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the temperature of the water at the surface and beneath it, in the lochs and firths where they may happen to be yachting or boating. It would be a pleasure to me, or to my colleague Mr. Morrison, to show the manner of working deep-sea thermometers, and to afford every information to any one who may be desirous of making observations of the kind ; and amongst the members of the Scottish Geographical Society there must be many such.

THE PHYSICAL AND BIOLOGICAL CONDITIONS OF THE SEAS AND ESTUARIES ABOUT NORTH BRITAIN.¹

BY JOHN MURRAY, PH.D., V.-P.R.S.E.,

Director of the " Challenger " Commission.

THE knowledge now possessed of the state of matters in the deep sea contributes greatly to a correct understanding of the various productive factors at work along both our own coasts and those of Scandinavia, which have the most abnormal of all the extra-tropical climates of the world. The surface of the earth may be marked off into three great areas,—first, the continents, covering 5-16ths, and having an average height of 900 feet above the level of the sea ; second, an abysmal region, covering 8-16ths, or one-half of the earth's surface, the average depth of which is three miles, or over 15,000 feet below the level of the sea ; third, a region lying between these, called the transitional area, covering 3-16ths of the earth's surface, and connecting the great elevated plateau of the continents with the great submerged plain of the abysmal region. In this border region deposits are now being laid down, which are chiefly made up of the *débris* of the adjacent continents. These deposits resemble in almost all respects those out of which the sedimentary rocks of our present continents must have been formed in past ages.

In the abysmal areas, we find here and there small volcanic islands rising as great cones from the bottom of the sea, sometimes capped with coral, and forming atolls ; but we do not find in these areas any traces of continental rocks. Indeed, it is extremely unlikely that any continental land ever existed in these abysmal areas during past ages, and the deposits now forming in these regions, far from our present continental lands, have, so far as we know, no analogues in the geological series of rocks.

While, then, it appears that there is no evidence that continents ever existed in the areas now comprised by the abysmal regions, the ocean, on the other hand, has in past times flowed over nearly every portion of the continents. What are now continents have been broken up into islands of greater or smaller size, and many islands—*e.g.*, Britain, Japan, the Philippines, and Australia—have at different periods formed parts of the existing neighbouring continents. The changes in level, which have been

¹ From Notes of an Address delivered before the Philosophical Society of Glasgow, 31st March 1886.

throughout so characteristic a phenomenon of the continental and border areas in past geological ages, have permitted the formation, at different times, of wide seas over these areas in a great many directions. These seas probably never compared in depth or extent with the great ocean basins, but they have often had a depth of many hundreds of feet, and were frequently filled with purely oceanic waters.

This breaking up of the land-masses has been one of the chief factors in the distribution of climates in past as well as at the present time; for by diverting equatorial oceanic currents, or by cutting them off from high northern or southern latitudes, a given fauna or flora has been able to flourish at widely different latitudes on the surface of the earth.

The warm current known as the Gulf Stream is not the only means by which equatorial warmth is carried northwards. There is a general movement of warm surface water from the equator towards the poles, and a return flow of the colder polar water to the south. In consequence of this, we find the curious fact that, at a depth of three-quarters of a mile, the water of the eastern Atlantic is warmer than that of any other sea in any part of the world at the same depth. Around our own coasts, in the shallow water, and in estuaries, the temperature conditions may be summed up in the statement, that in winter the surface water is colder than that at the bottom, while in summer it is warmer at the surface than at the bottom. The range is considerable between day and night, and between summer and winter, whereas in the open sea it is very small. The Firth of Forth has been studied in some detail; but the physical conditions of the Clyde are very imperfectly known, although during the past year, Mr. J. Y. Buchanan and Messrs. Mill and Morrison, of the Scottish Marine Station, have made an attempt to add to our knowledge of it. The lower end of the firth is, as it were, barred by a submarine ridge, stretching from Sanda, at the Mull of Cantyre, across to Ballantrae, in the south of Ayrshire, twenty-five fathoms beneath the surface, and the firth thus forms a loch with many branches. This consideration suggests a comparison between the Clyde and Loch Lomond, since we have now a year's observations in the hundred-fathom depths of that loch, and also of Loch Fyne. In March the temperature is practically uniform from surface to bottom in both lochs, being, throughout the whole hundred-fathoms in Loch Fyne, $41^{\circ}1$, and $39^{\circ}0$ in Loch Lomond. By the end of June heating has begun at the surface, but there is little change in either basin in the deeper layers of water. But by the end of August the bottom water in Loch Fyne has risen seven degrees, to $48^{\circ}1$, while the water at the bottom of Loch Lomond has remained throughout unchanged. Indeed, the bottom water in the latter loch does not appear to change more than one degree from season to season, so that the rise of the temperature in Loch Fyne appears to be due to mixing in consequence of the tides, and evaporation, which renders the salt water of the surface more dense, and thus causes it to sink. The changes in the fresh-water loch appear to be entirely due to conduction.

