceeding now to the South Atlantic, we meet with a circulation of the same kind, uncomplicated by any embaying of the Equatorial Current. The smaller division of this current which strikes the coast of South America to the south of Cape St Roque flows along the coast of Brazil at the rate of from 12 to 20 miles a day, forming the *Brazil Current*, which, however, is separated from the land by an intervening band of lower temperature, that has, during the winter months, a distinct flow towards the equator. The Brazil Current can be traced southwards, by its temperature rather than by its movement, as far as the estuary of the La Plata, before reaching which, however, a great part of it takes an easterly direction, and crosses the Atlantic towards the Cape of Good Hope, forming what is known as the *Southern Connecting Current*. The easterly movement of this current seems to be partly due to the westerly anti-trades, and partly to the excess of easterly momentum which is retained by the Brazil Current in its southward course from Cape St Roque; whilst it partly depends also on the junction of an Antarctic current that flows N.E. from Cape Horn, meeting the Brazil Current off the estuary of La Plata, just as the Arctic Current meets the Gulf Stream off Newfoundland,—dense fogs being produced, in the one case as in the other, through the precipitation of the vapour overlying the Equatorial Current, by the colder air that overlies the Polar. On meeting the coast of South Africa, the Southern Connecting Current turns northwards, and runs towards the Bight of Biafra, forming the *South African Current*, the movement of which is partly sustained by the southerly winds which prevail along that coast, but is partly attributable to the indraught set up to supply the efflux of the Equatorial Current. In its passage thither, however, the part of it most distant from the land is draughted westwards by the southern trade, forming the most southerly portion of the equatorial drift. Between this and the Southern Connecting Current is a central space, lying between the

parallels of 20° and 30° S., and the meridians of 0° and 25° W., over which there are no regular currents; and to this the name Sargasso Sea is sometimes applied by analogy, although its surface has no covering of sea-weed. (See Plate I.)

Temperature of the Atlantic.—The distribution of surface temperature over the area of the Atlantic has now been made out with considerable accuracy; and it corresponds closely with what has been already stated as the course of the surface currents. There is, of course, a seasonal change, alike in its northern and in its southern division, this change being more and more marked as we recede from the equator. Following the course of the mean annual isotherms, however, we find that they cross the South Atlantic at nearly regular intervals, in an east and west direction, the principal departure from that direction being shown at their western end in the bend they take towards the south under the influence of the warm Brazil Current, and at their eastern in the still stronger bend they take towards the north under the influence of the cold South African Current, which reduces to about 75° the temperature of the southern equatorial that flows alongside the Guinea Current, whose temperature is 82°. In the North Atlantic, however, the influence of the movement of oceanic water on the surface-temperature is very much more marked. The annual isotherms, which cross the Sargasso Sea with nearly regular parallelism, and on the African side tend somewhat to the south, where they meet the colder water of the North African Current, show a strong northward bend on the American side, along the early course of the Gulf Stream; but as its excess of temperature above that of the Atlantic generally diminishes as we trace it towards the Banks of Newfoundland, this northward deflection progressively becomes less. The marked contrast in temperature which is often there exhibited between two contiguous bands of water,—a thermometer hanging from a ship's bow showing a temperature of 70°, whilst another hanging from the stern shows only 40°,—is due not so much to the elevation produced by the Gulf Stream as to the depression produced by the Arctic Current. This depression manifests itself in the southward bend given, on the American side, alike to the summer and the winter isotherms (see Plate), beyond the summer isotherm of 70° and the winter isotherm of 60°, which may be considered as having nearly their normal position; whilst the northward tendency of these same isotherms on the European side not less conspicuously indicates a flow of warm water towards the western coasts of the British Isles, Norway, and even Iceland and Spitzbergen. It has been customary to regard this flow as an extension of the Gulf Stream; but if that term be limited (as it ought) to the current that issues from the Gulf of Mexico through the Florida Channel, the hypothesis is found to be untenable so soon as the thermal phenomena of that current are carefully examined. For, in the first place, the popular idea that the Gulf Stream retains its high temperature with little diminution during its passage first northwards and then eastwards is clearly disproved by observation, as is shown by the following table of average temperatures taken at different seasons in the warmest of its bands :—

