THURSDAY, SEPTEMBER, 2, 1880

THE CRUISE OF THE "KNIGHT ERRANT"

IT was accepted by us as one of the general conclusions from the temperature observations made on board the *Challenger* that the normal vertical arrangement of temperature in the ocean is somewhat in this wise. The water is warmest at the surface; from the surface it cools rapidly for the first hundred fathoms or so; it then cools more slowly down to five or six hundred fathoms; and then extremely slowly to the bottom, where the minimum temperature is reached.

I need not here enter into detail as to the causes of this normal condition, which have already been fully discussed.[1] I may state however, generally, that the temperature of the upper strata is raised by solar radiation, and its distribution is affected by currents and by many other local causes; and that the water which has been cooled down in the polar seas until it has acquired a high specific gravity, flows along the bottom and into the deepest abysses to which it has access.

This normal vertical distribution of temperature is by no means universal or even general; it exists only in those parts of the ocean which are continuous throughout their entire depth with a polar sea. No ocean is thus continuous with the Arctic Sea; a wide belt apparently under these normal temperature conditions surrounds the South Pole or the south polar land nearly if not entirely, but the gulf-like northward extensions of the water-hemisphere, the Atlantic and the Pacific, show a distribution of temperature to a certain extent abnormal, and in some seas which occupy more restricted areas, the deviation from the normal conditions is excessive. In oceans where the thermometer sinks steadily from the surface to the bottom, that is to say, in those under normal conditions, the bottom temperature at anywhere near 2,500 fathoms is a little below the freezing point. The Atlantic Ocean is divided into three areas; in one of these, an area extending from the Antarctic Sea along the coast of South America to ten degrees or so north of the Equator, the temperature sinks at the usual rate to 31°·5 F. at the bottom (2,900 fathoms). In another, the eastern basin, extending along the coasts of Europe and Africa, the temperature sinks steadily to 35°·5 at a depth of about 2,000 fathoms, and this temperature extends to the bottom (3,150 fathoms); in the third area, the western basin, off the West Indies and the coast of North America, the temperature falls to 35° at 2,000 fathoms, and this temperature is again continuous to the bottom (3,475 fathoms). As extreme instances of this abnormal condition, in the Celebes Sea, which attains a depth of 2,600 fathoms, the minimum temperature—38°·5 F.—is reached between 700 and 800 fathoms; the Banda Sea, with a depth of 2,800 fathoms, reaches its minimum temperature of 37° F. at 900 fathoms; and the Sulu Sea, which is at least 2,550 fathoms deep, has a uniform temperature of 50°·5 F. from a depth of 400 fathoms to the bottom.

[1] "Hydrographic Proceedings of the Voyage of H.M.S. *Challenger*." Report on Temperatures by Staff-Commander Tizard, R.N. (London, 1876); "The Atlantic," by Sir C. Wyville Thomson, F.R.S., vol. ii. p. 300, *et seq.* (London: Macmillan and Co., 1877.)

The combined results of our soundings and serial temperature determinations led us to conclude that those ocean basins in which the water is of a uniform temperature from a certain depth to the bottom are inclosed within a continuous barrier of a height corresponding to the depth at which the fall in temperature ceases; and that consequently no water at a temperature lower than the isotherm of that depth can pass into them. Suppose such a barrier to rise, as it does rise, in the Atlantic between the south-western and the eastern basins to a height of 2,000 fathoms below the surface, a sounding on the west side to the depth of 2,500 fathoms close to the barrier would give a temperature a little below 32° F., while the thermometer at the same depth on the other side of the barrier would register 35°·5 F. In this way we may have very different temperatures at the same depth, close to one another and apparently under absolutely similar circumstances, and from our experience we should be inclined to accept the existence of continuous barriers as the almost universal explanation of such phenomena.

Of course any generalisation such as I have indicated partakes more or less of the character of a speculation. It is impossible to trace out the entire line of the barrier limiting an ocean basin and to prove its continuity.

In discussing this matter during the cruise of the *Challenger*, Staff-Commander Tizard and I had often in our minds the singular instance of contiguous areas of widely different temperature conditions which had been examined by Dr. Carpenter and myself in the *Lightning* and the *Porcupine* in the years 1868 and 1869.