When the marine fauna and flora of the Firth of Clyde are compared with those of the Firth of Forth, the former is found to be much richer both in number of species and luxuriance of growth. While there are no species in the Firth of Forth which are not also found in the Clyde, there are, on the other hand, a considerable number of forms in the Clyde which do not occur in the Forth. At first sight, it might seem that the greater variety of coast-lines, and the greater depth of the Clyde basins might account for this difference; but when we compare the whole west coast with the east, the same contrast is found to hold good. When the whole fauna of the coasts of Britain, the Shetland Islands, and the coasts of Norway are compared with those of the Mediterranean, it is found that over sixty per cent. of the species are common to the two areas. This would seem to suggest that the overflow of water from the Mediterranean along the coasts of northern Europe facilitated the migration of other species to our shores. However, it is more probable that there is an Atlantic shore fauna which has migrated both to the Mediterranean and to the northern shores of Europe, which are under the influence of the warm waters of the Gulf Stream.

As the cold of the glacial period passed away, and the ice disappeared from the North and Norwegian Seas, the Atlantic fauna and flora gradually invaded the northern shores of Britain and those of Norway, always following the track of the Gulf Stream waters. The migration to the North Sea and the east coasts of Britain took place round the north of Scotland, and apparently not at all through the English Channel. Some of the west coast species have found their way as far as the Moray Firth, but have not been noticed farther south along the east coast. At some points on the east coast there are five or six species of shells to be found which are not to be found living on the west coast, though they have been discovered as fossils in the glacial clays. These appear to be remnants of the Arctic fauna, which in glacial times flourished around our coasts, but by degrees died out, or retired with the advent of warmer conditions and the invasion of the Atlantic fauna.

If the east coast and the North Sea are poorer in species than the west, there is some compensation in the enormous development of the numbers of individuals of many species which have been able to establish themselves in the shallower waters of the North Sea, with their more variable conditions of temperature. It is the great development of the numbers of individuals in the shallower waters of the North Sea which determines the position of the fishing banks; for the invertebrates which live at the bottom, and their larvæ, which at certain seasons swarm at or near the surface, supply food to the vast shoals of our edible fishes. Indeed we never find great fisheries except where there are relatively shallow banks, such as those in the North Sea and off Newfoundland, where invertebrates flourish at a depth which can be reached by fishes living in shallow water. The naturalist is struck by a similar difference between the banks situated in northern and temperate latitudes, and

those situated in the tropics ; in the latter there is a great development and variety in the number of species, while in the former the species are relatively few, and the development of individuals enormous.

We still require many more accurate observations of temperature, specific gravity, and the distribution of species at different points around our own coasts, before we can approach the many interesting questions relating to the fauna and flora, and the conditions under which they flourish. An earnest attempt is being made by the observers in connection with the Scottish Marine Station to collect and arrange the various data, and before long it may be hoped that we will be in possession of a better knowledge of the physical and biological conditions of our coasts.

The facts which have been referred to establish, however, beyond all question, the presence of water along our shores which has borne with it a large amount of heat acquired in tropical regions. The effects of this warm water can be traced not only in the estuaries and along the coasts of North Europe, but at a depth of three-fourths of a mile below the surface. A very moderate elevation of the Wyville Thomson Ridge and the Iceland Ridge would cut off this water from the Norwegian Sea and the North Sea, with the result that these seas would soon be covered with ice. On the other hand, we might conceive some slight elevations in the northern parts of the American continent, which would divert the Arctic water, which now flows into the Atlantic, into the Pacific, with the result that we might have in Greenland a climate as warm as appears to have existed there in Miocene times. The attention which has lately been given to the influence which astronomical phenomena may have in producing great recurring changes of climate, appears to have diverted attention from the great effects which may be brought about in extra-tropical regions by small changes in the configuration of continental land, and the consequent changes in the direction of oceanic currents. Yet it is certain that these produce very great effects at the present time, and have as certainly produced as great, if not greater, effects in past times. As a change in the direction of tropical currents brings in its train a change in the position of barometric maxima and minima, and in the direction and force of the winds, so the configuration of continental land with reference to oceanic currents must be looked upon as the most important terrestrial factor in the production of warm or cold extra-tropical climates.

[In the course of the discussion which followed the reading of his Paper, Mr. Murray urged the great importance of a detailed study of the physical, chemical, and biological conditions of the firth and lochs of Clyde, and suggested that the Philosophical Society might very well take the matter in hand. Every assistance to such a piece of work would, Mr. Murray said, be given by the Scottish Marine Station, which had for two and a half years been doing for the Firth of Forth what he hoped might be done for the Clyde by a Marine Station in some such position as Millport, supported in an adequate manner by the Society and by private individuals.]