.	Latitude.	Winter	Spring.	Summer	Autumn.
Florida Channel............	25 N.	77	78	83	82
Off Charlestown............	33 N.	75	77	82	81
Off Cape Hatteras.........	35 N.	72	73	80	76
S.E. of Nantucket Shoals	35 N.	67	68	80	72
S. of Nova Scotia..........	35 N.	62	67	78	69

From this it appears that, while the high surface-temperature with which the Gulf Stream leaves the Florida Channel is retained in summer with only 5° reduction as far as Nova Scotia, there is a reduction of 5° in winter during its northward passage to Cape Hatteras, and a further reduction of no less than 10° during its eastward passage from Cape Hatteras to Nova Scotia, making a total reduction of 15°. In spring, again, there is a total reduction of 11°, and in autumn of 13°; and in both cases the reduction during the *eastward* flow under the parallel of 35° N. is greater than the reduction in the *northward* flow from 25° N. to 35° N. The explanation of this is plainly to be found in the fact that in the early part of the course of the Gulf Stream its superheated stratum is a thick one, so that when its superficial film is cooled down by a superincumbent atmosphere of lower temperature, it is replaced by the uprising of a deeper stratum having nearly its original temperature. But as the stream spreads out superficially, its superheated stratum becomes proportionally thinner, and will consequently be more and more rapidly cooled down by the superincumbent atmosphere. Even supposing, therefore, that it were not subjected to any special cooling influence, it appears certain that, as the rate of the current slackens and its depth diminishes, the cooling process must continue at an increased rate, so as to bring down the surface-temperature of the stream to the normal isotherm of the locality, long before it could reach the shores of Europe. But it has been shown that when it passes Newfoundland the Gulf Stream *is* subjected to a special cooling influence—that of the Labrador Current with its fleet of icebergs, which melt away when borne into it; and this produces such an immediate reduction of its surface-temperature, that it thenceforth shows very little excess, although its sub-surface stratum still appears to be warmer than that of the ocean through which it flows.

But, further, the Gulf Stream, where it is last recognisable as a current, is flowing due east, and its southern portion turns first south-east and then south, whilst, on the other hand, the course of the isothermal lines (see Plate) clearly shows that the flow of warm water which carries them northward spreads across the whole breadth of the Atlantic, from the British Isles to Labrador, even extending up to the west of north into Baffin's Bay. When we contrast this immense body of north-moving water with the thinned-out film of what is by comparison a mere rivulet, it becomes obvious (1) that its northward flow cannot be attributable to the *vis a tergo* of the Florida Current, whilst (2) its convection of heat to the Arctic Sea cannot be accounted for by any amount of excess of temperature that is limited to a small depth, since the temperature of such a stratum, moving north-east at a rate of (at most) 4 or 5 miles per day, must soon be brought down to that of the atmosphere above it.

Influenced by these considerations, several eminent hydrographers, both British and American, have been disposed to deny, not only that the temperature of the North Atlantic is modified in any considerable degree by the true Gulf Stream, but that any other agency than that of warm S.W. winds is concerned in producing the climatic amelioration popularly attributed to it. They maintained, in fact, that the surface-temperature of the North Atlantic and Arctic Seas *follows* that of the superincumbent air,—the atmospheric temperature not being in any degree raised by that of warmer water beneath. This doctrine, however, is found to be inconsistent with the results of careful comparisons recently instituted between marine and atmospheric temperatures along the western coasts of Scotland, the Orkney, Shetland, and Faroe Islands, and especially with those obtained along the western coast of Norway. For it is found that during the winter months there is a constant *excess* of sea-temperature above that of the air, averaging