In the channel between the north coast of Scotland and the Shetland Islands, and the banks and islands of the Faroe group, the average maximum depth is from 500 to 600 fathoms. An abrupt line of demarcation divides this channel into two portions, one of which my colleague Dr. Carpenter called the *cold* and the other the *warm* area.[1] The temperature of the water to a depth of 200 fathoms is much the same in the two areas; in the *cold area*, which occupies nearly the whole of the channel, extending in a north-easterly direction from a line joining Cape Wrath and the Faroe fishing banks, the temperature at 250 fathoms is 34° F., and 30°·5 at the bottom (640 fathoms); in the *warm area* which stretches south-westwards from the same line, the thermometer registers 47° F. at 250 fathoms, and 42° F. at the bottom (600 fathoms).

When the phenomenon was first observed, we concluded than an indraught of cold water, passing southwards from the Spitzbergen Sea, welled into the Faroe Channel, and was met at its mouth and banked in by the north-easterly extension of the Gulf Stream, forming along the line of contact and partial mixture a "cold wall," comparable with that described as occurring in the Strait of Florida between the cold water of the Labrador Current and the Gulf Stream near its origin. This view however presented many difficulties, and on reconsidering the matter

[1] "Preliminary Report by Dr. W. B. Carpenter, V.P.R.S., of Dredging Operations in the Seas to the North of the British Islands, carried on in H.M. steam-vessel *Lightning*," by Dr. Carpenter and Dr. Wyville Thomson, Professor of Natural History in Queen's College, Belfast (*Proceedings* of the Royal Society of London, vol. xvii.). "Preliminary Report of the Scientific Exploration of the Deep Sea in H.M. Surveying-vessel *Porcupine* during the Summer of 1869, conducted by Dr. Carpenter, V.P.R.S., Mr. J. Gwyn Jeffreys, F.R.S., and Prof. Wyville Thomson, LL.D., F.R.S. (*Proceedings* of the Royal Society of London, vol. xviii.)

it now seemed certain that if our generalisation with regard to the cause of great differences in bottom temperatures within short distances be correct, a submarine ridge rising to within about 200 fathoms of the surface must extend across the mouth of the channel between the coast of Scotland and the Faroe banks. We recognised this as a test case which we might probably be able to examine thoroughly, as it was within our easy reach and on a sufficiently small scale; and I determined to take the first opportunity of making a careful survey of the channel with Capt. Tizard's co-operation, if possible before the *Challenger* temperature results were finally discussed.

I was prevented by various circumstances from taking any active steps in this direction until last year, when the Hydrographer of the Admiralty kindly consented to arrange another opportunity for sounding the Faroe Channel. I was obliged again to postpone the undertaking on account of a severe illness, and it was not until the early part of the present summer that I felt well enough to renew my application. I then wrote the following letter to the Hydrographer :—

"*Bonsyde, Linlithgow, June* 16, 1880

"DEAR CAPTAIN EVANS,—As you are aware, during our cruise in H.M.S. *Lightning*, in the year 1868, Dr. Carpenter and I found to our surprise that the channel between the Faroe Island and the coast of Scotland consisted of two very distinct 'areas,' the deep water in the two divisions differing in temperature to a marked degree. Consequent upon the difference of temperature, the faunæ of the two areas were also different. The 'warm' area was separated from the 'cold' by a distinct line of demarcation running apparently from about Cape Wrath past the Island of Rona, and as far as the southern Faroe fishing banks. During the voyage of the *Challenger* we met on many occasions with an abrupt change in the deeper temperatures along a definite line, and we arrived at the general conclusion that the phenomenon depended in all cases upon the interruption of the flow of an undercurrent by a raised submarine ridge. The instance between Scotland and Faroe still, however, remains the most conspicuous as well as the most accessible, and it is very important for us before concluding the Report of the *Challenger* Expedition, to have an opportunity of checking with our greatly increased knowledge our earlier observations.

"I have carefully considered what would be the minimum amount of work required for this purpose, and I now write to ask if you could, with the sanction of their Lordships, authorise Capt. Tizard, now surveying on the west coast, to run north to Stornoway and sound out the line indicated. This would occupy a month, or perhaps a little more.

"As remarkable differences in the distribution of marine animals accompany these differences in temperature, I should greatly regret if we had not a few casts of the trawl on each side of the line, but any additional expense involved for this purpose I will gladly meet. I regret greatly that my present state of health prevents my committing myself to accompany the vessel during the whole time, but I will be at Stornoway during the survey, and my chief assistant, Mr. Murray, is prepared to go. I should think that about the middle of July would be the best time for the trip, if that time would be convenient. Trusting for your assistance to the kind interest you have always taken in our work, believe me very truly yours,

"C. WYVILLE THOMSON"

I give this letter in full to show that our anticipations were very definite, although they were founded entirely upon the comparison of serial temperature soundings.