6°·2 Fahr. along the western coast of Scotland and its islands, and rising to 14°·5 at Fruholm near the North Cape. And it is also a very significant fact (ascertained by the careful inquiries of Mr Buchan), that while the *summer* isotherms cross the British Islands nearly east and west (the temperature diminishing pretty regularly from south to north), the *winter* isotherms traverse them nearly north and south (the temperature diminishing from west to east); whilst in Ireland the isotherms seem to envelope the islands in their folds, which increase in warmth from the centre of the island to its sea-board. So in Norway the isothermal lines run parallel to the coast-line, and this alike in summer and in winter,—the temperature falling in winter, and rising in summer, with the increase of distance from the sea. Nothing could prove more conclusively than such facts as these (taken in connection with the absence of ice in the harbours of Norway, even as far north as Hammerfest, through the whole winter) the dependence of the mild winter climate of the north-western coasts of Europe upon the proximity of a sea which is warmer than the superincumbent atmosphere; and we have now to inquire how this great N.E. movement of a stratum of warm water sufficiently thick to retain a surface-temperature considerably higher than that of the air above it is to be accounted for.

The solution of the problem seems to be afforded by the doctrine of a *General Oceanic Circulation*, sustained by opposition of temperature only, which was first distinctly propounded in 1845 by Professor Lenz of St Petersburg, on the basis of observations made by him during the second voyage of Kotzebue (1825–1828). Others had been previously led to surmise that "Polar Currents" flow along the floors of the great oceans, even as far as the equator, balancing the superficial counter-currents which are observable in the opposite direction. But Lenz was led to conclude that the whole of the deeper portion of the great ocean-basins in communication with the polar areas is occupied by polar water, which is constantly, though slowly, flowing towards the equator; whilst conversely the whole upper stratum of equatorial water is as constantly, though slowly, flowing towards one or both of the poles. And he particularly dwelt on the existence of a belt of water under the equator, colder than that which lies either north or south of it, as an evidence that polar water is there continually rising from beneath towards the surface,—a phenomenon which, he considered, admits of no other explanation. He further adduced the low salinity of equatorial water (previously noticed by Humboldt, and confirmed by his own observations), compared with that of tropical water, as evidence that the equatorial water of the surface is derived from the polar underflow. And he attributed the maintenance of this circulation to the continually renewed disturbance of equilibrium between the polar and equatorial columns,—the greater lateral (because downward) pressure of the former[1] causing a *bottom outflow* of polar water in the direction of the latter, whilst the reduction of level thus occasioned will produce a *surface indraught* from the warmer towards the colder areas.

The doctrine of Lenz, so far from meeting with the general acceptance to which it had a fair claim,—alike on theoretical grounds and from its accordance with the facts ascertained by careful observation,—seems to have been put aside and forgotten, a preference being given to the doctrine of the prevalence of a uniform deep-sea temperature of 39°, which was supposed to be established by the thermometric observations made in the voyages of D'Urville and Sir James Ross. No such precaution was taken, however, in these observations as that to which Lenz had recourse, to obviate the effects of the tremendous pressure (1 ton per square inch for every 800 fathoms of depth) to which deep-sea thermometers are exposed; and it is now certain that the temperatures at great depths recorded by D'Urville and Ross were several degrees too high.

It was in entire ignorance of the doctrine of Lenz, and under the influence of that of D'Urville and Ross, which had been stamped with the great weight of Sir John Herschel's weight of authority,[2] that Dr Carpenter commenced in 1868 (in concert with Professor Wyville Thomson) a course of inquiry into the thermal condition of the deep sea, which at once convinced him of the fallacy of the uniform 39° doctrine, and led him to conclusions essentially accordant with those of Lenz. For in the channel of from 500 to 600 fathoms' depth between the north of Scotland and the Faroe Islands, they found the deeper half to be occupied by a stratum of glacial water, whose temperature ranged downwards from 32° to 29°·5; whilst the upper half was occupied by a stratum warmer than the normal temperature of the latitudes. This phenomenon was interpreted by Carpenter as indicating a deep glacial flow from N.E. to S.W., and a warm upper flow from S.W. to N.E.; and finding that to the west of this channel, on the border of the deep Atlantic basin, the excess of warmth extended to a depth of more than 500 fathoms, he came to the conclusion that the north-moving stratum which brought it could not be an extension of the true Gulf Stream, but must be urged on by some much more general force. A series of temperature-soundings taken along the west of Ireland, the Bay of Biscay, and the coast of Portugal, confirmed him in this view, by showing that the division between an upper warm stratum and a cold under-stratum exists in the North Atlantic at a depth of from 700 to 900 fathoms, the whole mass of water below this having either flowed into the basin from the polar area, or having had its temperature brought down to from 39° to 36°·5 by mixture with the polar inflow. And this conclusion was confirmed by the result of temperature-soundings taken at corresponding depths and under the same parallels of latitude in the Mediterranean; for as they showed a uniform temperature of from 54° to 56°, from beneath the stratum of 100 fathoms that was superheated by direct insolation, to the very bottom, it became clear that depth *per se* could have no effect in reducing the bottom-temperature; and that the cause of the excess of temperature in the mass of water occupying the Mediterranean basin above that of Atlantic water at the same depths, lies in the seclusion of the former from the polar underflow which brings down the deep temperature of the latter. This conclusion having received marked confirmation from temperature-soundings taken in the Eastern seas, was put forward by Carpenter as justifying the doctrine of a *vertical* oceanic circulation sustained by opposition of temperature only, quite independent of and distinct from the *horizontal* circulation produced by wind,—which doctrine he expressed in terms closely corresponding with those that had been used by Lenz. And the collection of data for the establishment or confutation of this doctrine was one of the objects of the "Challenger" expedition, which has already made, in the determination of the thermal stratification of the Atlantic between 38° N. lat. and 38° S. lat., what may be fairly characterised as the grandest single contribution ever yet made to terrestrial physics.

The following are the most important of the facts thus

[1] It must be borne in mind that sea water does not expand like fresh water in cooling below 39°·2, but continues to contract down to its freezing point, which lies between 27° and 25° Fahr., according as it is still or agitated.

[2] See his *Physical Geography of the Globe*, originally published in the tenth edition of this *Encyclopædia*.

established:—Of the water which fills the deep trough of the North Atlantic (fig. 1) between Teneriffe (lat. 28½° N.) and St Thomas (lat. 18½° N.), divided by the "Dolphin rise" into an eastern and western basin, by far the larger

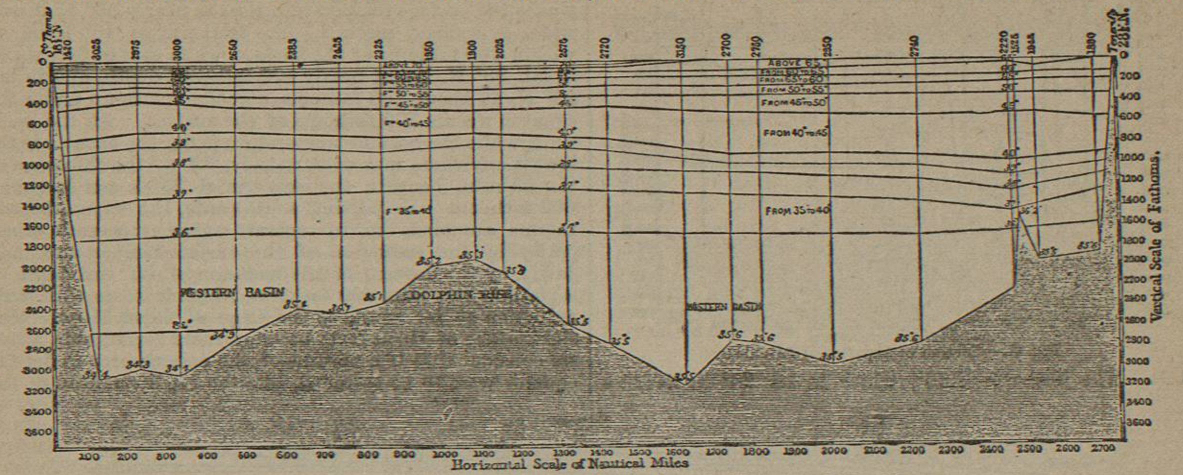

Fig. 1.—Section of North Atlantic Ocean between St Thomas and Teneriffe.