Their Lordships agreed to my proposal, and on July 22, 1880, I joined the *Knight Errant* at Oban, and proceeded to Gairloch, and thence to Stornoway, where we arrived at mid-day on Saturday, the 24th. The weather was delightful, and the Minch as smooth as glass; when we reached Stornoway, however, the barometer had begun to fall, and continued sinking steadily with a rising breeze from the north-east. After coaling on Monday forenoon, the vessel left Stornoway Harbour at 1 p.m. with a rather unfavourable weather forecast. I meant to have gone with her on this trip but I was advised to give up the idea, and the civilians who accompanied Capt. Tizard were Mr. Murray, our indefatigable assistant Mr. Frederick Pearcey, with my son as a supernumerary. Taking the island of North Rona as a point of departure, during Tuesday the 27th, and Wednesday the 28th, the *Knight Errant* ran a sectional line of soundings, the distance between the soundings averaging ten miles, between the shallow water on the Scottish coast and the bank to the south-west of the Faroe Islands. Fourteen soundings on this line gave the following depths and bottom temperatures :—

	Depth, fathoms.	Temp. °		Depth, fathoms.	Temp. °
1	88	49·5	8	405	46·0
2	178	49·6	9	355	43·8
3	400	45·8	10	270	43·5
4	560	45·2	11	335	41·0
5	540	46·0	12	245	41·8
6	300	47·5	13	120	47·5
7	305	46·5	14	130	46·0

The line was therefore entirely in the *warm area*, and no perceptible amount of water from the cold area could be shown to pass in this direction towards the Atlantic.

Capt. Tizard then proceeded a little way to the north-eastward, and commenced running a second line, parallel to the first and about eight miles from it, back towards the Scottish coast. Soundings were continued on the second line at the same average distances as before on Wednesday and Thursday morning, when, the barometer falling rapidly and the sea running high with a gale from the north-east, it was thought prudent to bear up for Stornoway, which they reached on Friday after a somewhat anxious twenty-four hours.

On Tuesday, August 3, the weather looking somewhat better, the *Knight Errant* left Stornoway and carried a sectional line north-north-west from Rona towards the last sounding; they completed the second line of soundings on the evening of Wednesday, the 4th inst. On this line twelve soundings gave depths and bottom temperatures according to the following table :—

	Depth, fathoms.	Temp. °		Depth, fathoms.	Temp. °
1	370	35·5	7	285	45·8
2	375	31·0	8	255	48·0
3	375	31·0	9	460	46·0
4	285	32·5	10	202	48·2
5	210	47·0	11	145	49·5
6	260	47·5	12	93	50·0

All these soundings therefore, with the exception of Nos. 1, 2, and 3, which were across the ridge in the *cold area*, and No. 9, which was in the deep water of the *warm area*, gave a depth of under 300 fathoms, and were consequently on the ridge.

On August 10 the *Knight Errant* went out again and got several fairly successful hauls of the trawl and a serial temperature-sounding in the *warm area*, returning on Thursday the 12th, and she left Stornoway for the fourth time on Monday, August 16, when the party landed on Rona and gave it a cursory examination. They then steamed towards the deep water of the *cold area*, and on Tuesday the 17th they trawled successfully, and took a serial temperature-sounding in 540 fathoms. They returned to Stornoway for the last time on the evening of Thursday, and left on the following day for Greenock, where they arrived on Monday, the 23rd.

The observations made by Capt. Tizard in the *Knight Errant* have fully corroborated the results of the *Lightning* and *Porcupine* as to the facts of the abnormal distribution of temperature in the Faroe Channel. They have also established the existence of a submarine ridge rising to within 300 fathoms of the surface, in the position in which such a ridge is required to satisfy the conditions of the doctrine of the interference of continuous barriers with the distribution of deep-sea temperatures. Thus far they may be regarded as entirely successful.

The highest line of the ridge has probably not been found, and the details of temperature have yet to be traced out more accurately along the line and for a short distance on either side. I consider that it would be of the greatest interest to work this case out fully as a striking example, within a few miles of our own shore, of a physical phenomenon of importance from its wide occurrence.

The *Knight Errant* was found quite unsuitable for such work; a small steamer of ordinary strength, with stowage for coals for a fortnight's steaming, and with sails to enable her to lie to in a breeze, could do all that is required within a month or six weeks of the ordinary variable weather of these seas.

Although the solution of this temperature problem was the principal object of this summer's trip, I wished greatly to make some additional observations on the nature of the faunæ on the two sides of the ridge, and I was especially anxious to procure some fresh specimens of sponges as material for the structural part of the memoir in which I am engaged with Prof. Franz Eilhart Schultze on the Hexactinellidæ of the *Challenger* Expedition.