mass has a temperature ranging from 40° downwards, in the eastern basin, to a bottom-temperature of 35½°, whilst in the western basin—apparently under the influence of the Antarctic underflow—the bottom-temperature sinks to 34°·4. A tolerably regular descent is shown in this section, from a surface-temperature rising near St Thomas to 75°, to the bathymetrical isotherm of 45°, which lies between 400 and 600 fathoms' depth; there is then a stratum between 45° and 40°, of which the thickness varies from about 250 to 450 fathoms, the isotherm of 40° lying at between 750 and 1000 fathoms' depth, while below this, down to the bottom at between 2000 and 3000 fathoms, the further reduction to 34°·4 is very gradual.

The same general condition prevails in the South Atlantic (fig. 2), between Abrolhos Island (lat. 18° S.) on the coast of Brazil, and the Cape of Good Hope (lat. 34½° S.), this trough also being divided into two basins by the elevation of the bottom which culminates in the island of Tristan da Cunha. The temperature of the water that occupies it, however, is lower through its whole vertical range than that of the North Atlantic. The stratification is nearly uniform from the surface downwards to the isotherm of 40°, which lies at from 300 to 450 fathoms' depth, the isotherms of 39° and 38° also lying within about 500 fathoms; there is then a slower reduction down to the isotherm of 35°, which lies between 1400 and 1800 fathoms; while the whole sea-bed is covered by a stratum of about 600 fathoms' thickness, whose temperature ranges downwards from 35° to 33°. The whole of this deepest stratum is colder than any water that is found in the corresponding portion of the North Atlantic. except near St Thomas.

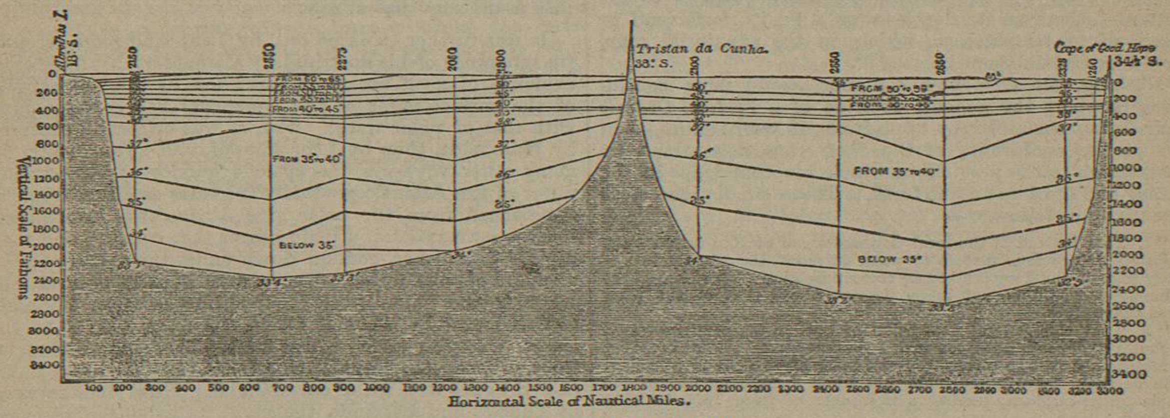

Fig. 2.—Section of South Atlantic.

It is not a little remarkable that the sub-surface stratum of water, having a temperature above 40°, is thinner under the equator than it is in any other part of the Atlantic from the Faroe Islands to the Cape of Good Hope. Notwithstanding the rise of the surface-temperature to 76°–80°, the thermometer descends in the first 300 fathoms more rapidly than anywhere else; so that polar water is met with, as shown in fig. 3, at a much less depth than in the North Atlantic (fig. 1), and 100 fathoms nearer to the surface than even in the colder South Atlantic (fig. 2); whilst the temperature of the bottom is but little above 32°. Thus the influence of the polar underflow is more pronounced under the equator than it is elsewhere; as is distinctly seen in the section shown in fig. 4, which is taken in a north and south direction so as to exhibit the relation of the thermal stratification of the North to that