The Admiralty declined to give us any material assistance in this direction, but they allowed me to take the gear on board and to get a cast of the trawl or dredge in the intervals of sounding, or when the sounding work was over. I accordingly provided 1,000 fathoms of $2\frac{1}{2}$ inch dredge-rope and other necessary appliances, and Messrs. Henderson, ship-builders, Glasgow, kindly lent us an excellent steam-winch, which was fitted on deck and was of the greatest service both in sounding and trawling. Owing to the boisterous weather and insufficiency of the vessel, this part of our undertaking was not very successful. I got none of the coveted sponges, but two or three hauls of the trawl were taken in each area, and a number of highly-characteristic abyssal forms were procured, including some deep-sea fishes, several crustaceans, and a number of gigantic pycnogonids, some interesting echinoderms, including *Porocidaris*, *Asthenosoma*, *Phormosoma*, *Pourtalesia*, *Rhizocrinus*, and others; some corals, and many curious rhizopods. As the vessel has not yet returned, I take these names from Mr. Murray's rough notes.

Enough has been done to give further evidence, if such were needed, that a small district on the northern slope of the coast of Scotland will afford a richer harvest to a properly-organised dredging-excursion than perhaps any other spot on the earth. The whole area is singularly productive, and it is bisected by a narrow line, on the one side of which the warm sea at a depth of 500 to 600 fathoms vies in abundance and variety of abyssal forms with the favoured patches off Inosima and Zebu; while on the other side of the line, within a distance of a few miles, we find an epitome of the fauna of the depths of the Arctic Sea.

C. WYVILLE THOMSON

LETTERS TO THE EDITOR

[*The Editor does not hold himself responsible for opinions expressed by his correspondents. Neither can he undertake to return, or to correspond with the writers of, rejected manuscripts. No notice is taken of anonymous communications.*

[*The Editor urgently requests correspondents to keep their letters as short as possible. The pressure on his space is so great that it is impossible otherwise to ensure the appearance even of communications containing interesting and novel facts.*]

A Fragment of Primeval Europe

THE paper in NATURE, vol. xxii. p. 400, by Prof. Archibald Geikie, on the glacial phenomena of the north-west coast of Scotland, contains on many points a most true and graphic description of a most peculiar and a most interesting country. But I demur to its accuracy on one of the main features to which he refers. The amount of glaciation on the hills of Laurentian gneiss, as represented in the sketch on p. 401, is inordinately exaggerated. I know that country well, both in its general aspect and in its details, and no part of it presents such a scene of symmetrically rounded hills, like the huts of Caffres in Zululand, as that depicted in the sketch.

It is true that all the lower hills are more or less strongly glaciated. But they are also full of low cliffs, and precipitous rocks upon the sides of the glens, and the whole character of the glaciation is such as to suggest the action of heavy floating ice such as that of the "Palæocrystic Sea," and which acted only upon surfaces specially exposed.

Ben Stack, which is 2,364 feet high, and is composed of the same rock, is not rounded at all, and on the north-west face is full of great precipices along which no glaciation can be seen.

It is perfectly true that the same glaciation which is common on the exposed surfaces of the gneiss cannot be traced on the Cambrian sandstones which overlie it. But this is probably due to the obliteration of the ice-marks by subsequent atmospheric action, which tells rapidly and powerfully on the sandstones, whilst it is almost inoperative on the intensely hard and tough Laurentian gneiss.

That this is the true explanation of the difference now presented by the two rocks, is evident from the fact that the next rock in the ascending series, namely, the white quartzites, do retain surfaces in abundance which are splendidly glaciated. I know no spot in Scotland where the polished surfaces due to glaciation are seen on a greater scale than on the top of the white quartzites which cap the mountain of Queenaig in Assynt. This is a classical area in geology—a sketch of it forming the frontispiece of Murchison's "Siluria." The road from Inchnadamf to Kylescue and Scourie passes over a plateau formed of this quartzite, and the beds of white rock, highly glaciated, shine for miles through the heather.

The glaciation which left these surfaces must have passed over the sandstones also. But the rock was not of a material calculated to retain the marks.

Nevertheless I am not prepared to deny that possibly the gneiss of Sutherland may have been doubly glaciated—once in the glacial epoch as hitherto known to geology, and also at some former epoch inconceivably remote, when similar conditions had prevailed.

If well glaciated surfaces of the gneiss can be distinctly traced